Assessment of Carbon (CO_2) emissions avoidance potential from the Nile Basin peatlands

Technical Report

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Summary

This report is the first deliverable of the project 'Biodiversity Conservation and Sustainable Utilisation of Ecosystem Services of Wetlands of Transboundary Relevance in the Nile Basin' (in short: the NBI Wetland Project). This project is part of the baseline studies on the Nile wetlands and their ecosystem services, particularly in relation to climate change mitigation, and their integration in river basin planning. The report presents the results of the peatland mapping, carbon stock estimation, land use assessment and the evaluation of CO_2 emissions avoidance potential in the Equatorial Nile (Nile Equatorial Lakes – NEL– and Sudd) and Blue Nile sub-systems (Ethiopia).

The total area of peatlands and other organic soils in the total Nile Basin amounts to about 30,445 km^2 (3,044,500 ha). This area contains a peat carbon stock of 4.2 - 10 GtC (Gt= 1x10^9 tonnes; C= organic carbon), i.e. 5 to 10 % of the total tropical peatland carbon stock. The range is caused by uncertainties in peat depth and carbon density of the peat.

The NEL region is estimated to contain 12,534 km^2 of peatlands and to contribute 58.5 % of the total carbon stock of the Nile Basin. The majority of the NEL region peat carbon stock is located within the sub-basins of Lake Victoria and the Victoria Nile, especially the Kagera subset, which contains about 50 % of all peatlands in the NEL region. The Lake Albert sub-basin also contains substantial peatland areas but is the smallest peatland area of the NEL region.

The most important concentration of peatlands in the Nile Basin lies possibly in the Sudd wetlands, where we estimate the area of peatlands (organic soils) to be ~15,780 km^2, which would represent about 50 % of the total peatland area and 37 % of the total carbon stock of the entire Nile Basin. The proportionally small carbon stock value is attributable to the use of a small average peatland depth (2 m) compared to the rest of the peatlands in the Nile Basin. The Blue Nile sub-system (Ethiopia) holds an estimated peatland extent of about 1110 km^2, concentrated around Lake Tana and the south-western Ethiopian Highland. The latter peatlands have only recently been discovered and remain largely unknown, probably because their vegetation differs from the standard papyrus.

Most peatlands are characterized by papyrus (*Cyperus papyrus* L.), but *Raphia* palms, other sedges (e.g. *Cyperus latifolia)* and tall grasses are also common, and partly grow in patches together with papyrus. Peat deposits are mostly found in dendritic shaped valleys, which may be channelled, i.e. with a river flowing in the middle (e.g. Akanyaru peatland in Rwanda) and/or non-channelled (e.g. mountain peatlands in Ethiopia). Peat deposits were also found in the floodplains of lakes (Victoria, Albert, George and Mburo/Nakivali) and on river banks, e.g. of the Kagera and Albert rivers. Afro Alpine peatlands occur in various parts of the Nile Basin at high altitudes (>4000 m).

Land use change has recently accelerated and an increasing area of peatlands is being impacted directly (burning and clearing for agriculture, peat extraction for energy) or indirectly (drainage for infrastructure, surrounding plantations causing groundwater drawdown). The impact depends on the duration and intensity of use. Other threats to peatlands include changing rainfall patterns and fire hazards. The consequences are increased CO_2 emissions and the loss of carbon stocks and productive land.

Peat carbon stock losses and emission reduction potential within the NEL region were explored with a model assuming that in 2015 25% of all peatlands were drained and that from 2015 until 2050 the drained area will increase annually with 1 % of all peatlands. The resulting losses of about 0.2 GtC over the period 2015 - 2050 can be regarded as CO_2 emission reduction potential if no new drainage will be implemented and all drained peatlands are rewetted in 2025. Potential emission reduction following such a ‘rewet all’ scenario would then be in total 678 Mt CO_2, or 19.4 Mt CO_2 per year. The carbon stock losses and emission reduction potential are proportionally higher with a larger proportion of drained peatland in 2015, like Kenya and Rwanda (both 46 %) and Burundi (91 %). Calculations based on a more differentiated estimation of initial (2015) drained area per country arrives at a higher emission reduction potential for the NEL countries of 885.5 Mt CO_2.

Further research needs to include mapping and ground-truthing especially in the Sudd and Ethiopia. Areas dominated by *Raphia* palms require special recognition, as these are often incorrectly overlooked as peatland areas. Mapping and monitoring are necessary to estimate the impact of land-use and land use change on peatland GHG emissions and the loss of ecosystem services. Pilot ecohydrological studies must clarify the hydrological functioning of the peatlands to better inform development plans and sustainable use. Paludiculture feasibility studies should be initiated in transboundary peatlands to strengthen cross-border collaboration and promote sustainable land-use in the Nile Basin.

Figures

1. Introduction

This report is the first deliverable of the project 'Biodiversity Conservation and Sustainable Utilisation of Ecosystem Services of Wetlands of Transboundary Relevance in the Nile Basin' (in short the NBI Wetland Project)/ PN 2014.9029.1, commissioned by GIZ on behalf of the Nile Basin Initiative (NBI) through the support of the Federal Ministry of Environment/International Climate Initiative (ICI; BMUB) of the Federal Republic of Germany. The project goal is "Elaborating the knowledge basis for sustainable management, based on an ecosystem approach, of peatlands of transboundary relevance in the Nile Basin wetlands" with the specific indicator: "Baseline studies on the Nile wetlands, their ecosystem services and their integration in the Nile hydrology, the economics of wetland conservation and options for action for conservation and sustainable use of ecosystem services and their integration in river basin planning are in place by 6/2018". The report was prepared by an expert consortium of consultants from DUENE e.V., partner in the Greifswald Mire Centre, and Wetlands International, in close collaboration with the NBI bodies (e.g. the Nile Equatorial Lakes Subsidiary Action Program NELSAP and the NBI wetlands regional working groups).

Peatlands have the ability to sequester and store carbon over long periods of time and consequently hold huge carbon stocks (Clymo et al., 1998). Peatlands originate where the soil is water saturated throughout the year and anaerobic conditions prevent the complete decomposition of dead plant material (Mitsch & Gosselink, 2000; Joosten & Clarke, 2002; Brix et al., 2012). The accumulated incompletely decomposed plant material is called 'peat'. Peatlands are estimated to constitute worldwide about 50 % of all wetlands.

Tropical peatlands are found from the coast to high altitudes. While all peatlands need near-permanent wet conditions, their development, water supply and landscape setting differ (Figure 1). In the tropics, suitable conditions for peatland formation are found in areas:

- with frequent and excessive rainfall (humid tropics);
- with high rainfall and restricted evapotranspiration (montane and afro-alpine environments; >4000 m, Bussmann, 2006);
- where large catchments guarantee regular water inflow and retention (terrain depressions, valley bottoms and floodplains);
- and along coastlines.

Carbon stocks in tropical peatlands have received more attention over the last decade (e.g. Joosten, 2009; Yu et al., 2010; Page et al., 2011). Recent estimates of the extent of tropical peatlands range between 30 - 45 million hectares (ha) (Sorensen, 1993; Solomon et al., 2007; Page et al., 2011) and 170 million ha (Gumbricht et al., 2017). These figures are based on best available science, but their range indicates the uncertainties involved. Tropical peatlands are known to be the most space-efficient terrestrial carbon stock pool, with their carbon stock per hectare 10-15 times higher than a tropical rain forest on mineral soil (Figure 2; Parish et al., 2008).

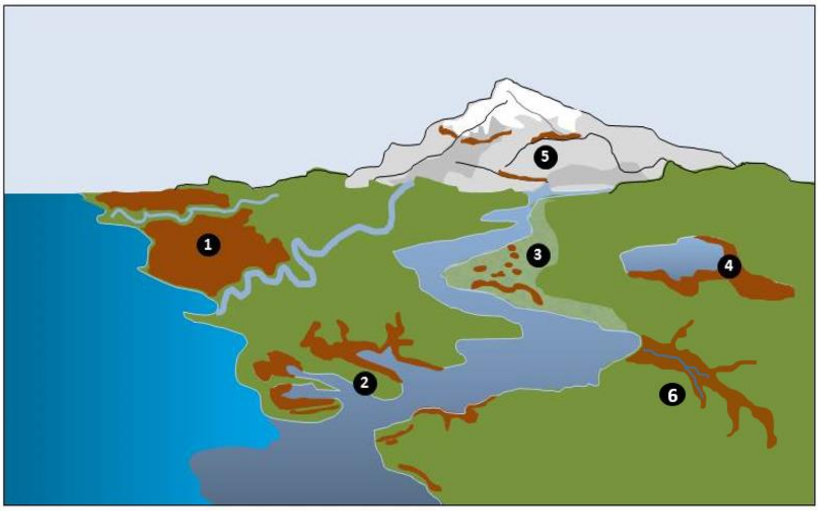

Figure 1. Tropical settings in which peatlands may occur 1. Coastal lowlands, 2. Perimarine areas, including river deltas, lagoons, salt marshes and back-swamps, 3. Floodplains, including oxbow lakes and pan depressions; 4. Lake margins, 5. Montane and alpine environments, including peat filled valleys or areas covered by 'blankets' of peat, 6. Depressional valley bottoms (channelled or non-channelled). After Barthelmes & Joosten (2018).

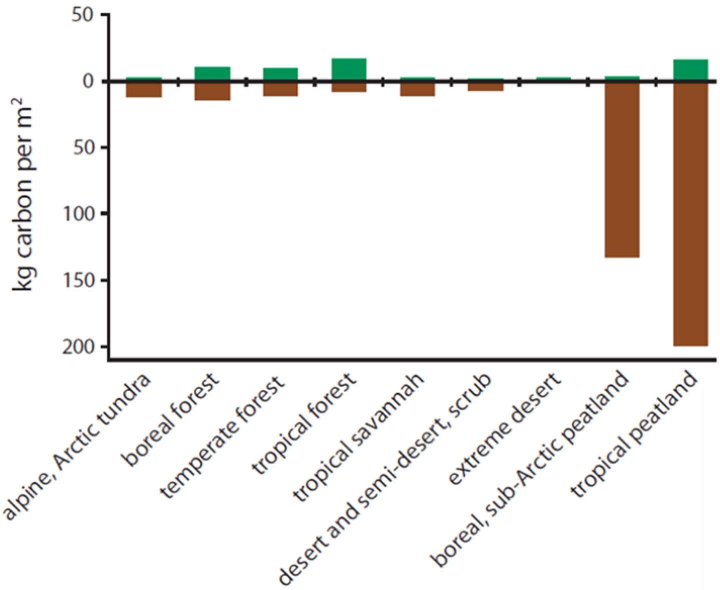

Figure 2. Carbon stocks for different terrestrial ecosystems (adapted from Victoria et al., 2012).

1.1 Nile Basin peatlands and carbon

Estimates for the peat carbon content of the Nile Basin countries average at 3.2 GtC (Page et al., 2011), but this estimate does not include Egypt, Ethiopia, and Tanzania. Joosten (2009) estimated the Nile Basin countries to contain about 5.6 GtC of peat carbon. These values are less than the most recent estimates of the carbon stock of papyrus wetlands of 6.9 GtC (Saunders et al., 2014). However, all these estimates are based on limited data points and sometimes a rather high average peat depth of 5.75 m (e.g. Saunders et al., 2014), which was assumed to be present in all papyrus wetlands, independent of whether peat is present or not.

Most of the limited peatland related scientific knowledge in East Africa is derived from areas above 2000 m a.m.s.l., i.e. Rwanda, Burundi and southwest Uganda as the pendant to the temperate climates in the northern hemisphere (e.g. Hamilton & Taylor, 1986; Namaalwa et al., 2013; Dullo et al., 2015). Only few studies refer to the presence of large peat carbon stocks in Africa, but these are primarily linked to papyrus wetlands (Joosten, 2009; Page et al., 2011; Saunders et al., 2014).

Whereas their importance as carbon sinks and stores is starting to be recognized, the peatlands of the Nile Basin are often seen as merely water loss areas (Sutcliffe & Brown, 2018), with limited effect on local climate and hydrology, which better could be drained to increase water supply for the lower reach countries (Mohamed et al., 2005; Bastawesy et al., 2013). This narrow view, the high population pressure and the need for resources have opened the door for utilizing peatlands unsustainably for water supply, agriculture or energy generation, which generally turns peatlands from a carbon sink to a huge carbon source (Namaalwa et al., 2013; Hakizimana et al., 2016; Hedman, 2019; Langan et al., 2019).

1.2 Drainage, greenhouse gas emissions and avoidance

Three greenhouse gases are in play with regards to peatlands, namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). While peatlands in their natural state and after rewetting are CO_2 and N_2O sinks, they are also CH_4 sources. CH_4 has a high global warming potential but a short-life time in the atmosphere and oxidizes to CO_2 with its low global warming potential after about 12 years (Günther et al. 2019). N_2O emissions are absent from wet peatlands but erratic, i.e. independent of water level, in drained condition (Couwenberg et al., 2010). The net effect of peatlands under wet conditions, i.e. with the water table at or near the surface, is climate cooling. Figure 3 shows the net effect of greenhouse emissions from peatlands on the instant radiative forcing, and consequently, global average temperatures under various land use scenarios (Günther et al., 2019). CO_2 is the most important greenhouse gas with regard to emissions from peatlands.

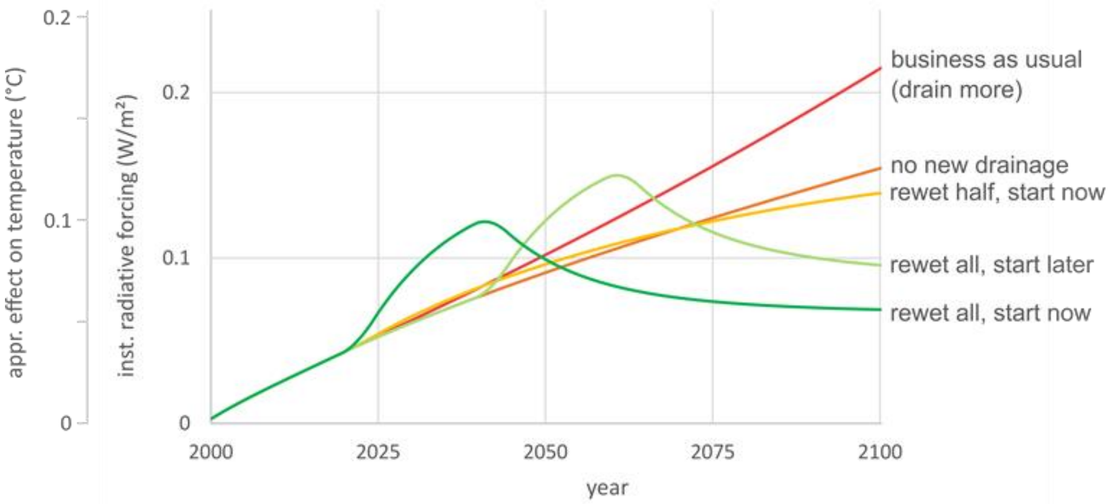

Figure 3. Scenarios of peatlands drainage and rewetting and their impact on global temperatures (Source: Günther et al., 2019).

Globally, drained peatlands emit about 2 giga tonnes of CO_2 ($GtCO_2$), which amounts to about 5 % of the global CO_2 emissions. CO_2 emissions from drained peatlands equal more than 50 % of national fossil fuel and cement emissions in Burundi, Rwanda and Uganda, and in Kenya they account for more than 10 %, indicating the importance of peatlands for national climate policies in these countries. Drained peatland emissions are, therefore, of national significance and should be considered in Nile basin countries' NDC's (Figure 4). Preventing further drainage (i.e. keep wet peatlands wet) and rewetting already drained peatlands (i.e. make drained peatlands wet again) would lead to avoidance and reduction of further emissions. Rewetting all peatlands now would have the most positive contribution to achieving the Paris Agreement goals (Günther et al., 2019).

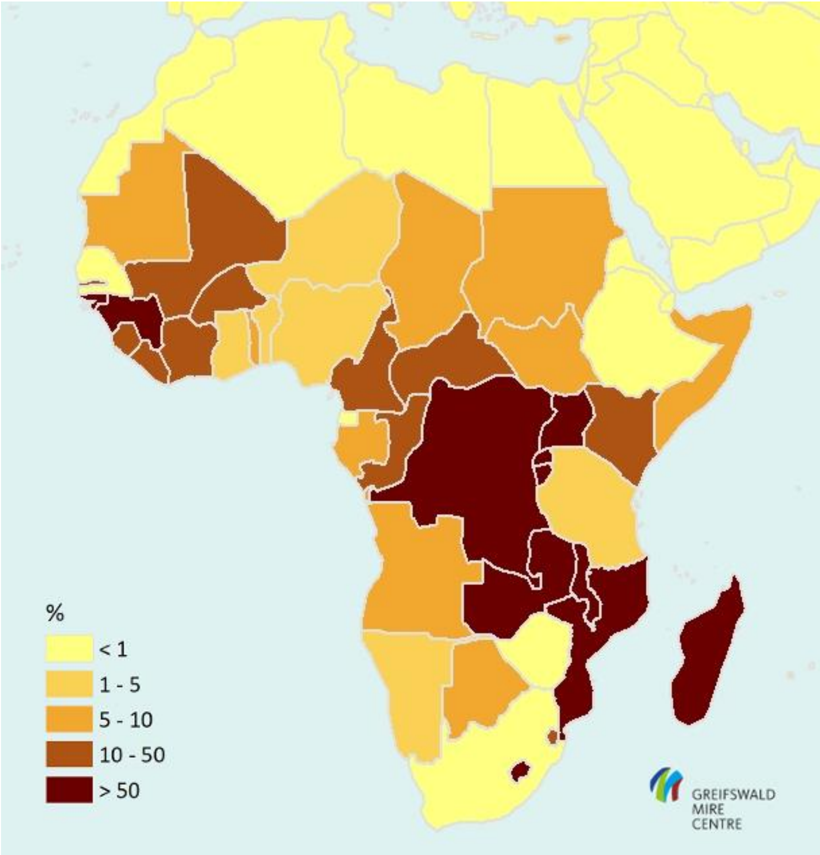

Figure 4. Peatland CO_2 emissions for African countries as % of national fossil fuel and cement emissions (Source: Greifswald Mire Centre, 2018).

1.3 Aim

This report aims at quantifying the CO_2 emissions avoidance and reduction potential from peatlands by conservation (cf. Q 1 and 2) and rewetting (cf. Q 3 and 4). The research questions are:

Q1) What is the spatial distribution and area of peatlands in the Nile Basin?

Q2) How much carbon is stored in the peatlands of the Nile Basin, i.e. what is the peat carbon stock?

Q3) What is the drainage status of these peatlands?

Q4) How much CO_2 is currently being emitted from the Nile Basin peatlands and how may emissions develop in future?

2. Materials and methods

Despite the rapid development of remote sensing methods, peatland mapping from space still has to struggle with the complexity of peatlands and their use (Montanarella, 2014). Across the globe, a vast diversity of natural peatland types exists with their specific intrinsic signatures for remote sensing, which hampers the successful extrapolation of these signatures to other regions. Furthermore, drained and used organic soils lose many of these key features like the homogenous vegetation and high soil moisture.

Accordingly, our mapping approach concentrated on the merging of already existing, often national geospatial soil and proxy information and the use of recent satellite and aerial imagery (Barthelmes et al., 2015). Furthermore, we made a first assessment of the drainage and degradation intensity of organic soils. It should be noted that the estimates do not account for the total area of peatland in each country, but only for the areas within the respective Nile Basin boundaries.

The study area was divided into two sub-systems according to the general Nile Basin division: 1) The Equatorial Nile sub-system, which includes the Nile Equatorial Lakes region (NEL, including the sub-basins of Lake Victoria, Lake Albert and Victoria Nile) and the Sudd wetlands in South Sudan and 2) The Blue Nile sub-system (Ethiopia). Egypt and Sudan are not covered specifically, because these countries have very little peat, but the available literature on peatlands and other organic soils in these countries is included in Annex 1. We used a variety of methodologies and information sources to identify possible peatland occurrences (see Barthelmes & Joosten, 2018; Figure 5).

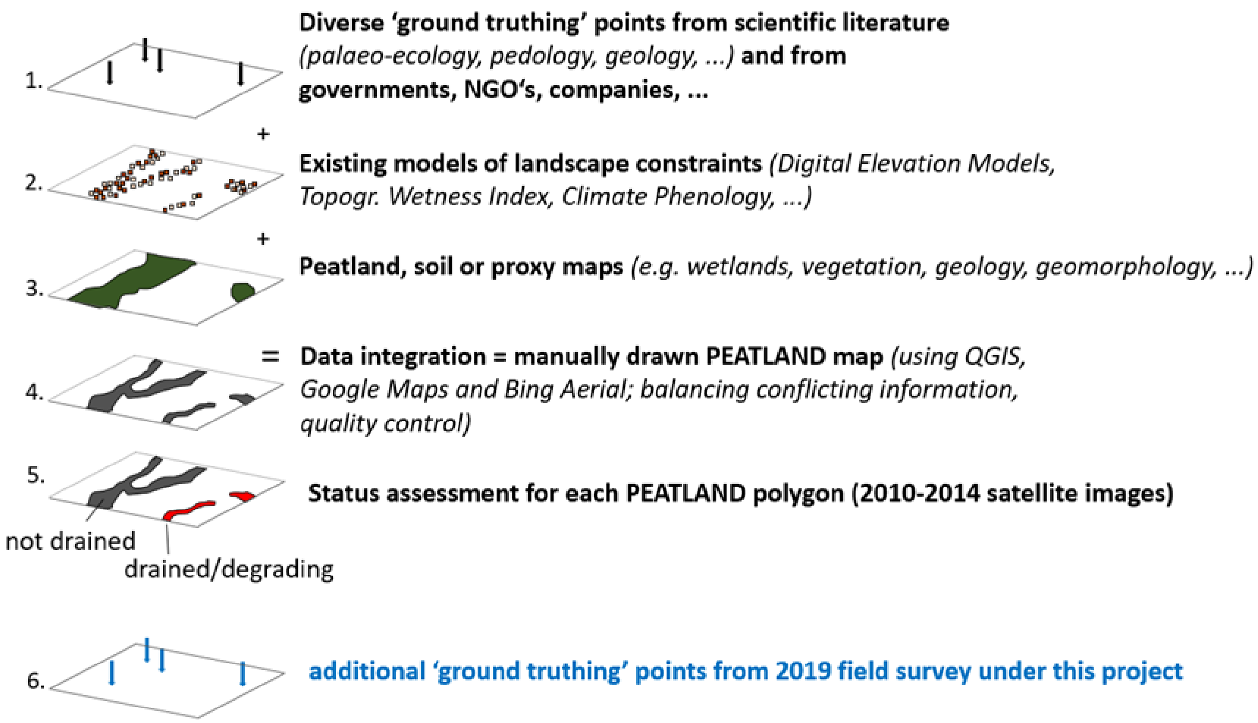

Figure 5. Scheme illustrating the data integration during the mapping procedure.

2.1 Peat and peatland identification and delineation

For the Nile Equatorial Lakes region and the Blue Nile sub-system, legacy soil maps, dispersed notes of peat occurrences (e.g. from palaeo-ecological studies) and spatially explicit peatland proxy data (e.g. on bedrock, relief, landforms, wetlands, vegetation, land use) were gathered from open access online archives including ISRIC (World Soil Information), JRC (Joint Research Centre), FAO Corporated Document Repository, SPHAERA (Base de données Sphaera du service Cartographie), WOSSAC (World Soil Survey Archive and Catalogue), the Perry Castanea Library of Austin University, and the Peatland and Nature Conservation International Library (PeNCIL[1]). Using the freely available program *QuantumGIS*, these data were overlain with free satellite (*Google Maps*) and aerial imagery (*Bing Aerial*), and with the Topographical Wetness Index of the African Soil Information Service. On the basis of this integrated information, the peatland extent was mapped manually using a detailed decision key to arrive at a high resolution (1:25,000) map of 'confirmed', 'probable' and 'possible' occurrences of organic soil (See Annex 2). We used the broad IPCC definition of 'organic soils' as soils having a minimum organic carbon threshold of 12 % and a minimum depth of the organic layer of 10 cm (see box 1). The resulting GIS database includes for every peatland polygon information on key references.

Box 1: Organic soils in the IPCC Guidelines

There are no worldwide standardized definitions for peat and peatland. In the IPCC 2013 Wetlands Supplement (IPCC 2014) the concept of peatland is considered to be included in '(land with) organic soil'. The Supplement follows the definition of organic soils in the 2006 IPCC Guidelines. In the 2006 IPCC Guidelines (Annex 3A.5, Chapter 3 in Volume 4), organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO 1998):

1. Thickness of organic horizon ≥10 cm. A horizon < 20 cm must have 12 % or more organic carbon when mixed to a depth of 20 cm.
2. Soils that are never saturated with water for more than a few days must contain > 20 % organic carbon by weight (~35 % organic matter).
3. Soils are subject to water saturation episodes and has either:

a. ≥ 12 % organic carbon by weight (~20 % organic matter) if the soil has no clay; or
b. ≥ 18 % organic carbon by weight (~30 % organic matter) if the soil has 60 % or more clay; or
c. An intermediate proportional amount of organic carbon for intermediate amounts of clay.

The IPCC thus largely follows the definition of Histosol by the Food and Agriculture Organization (FAO), but has omitted the thickness criterion from the FAO definition to allow countries to use their country specific definitions.

[1] https://greifswaldmoor.de/pencil-142.html

For the Sudd wetlands (South Sudan) we used a two-step approach. We combined the L-band radar-derived permanent wetland map of Rebelo et al. (2012) with the NDVI-based (permanent and non-permanent) wetland map of Hydroc GmbH (Hydroc, 2009) (Figure 6) to cover also the wetlands west of the Bahr-el-Jebel towards the Bahr-el-Ghazal, which are not covered by the Rebelo map (See Annex 3).

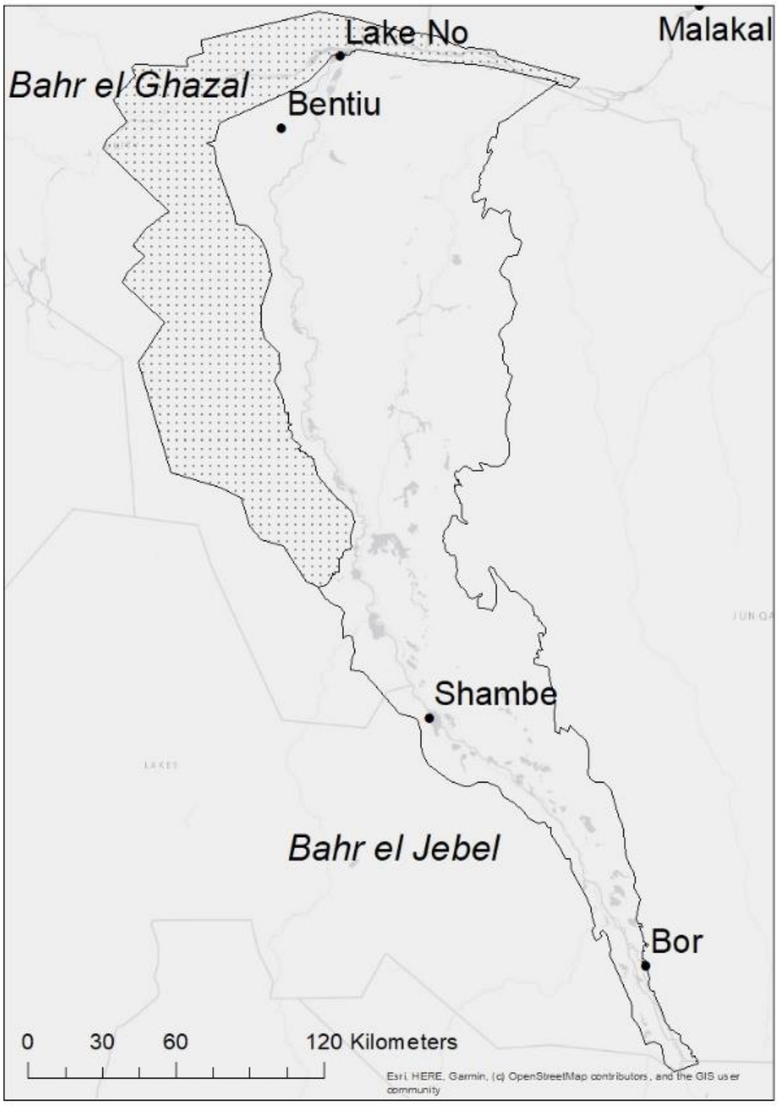

Figure 6. Assessment area in the Sudd: framed *area without filling* is the area covered by the Rebelo et al. (2012) map and *the dotted area* is the area additionally covered by the Hydroc (2009) wetland map.

Within the thus obtained "permanent" wetland boundaries, we determined by remote sensing the distribution of *Cyperus papyrus* L., *Phragmites mauritianus* Kunth. and hippo grass (*Vossia cuspidata* Grift.) (the latter two grasses jointly classified as "reeds"). These species require water saturated conditions throughout (almost) the entire year (Rzoska, 1974; Denny, 1984) and were considered as indicators for the occurrence of peat.

The distribution of papyrus and "reeds" was derived through "Random Forest Classification" (Amani et al., 2017) using Sentinel-2 scenes from mid-January 2018. January is in the middle of the dry season when wetland vegetation extent is reduced to minimum and permanent wetlands have their most stable reflectance values (Di Vittorio & Georgakakos, 2018). Tiles from two scenes sensed with two days difference were pre-processed and mosaicked.

Sentinel-2 provides images of a location every 5 days and with 10 spectral bands of which the green (Band 3), red (band 4), near-infrared (8) and short-wave infrared band (11) were combined to scenes of 10 m resolution. This resolution generates generally higher accuracy compared to Landsat or MODIS imagery with 30m and 500m resolution, respectively.

Field information on the occurrence of papyrus and "reeds" in the permanent wetlands and on grass vegetation in non-wetland areas of the Sudd close to Bor was generously provided by Georg Petersen (Hydroc GmbH) and served as ground truthing. The information dates back to 2008 and vegetation composition was assumed to have been constant since then. All other non-wetland classes were derived from image interpretation only.

Box 2: Papyrus and peat in the Sudd in older literature

Papyrus has been described from the surroundings of lake No and from 80 km upstream Bahr el Jebel as building root mats of several meters thick, forming river banks and constituting the upper soil layer of at least 1 m thick more than 40 m away from the river (Hurst & Phillips, 1931). Christy (1923) gave two descriptions of Sudd, the word meaning "block" in Arabic: "one a peat-like formation, up to 8 or 10 feet in thickness, composed of papyrus roots and rotting vegetation; the other consists of masses, 3 to 5 feet thick, of the tangled and rotting roots and stems of a species of pennisetum grass known in Arabic as "umsuf." Papyrus sudd is to be seen on the Bahr el-Gebel, which at one time was completely blocked to navigation by it, but to-day is a fine waterway. The " umsuf" sudd, both fixed and fugitive, is the main cause of the blocking of the rivers of the Bahr el-Ghazal, where very little papyrus is to be found." Griffin (1924) described soil mats consisting of roots and other organic components of locally more than 3.7 m thick from the Chaba Shambe area, whereas Marno (1881) reported the similarity of papyrus root mats and peat and the black colour of the water coming from the swamps , which is a common characteristic of water from peatlands with its high content of humic acids and other dissolved organic matter. According to Rzóska (1974) "the soils of the permanent swamp are saturated with water and have a surface layer of organic origin, up to 1-5 m deep. This is composed of rhizomes, plant roots and plant litter resting on humified 'peat' with mineral sediments which, deeper down, form the river bed. Dark brown in colour, these soils are often slightly acid on the surface but alkaline deeper down; oxidation of organic matter is very slow. The vegetation is dominated by papyrus (*Cyperus papyrus* L. var. *antiquorum* C.B. Clarke), locally interspersed by stands of *Vossia cuspidate* GrifF. and *Phragmites mauritanus* Kunth. and in lesser degree *Typha angustifolia* L."

Contrary to the original project plans, own ground data on vegetation and soil could only be collected - by the S. Sudanese partners - from the margins of wetlands that were - according to our probability map – situated on mineral soils. Whereas they were useful for confirming mineral soil occurrences, they could not be used for a positive verification of peat occurrence nor for testing to what extent the delineated permanent wetland vegetation is an indicator for the occurrence of peat. As – in contrast to general wetland delineation - ground-truthing is obligatory for robust peatland delineation (e.g. Rebelo et al., 2012; Sosnowski et al., 2016), and no ground verification could take place, all results and products on peat distribution in the Sudd remain preliminary.

Areas that we had classified as having permanent wetland vegetation were compared with the permanent wetland extent of Rebelo et al. (2012). Overlapping areas were considered to be *probable* peatlands. Permanent wetland vegetation outside the permanent wetland extent was considered to indicate *possible* peatland, as was the permanent wetland without permanent wetland vegetation. Also, permanent wetland vegetation west of the Rebelo et al. (2012) map and where Hydroc (2009) had mapped wetland, was considered to be possible peatland (see Table 3). The differentiation between probable and possible peat areas allows conservative estimates.

2.1.1 Fieldwork

The desk-based mapping efforts resulted in peatland probability maps, which served to select areas for ground truthing using the following criteria:

1) representativeness to allow extrapolation to other areas,

2) not confirmed as peatlands so far,

3) covering large areas.

Based on these criteria, nine sites were selected in the sub-basins of Lake Albert, Lake Victoria and Victoria Nile and investigated during various field campaigns in 2019.

Coring was done using a Russian D-section peat corer with a chamber of 50 cm length and 5 cm diameter. At each location, the corer was inserted at intervals of 50 cm from the top; the first 10 cm of each following interval were excluded from sampling and interpretation because the deposits could have been mixed by the 10 cm long corer nose.

In total 59 samples were collected to cover representative peat types with different botanical composition and degree of humification. Samples with a standard size were cut out with a knife while still in the corer to allow calculation of the *in-situ* volume, sealed in a plastic bag, and given a code with a permanent marker.

During the field campaigns, national wetlands officers, scientists and technicians were trained in field prospection, peat and peatland identification and calculating carbon stocks (Figure 7). In March and April 2019, two officers from the Ministry of Water and Environment Uganda (water officer Asadhu Ssebyoto and forest officer Leonard Cherop) accompanied the team for two weeks, while prospecting sites in Uganda and Tanzania. An introduction to peatlands was presented to the Scientific Manager of Lake Mburo National Park, MSc. Dorothy Kirimira, and staff. Further, 13 district wetland, environment and forest officers in Uganda (Kasese 1; Lake Albert 1; Mburo 3; Wakiso 1; Pallisa 1; Mbale 2; Torroro 2 and Busia 2) and three officers in

Missenyi district in the Kagera region in Tanzania were introduced to peatlands and peat recognition in their respective areas. Two further presentations/trainings were given in Missenyi district in Kyaka, Tanzania, for district officials (12 people). In Kampala, Uganda, 15 staff members of Nature Uganda participated in a field excursion to Nakivubo wetland. Lastly, in June 2019 two Ethiopian and two South Sudanese wetland officers were trained in coring and peat identification during a fieldtrip in Ethiopia. The latter afterwards carried out independent fieldwork in the Sudd wetlands to explore the presence of peat deposits (Annex 4).

Figure 7. Pictures of the ground-truthing training in 1) Uganda for a Ugandan wetland officer (left) and 2) Ethiopia for wetland scientists and officers from Ethiopia and South Sudan (right).

2.2 Peat carbon stocks

The newly acquired data were used to recalculate the peat carbon estimations of Joosten (2009). For peat depth the average depth in each country was assessed on the basis of available literature (Annex 1), own corings and expert judgement informed by landscape relief, and classified in three classes 'deep', 'medium' and 'shallow' (Table 1).

Table 1. Peat depth classes assigned to peatlands in the various Nile Basin countries.

country	Peat depth class	average depth (m)
Burundi	Deep	5.75
DR Congo	Shallow	2
Ethiopia	Medium	4
Kenya	Shallow	2
Rwanda	Deep	5.75
South Sudan	Shallow	2
Tanzania	Medium	4
Uganda	Medium	4

The class 'deep' was assigned an average peat depth of 5.75 m and used for Rwanda and Burundi (cf. Saunders et al., 2014). The class 'medium' was 4 m, and used for Ethiopia, Tanzania and Uganda. The class 'shallow' was 2 m, and used for Kenya, DR Congo and South Sudan. For DR Congo, the shallow peat depth average refers to the peatlands within the DRC part of the Nile Basin and is attributable to the shallow peat occurrences in the vicinity of Lake Albert. Other peatlands in DR Congo may well belong to other depth classes.

Samples were analysed for dry bulk density (with the loss-on-ignition method) and carbon content (using a CN analyser) at the Soil Laboratory at Makerere University in Uganda. Unfortunately, because of defect sample registration and inconsistent results, the analyses had to be excluded from further calculations. Bulk density and carbon content were instead adopted from literature from other peatlands in or near the Nile Basin (e.g. Dargie et al., 2017; Langan et al., 2019).

Carbon stocks were calculated with the equation:

Carbon stock (tonnes) = Peatland area (m^2) * Peat depth (m) * Bulk density (tonnes/m^3) * carbon content (% dry weight)

2.3 CO_2 emissions avoidance potential

In order to estimate peat carbon stock losses and CO_2 emission reduction potential, a time-series model was developed stating the relationship between drainage status, carbon stock changes, and CO_2 fluxes. Net changes in carbon stock were estimated using the IPCC default carbon loss value of 14 tonnes C per ha per year for drained tropical peatland used as cropland or fallow land (IPCC, 2014) and a gain of 1 ton C per ha per year for the undrained areas (cf. Saunders et al., 2012; Dargie et al., 2017; Langan et al., 2019). Carbon stock changes were converted to CO_2 fluxes using the factor 3.67. For the initial (2015) proportion of drained peatland we took 25 % of the entire peatland area. The total net CO_2 fluxes are then the total CO_2 emissions from the drained area minus the CO_2 removals in the undrained peatlands (initially taken to be 75 % of the total peatland area). The model was only applied to the NEL countries, because of lacking data for Ethiopia and S. Sudan.

Three scenarios were explored:

a) business as usual (BAU, baseline scenario): every year an extra 1% of the total peatland area is drained to a total drained proportion of 60 % in 2050,
b) no change: the initial area of 25 % drained peatlands remains unchanged, and
c) rewet all: all drained peatlands are rewetted in 2025.

The emissions avoidance potential was calculated as the difference between the baseline (scenario a) and scenarios b) and c), respectively.

3. Results and discussion

The total peatland area in the Nile Basin is estimated to be about 29,514 km^2. This is excluding Egypt and Sudan, where peatlands do occur (e.g. El-galladi et al., 2007), but only with a very small area. About 40 % of the total peatland area estimated for the entire Nile Basin is found in the NEL countries (Figure 8). South Sudan potentially has, with an estimated area of about 15,780 km^2, the largest share of peatlands within the Nile Basin.

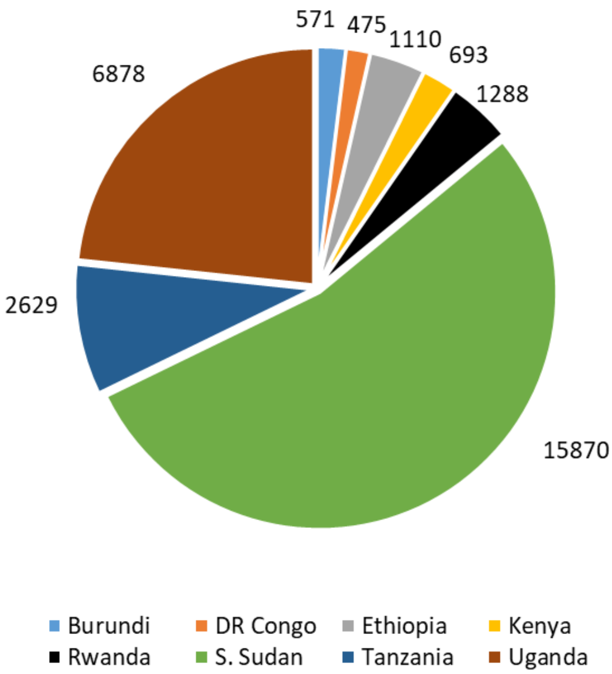

Figure 8. Proportional distribution of confirmed, probable and possible peatland/organic soil areas within the Nile Basin, excluding Egypt and Sudan (see Table 2 for the NEL countries).

3.1 Equatorial Nile sub-system

3.1.1 Nile Equatorial Lakes region

Within the NEL region, large peatland areas are found in the Lake Victoria Sub-basin, especially in the dendritic inter- and depressional valley bottoms and along rivers in Burundi, Rwanda, Tanzania and Uganda, e.g. along the Kagera River and its tributaries (Figure 8, Table 2). Peatlands are also present or can be expected around the rivers flowing into Lake Victoria from the west (e.g. into Mabamba Bay) and south east (e.g. Mara river, see Annex 5).

Table 2. Probabilities of peatland occurrences in the NEL countries. For definition of the probability scale, see Annex 2.

Country	Peatland area (ha)			
	confirmed	probable	possible	Total
Burundi	23,192.7	28,187.0	5,694.4	57,074.1
DR Congo	1,600.0	7,900.0	38,000.0	47,500.0
Kenya	39,735.9	14,906.7	14,654.7	69,297.3
Rwanda	106,191.4	20,038.3	2,591.9	128,821.6
Uganda	145,553.5	262,110.4	280,133.3	687,797.2
Tanzania	102,171.8	43,810.7	116,945.5	262,928.0
Total	418,445.3	376,953.1	458,019.8	1,253,418.2

In the Lake Albert Sub-basin small peatlands are found in the floodplains of Lake George, Lake Edward and Lake Albert, and also along the Albert Nile in the north of Uganda. The areas west of Lake Victoria are also home to dendritic filled-in valleys, for example around the city of Fort Portal.

The Victoria Nile Sub-basin has peatlands mainly in the form of dendritic filled-in valleys around Lake Kyoga and the extensive floating mats at Lake Victoria itself (e.g. Mabamba Bay). There are also small peatlands in the mountains in west Kenya, southwest Uganda, and Rwanda and Burundi. The probabilities of peatland occurrences are listed in Table 2.

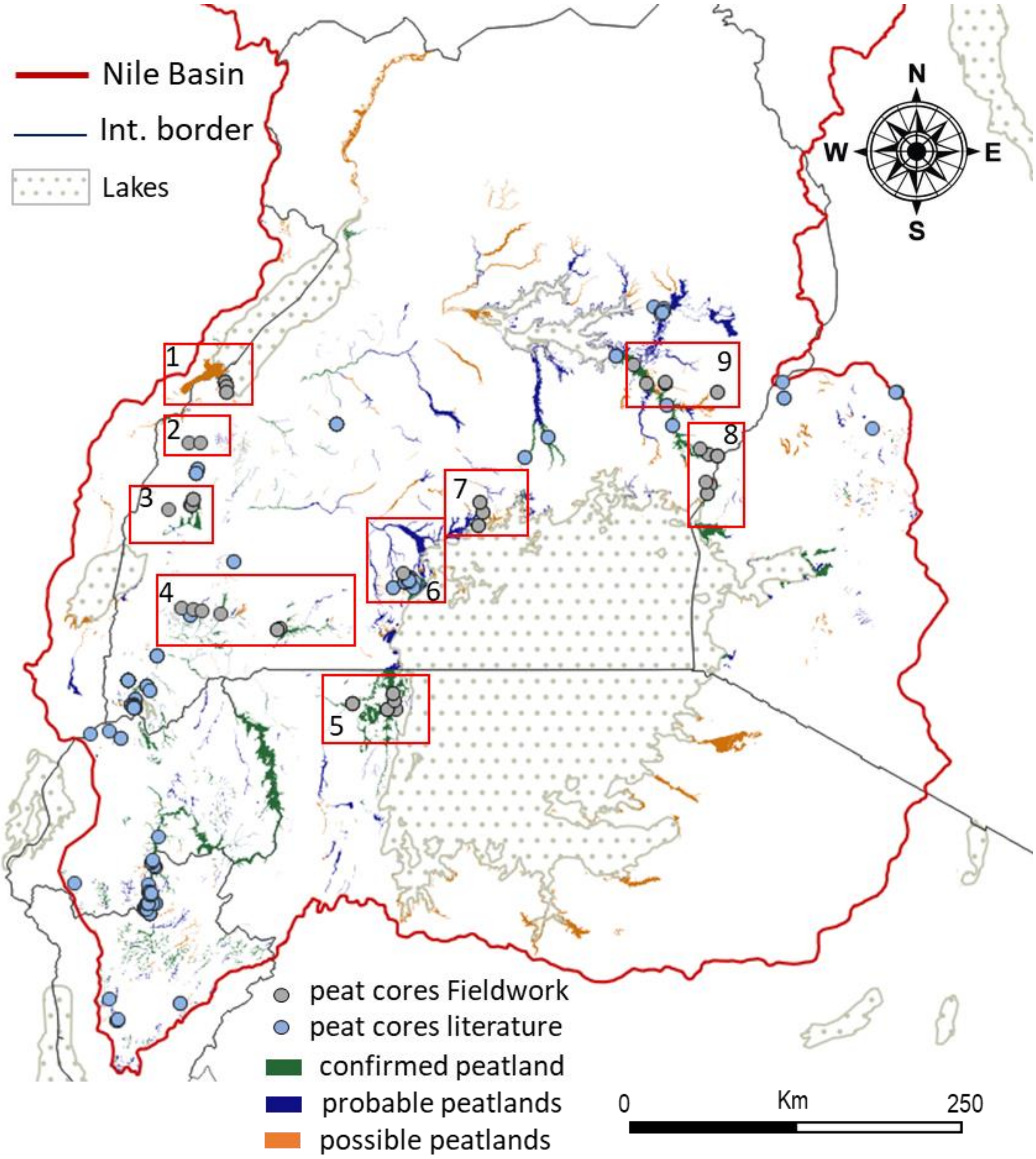

Figure 9. Peatland distribution in the NEL region. Blue=confirmed, green=probable, and orange=possible peatland occurrence. Fieldwork sites (red boxes) and coring (grey dots) and literature (blue dots) validation points are indicated.

The peat in most peatlands west of Lake Victoria Sub-basin has a medium degree of humification, whereas the peat in east Uganda in the Victoria Nile and in the east of the Lake Victoria Sub-basin is more strongly decomposed or only left with few centimetres thickness after burning and conversion (Figure 10). The swamps and tributaries of Lake Victoria exhibit specific features as larger water lenses and litter with recent roots and root mats in the uppermost layers.

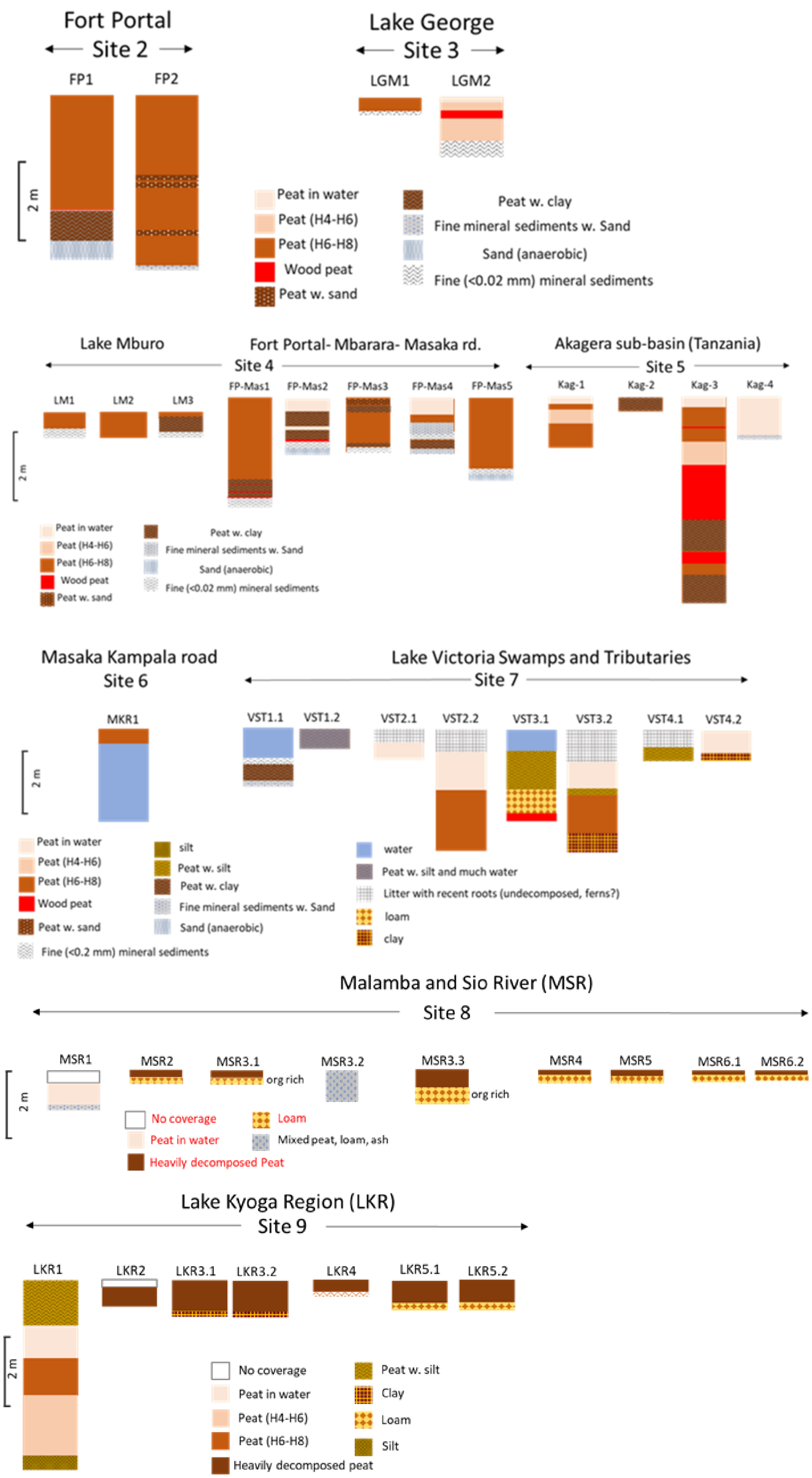

Figure 10. Peat cores from some of the visited sites (sites 2 to 9). Each core shows the measured peat depth, type and humification degree (von Post scale).

Most peat is composed of papyrus, sedges and common reeds. *Raphia* wood peats are common, especially in the deeper parts of the peat deposits. Such wood peat in tropical inter-valleys is also known from Maputaland in South Africa (Faul et al., 2016). The high degree of humification and high percentages of clay in the cores reflect the dynamic, often seasonal conditions under which the peat has been accumulated. Increasing clay concentrations at the top of the cores are often associated with deforestation of the surrounding areas and associated erosion. Peat depths are often related to the relief of the surrounding landscape, for instance cores in floodplain associated peatlands reflecting the gentle relief of the underlying mineral soil (e.g. in the floodplains of Lake Albert).

Dominant vegetation types at the visited sites included: *Raphia* palm, *Cyperus papyrus*, *Cyperus latifolius, Mimosa, Carex, Typha*, ferns with brown mosses and floating vegetation. Sedge dominated, species-rich vegetation has been found in vast peat-filled valley bottoms in the Kagera subset (Site number 5 in Figure 9) of Tanzania (Figure 11a, b). Other reeds included *Typha* and/or *Phragmites* (Figure 11c, f), which both also occur in mosaic with *Cyperus papyrus* in dendritic valley bottoms in the NEL region. Floating mats of the Lake Victoria margins (as a form of terrestrialisation) host a wide variety of species in distinct mosaics of fern dominated stands with brown moss, aquatic plant, sedge or *Typha* dominated zones (Figure 11d-f).

Cyperus papyrus dominating the rivers banks was observed along the Kagera River in Tanzania and its tributary the Akanyaru River in Rwanda (Figure 11h). Similarly, the peatland sites visited in Uganda were mostly dominated by *Cyperus papyrus*, especially the peat-filled valley bottoms around Lake Victoria, Lake Albert, Lake Mburo-Nakivali system and Lake Kyoga (Figure 11g). Undisturbed *Cyperus papyrus* stands are not very species-rich, but with increased human impact (such as drainage and grazing) climbing plants and shrubs (e.g. *Mimosa*) enter the vegetation (Figure 11i, j). *Cyperus latifolius* was found to dominate peatlands in the mountains around Masha town in Ethiopia (Figure 11k). *Raphia* palm is especially associated with the peatlands around Lake George in the Lake Albert sub-basin (Figure 11l-n), but was also found in other areas, e.g. Lake Kyoga where it occurs in the higher parts of peat filled valley bottoms.

3.1.2 Sudd: Bahr el Jebel, Bahr el Ghazal and White-Nile sub-basins

The area of wetlands in the Sudd as given by Rebelo et al. (2012) is approximately 26,500 km², of which 9,176 km² are permanent wetlands (Figure 12 Left). These numbers are most likely underestimates because the map of Rebelo et al. (2012) doesn't cover the entire Sudd. Also, the fact that Rebelo et al. (2012) mention "flooding below vegetation" as an explicit category may imply that water-saturated but not-flooded soils are neglected and the total permanent wetland area is in reality larger. Di Vittorio & Georgakakos (2018) mention an area of permanent wetland for the Sudd of 12,530 km². It is unclear however the total area covered in their research, which focused only on flooding assessment.

Hydroc (2009) maps an additional 5,627 km² of (both permanent and seasonal) wetland in the Sudd west of the Rebelo et al. (2012) map. The use by Hydroc (2009) of MODIS with a coarse resolution of 500m per pixel and the failing spectral distinction between various wetland vegetation types with NDVI make a clear distinction between permanent and non-permanent wetland impossible. Indeed, our field observations in the Gambela area (Ethiopia) confirmed that the Hydroc (2009) map includes a range of non-permanent wetlands.

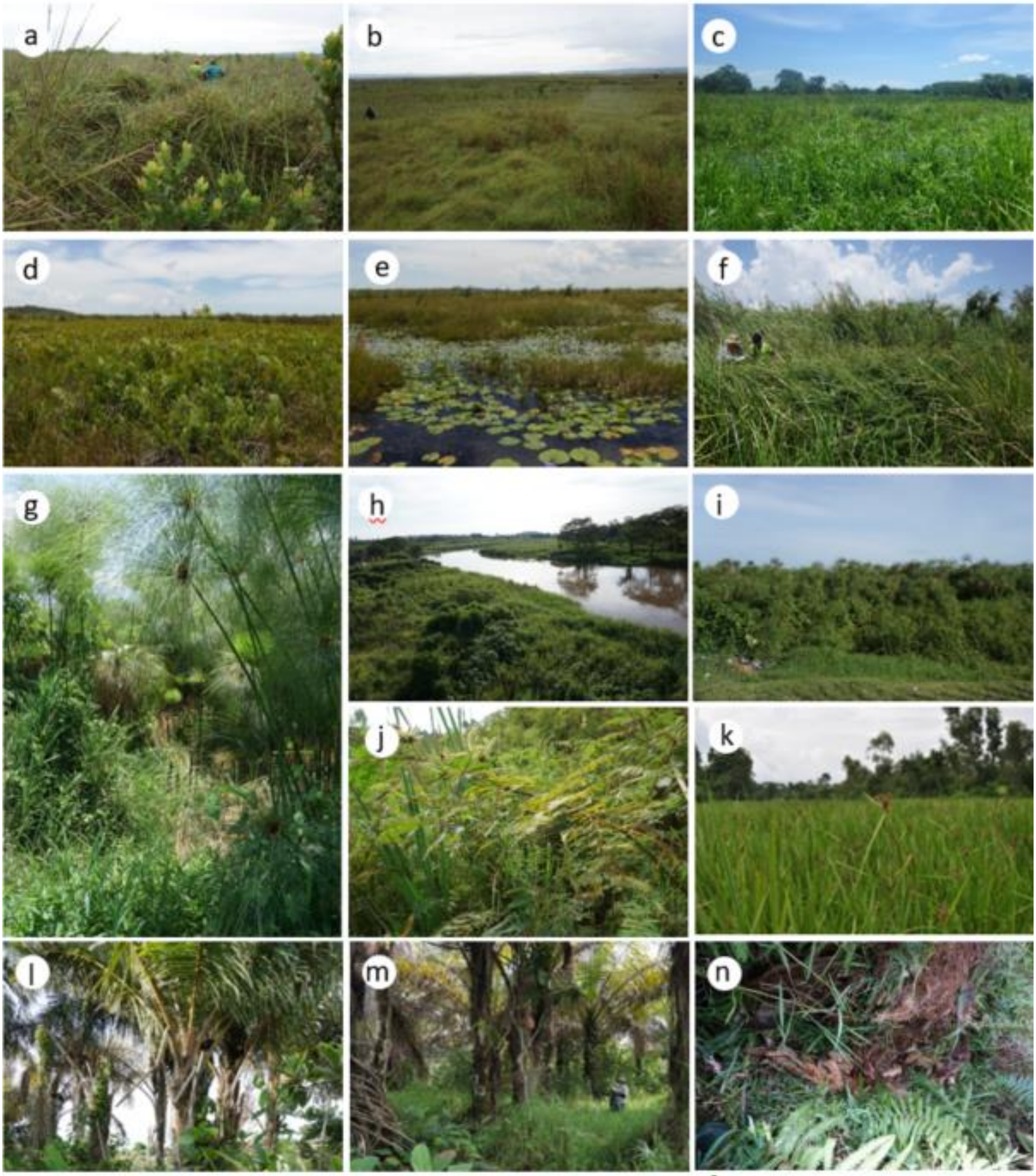

Figure 11. a-b) sedge dominated species-rich vegetation with hummocks[2]; c) sedge and *Typha*; d-f) floating mats with dominance of ferns and brown mosses, aquatic plants and sedges with *Typha*, respectively; g, h) less disturbed *Papyrus* stands; i, j) degrading *Papyrus* stands with climbing plants and *Mimosa* spec.; k) *Cyperus latifolia*; l, m) *Raphia* palm forest with species-rich understory; n) decaying wood in *Raphia* forest. Photos: Alexandra Barthelmes, Samer Elshehawi, Hans Joosten and Tatiana Minayeva.

[2] a, b: Bukoba (Tanzania); c: Fort Portal (Uganda); d-f: Mabamba Bay (Uganda); g-j: Masaka road (Uganda); k) Masha (Ethiopia); l-o) Masaka road (Uganda)

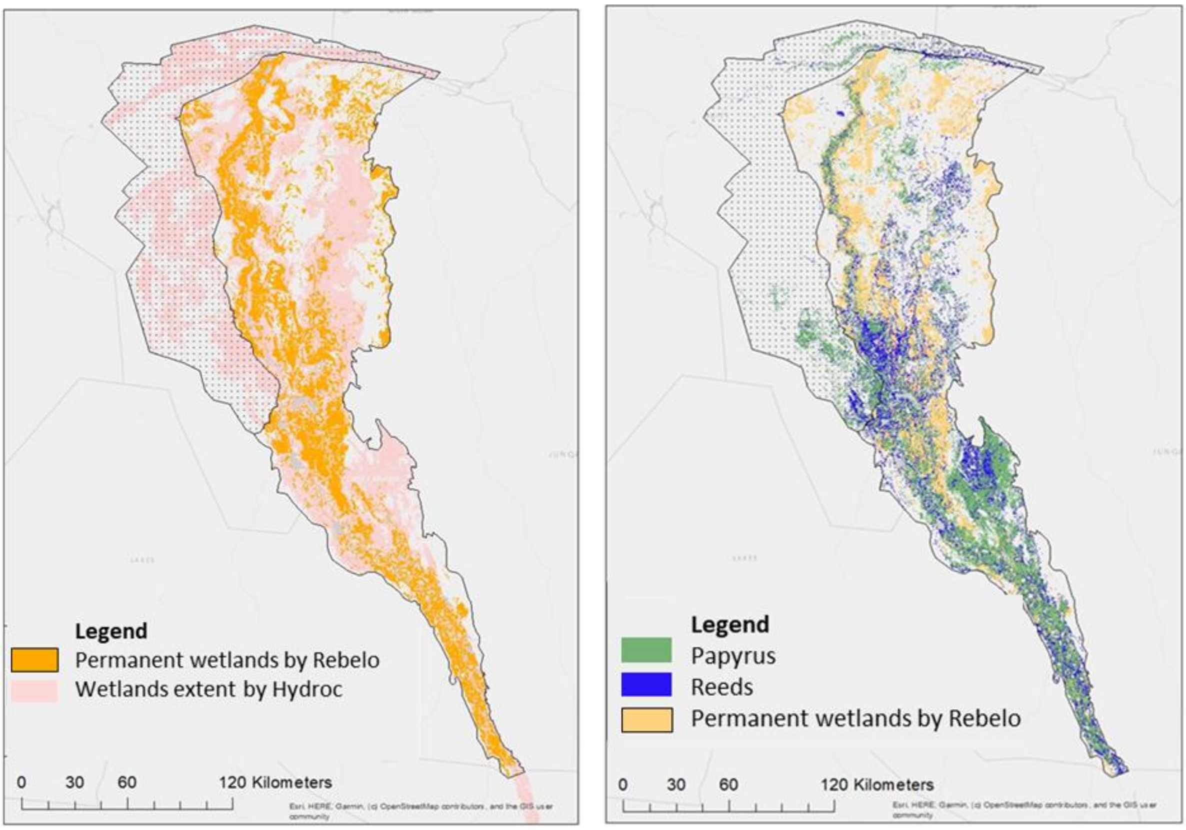

Figure 12. Left: Wetlands extent in the Sudd based on Hydroc (2009) and permanent wetlands extent based on Rebelo et al (2012). The *dotted area* is only covered by Hydroc (2009). Right: Extent of permanent wetland vegetation (Papyrus and "Reeds"), as identified using Sentinel-2.

We distinguished with Sentinel-2 eleven spectral wetland classes of which papyrus and "reeds" were assumed to represent vegetation indicative of permanent wetland (which was confirmed by our ground truthing) and the others non-permanent wetlands (see Annex 3.3). Identification accuracy is high as shown in the confusion matrix (see Annex 3.1). Permanent wetland vegetation (classes papyrus and "reeds" combined) cover an area of 8,567 km² in the Sudd, of which approx. 2,800 km² overlay with the permanent wetlands of the Rebelo et al. (2012) map and thus considered as 'probable' peatlands. A Further 970 km² of classified permanent wetland vegetation overlay with the Hydroc (2009) map. There are 5,730 km² of permanent wetland vegetation distinguished from the Sentinel-2, which are found outside delineated permanent wetland areas (Figure 12 Right; Table 3; Annex 3.2). Together with 6,334 km² of permanent wetlands from Rebelo et al. (2012), which do not have permanent wetland vegetation, these classes form 13,034 km² of 'possible' peatlands.

Papyrus alone covers an area of 5,879 km² in the Sudd of which 1,893 km² overlay the permanent wetlands of Rebelo et al. (2012) and more than two thirds other land (Annex 3.2.). Papyrus and permanent wetlands largely lack overlap from Shambe (for location see Figure 6) northwards where the Sudd widens, which may be due to spectrally different vegetation classes compared to the Bor area in the south. The areas to the north of the Sudd generally haven't been described and verified due to lacking access and ground information. Accounts from literature (Marno, 1881; Griffin, 1924; Hurst & Phillips, 1931; Rzoska, 1974;

Denny, 1984) describe dense papyrus stands from Lake No (for location see Figure 6) southwards along the Bar el Jebel, illustrating the persistent abundance of papyrus in the northern part of the Sudd. The “reeds” class covers 2,688 km² of which 943 km² are overlaying with the permanent wetlands of the Rebelo et al. (2012) map.

Table 3. Estimated probable and possible peatland area in the Sudd according to the combination of various criteria.

Rebelo et al. (2012) permanent wetland (km²)		Hydroc 2009 additional wetland (km²)	Sentinel-2 permanent wetland vegetation (km²)		Probable peatland (km²)	Possible peatland (km²)
Yes	No		Yes	No		
9170			2836		2,836	
9170				6334		6,334
	0		5730			5,730
		5627	970			970
				Sub-total	2,836	13,034
				Total	15,780	

The lack of ground verification data for spectrally different wetland areas and vegetation types in the northern Sudd is a severe shortcoming for classification and identification. The retrieved extent of papyrus and “reeds” seems to be too low.

It is nearly impossible to acquire Sentinel-2 scenes for the entire Sudd without traces of recent vegetation fires. Fire changes the spectral characteristics significantly and may thus lead to misidentification. At the end of the wet season in November/ December, the burned area seems to increase rapidly over the Sudd (own Sentinel 2 image interpretation). Imagery from mid-January, i.e. in the middle of the dry season, shows rather little burned area, while non-permanent wetland vegetation is best distinguishable from permanent wetland vegetation (Di Vittorio & Georgakakos, 2018). Vegetation classification and identification based on time-series analysis instead of imagery from only one point in time may allow to correct for misclassification/misidentification due to fire. The estimated extent of 15,870 km² of ‘probable’ and ‘possible’ peatlands in the Sudd is based on various assumptions and must be considered preliminary.

Further field surveys to verify peat occurrence and vegetation types will be required to improve modelling and remote sensing approaches. The field work in the Sudd in July 2019 by two trained South-Sudanese scientists was limited to an area close to Bor, where four corings were made: two at river margins and two at the edge of the wetland (Figure 13). Descriptions and photo interpretation of the cores reveal only clayey soils, with potentially high organic carbon content but still mineral. At finalization of this report, results of the laboratory analysis were not yet available. The field trip report (Annex 3) describes various challenges, which limited the number of coring points. For the remote sensing classification, coring points could not be taken into account due to insufficient accuracy of the GPS locations recorded in the field.

In order to get a robust picture of the distribution of organic soil in the Sudd, coring along representative transects north of Bor from the rivers via the extensive flats to the margins of the Sudd is necessary. The location of the transects should be informed by the landscape relief, which shapes the occurrence of permanently wet areas and thus peat forming conditions.

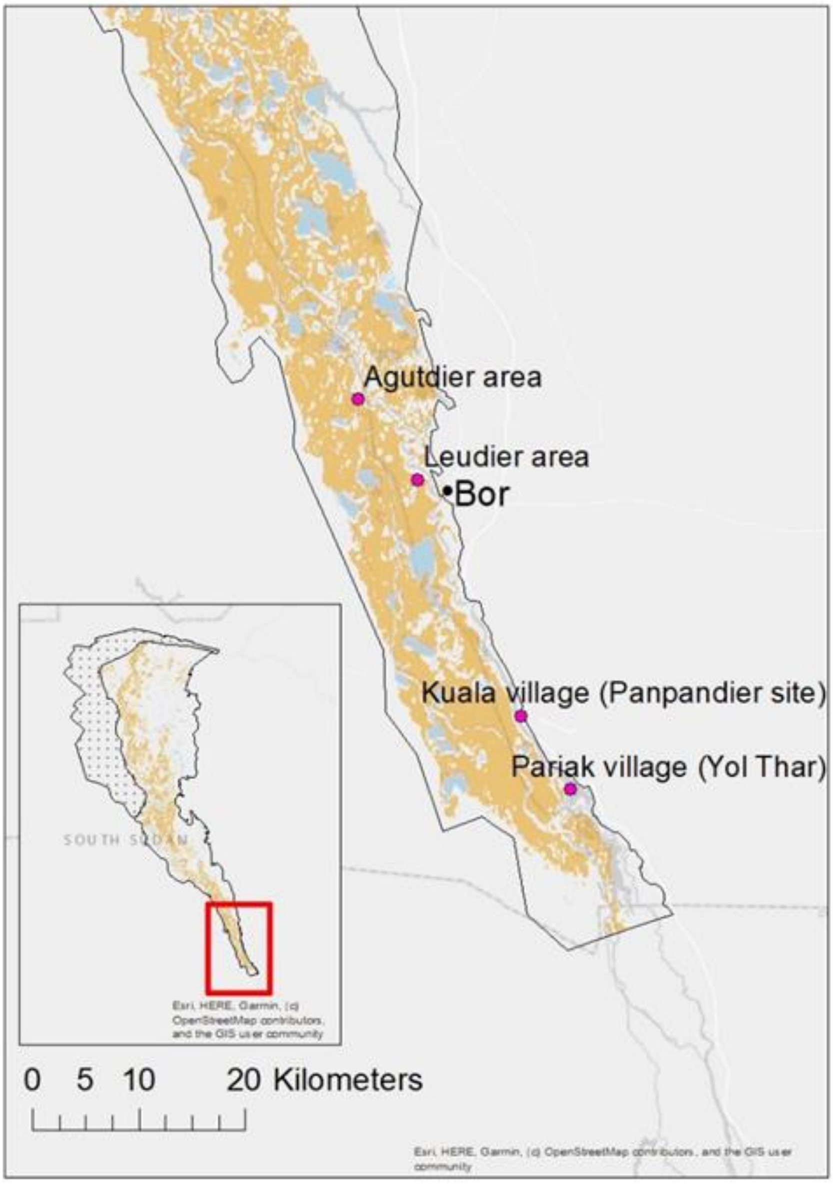

Figure 13: Coring points in the Sudd as retrieved in July 2019 by South-Sudanese scientists (only clayey mineral soils).

3.2 Blue Nile Sub-system

3.2.1 Ethiopia: Baro-Akobo-Sobat, Tekeze-Atbara and Blue-Nile sub-basins

The reconnaissance mapping in Ethiopia produced a minimum area of about 1,110 km^2 of peatlands (Figure 14; Table). Some peatlands seem to extend over the assumed boundary of the Nile Basin, which points at the necessity to further investigate the direction of water flow. The reliability of the peatland map is, however, limited, because the field survey in Ethiopia rather focused on preparing the South-Sudanese colleagues for their Sudd expedition. Most peatlands lie in the mountains, as lake margins and in channelled and non-channelled valley-bottoms.

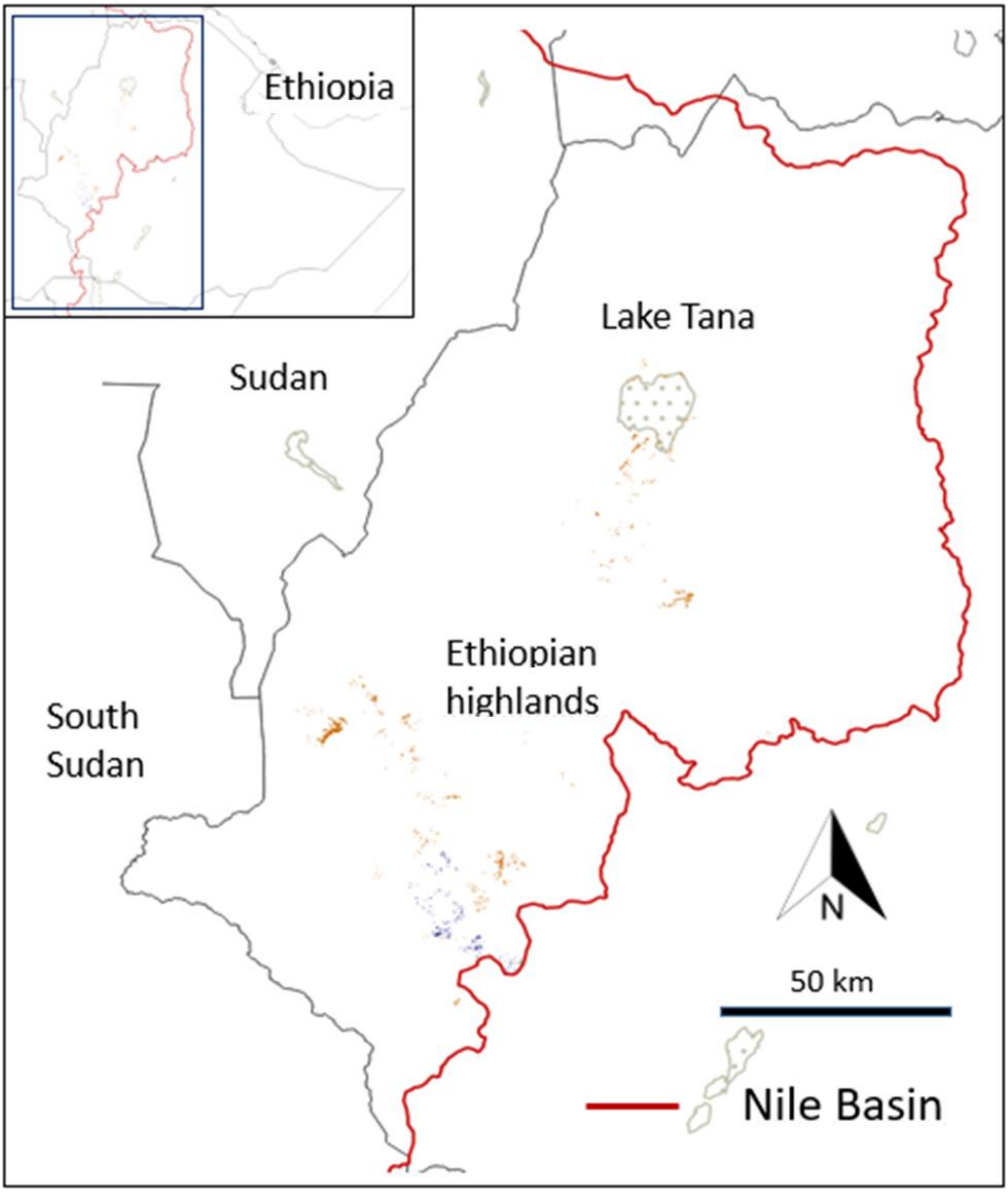

Figure 14. Delineated peatlands in Ethiopia. Peatland reliability: green=confirmed peatlands; blue=probable peatlands; orange=possible peatlands.

Table 4. Estimated peatland area in Ethiopia within the Nile Basin and mapping reliability.

Reliability	Peatland area (km^2)	Peatland area (%)
confirmed	21	2
probable	271	24
possible	818	74
Total	1110	

Our short ground-truthing trip in the western Ethiopian highlands confirmed the presence of peatlands at the sources of the Baro and Akobo rivers (Figure 15), where we found up to 3.5 - 4 m of peat without having reached the centre of the respective peatlands where peat layers up to 6 - 7 m may be expected (Figure 16). Areas in the vicinity of Lake Tana have been reported to contain peat up to 4 m thick (Mundt et al., 2012).

Figure 15. Ground-truthing points from the field trip in Ethiopia.

Figure 16. A core from a peatland in the western Ethiopia highlands near Masha town (1.68-2.18 m peat section; Left); upon taking a small section and looking closely, dead plant material can be seen by the naked eye (Right). Coordinates: 7°46'19.9"N, 35°27'58.8"E.

3.3 Carbon stocks

Figure 17 shows our estimates of the peat carbon stock for the area of the countries that is situated within the Nile Basin, i.e. areas outside the Nile Basin were excluded. The country with the highest carbon stock is South Sudan (1.5 - 3.59 GtC), the second Uganda (1.3 - 3.1 GtC), with the highest spatial concentration in the Lake Victoria Sub-basin. The Kagera subset is estimated to contain more than 50 % of all peat carbon in the NEL region. Also, the sub-basins of Lake Albert and Victoria Nile harbour considerable peat carbon in the floodplains around lake George, Lake Albert, Lake Kyoga and in the inter-valleys in the plateau steps from Lake Albert to Lake Victoria. Tanzania follows Uganda within the NEL region with 0.5 - 1.2 Gt of peat carbon. Rwanda and Burundi have large stocks in comparison to their small size, which is attributable to the larger depth of their peatlands (e.g. Pajunen, 1996). The peat carbon stock of the Ethiopian highlands and the margins of Lake Tana ranges between 0.2 and 0.5 GtC, but this estimate is based on a probably too small peatland area estimate and a possibly too conservative peat depth class (medium; 4 m average depth).

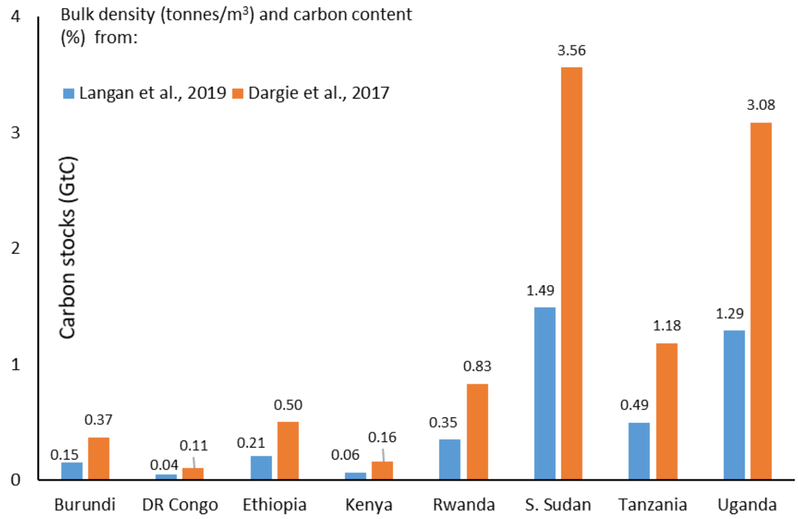

Figure 17. Carbon stock estimates (GtC) per country, based on bulk density and carbon content values of Dargie et al., 2017 (orange) and Langan et al., 2019 (blue). Only areas within the Nile Basin are included.

The estimated carbon stocks depend strongly on the depth class assumed for the respective country, which is mostly rather subjective due to limited ground information. For instance, whereas the estimated extent of peatland in South Sudan makes up more than 50 % of the total peatland area in the Nile Basin (Figure 8), the carbon stock is less than 40 % of the total (Figure 18), because of the assumed shallow peat depth in the Sudd. The stock estimates using carbon density values of Dargie et al. (2017) may be too large because these values are derived from Congo Basin Peat Swamp Forest peats with higher organic content and less clastic materials from surface water during floods.

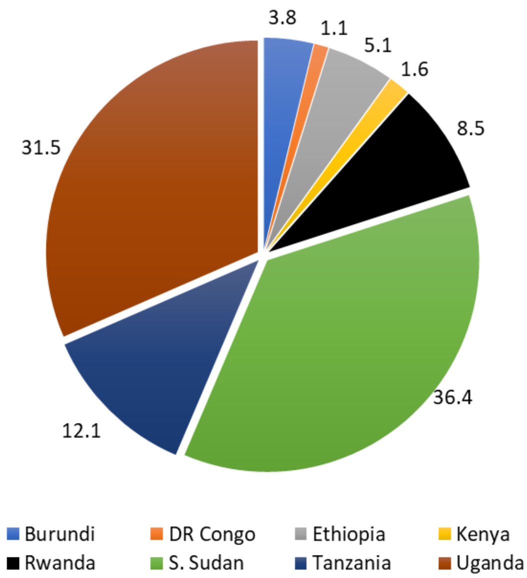

Figure 18. The contribution (in %) of various countries to the estimated total peat carbon stock of the Nile Basin.

3.3.1 Estimates of carbon stocks in transboundary areas

Figure 19 shows the carbon stock estimates of some of the transboundary peatlands in the NEL region. The carbon stocks of the transboundary systems in the Kagera subset especially reflect the importance of this subset to the Nile Basin. The transboundary systems are shared between four countries: Burundi and Rwanda (Rweru- Akanyaru complex) and Tanzania and Uganda (Sango Bay- Minziro) (see Annex 5). The two systems combined represent about 10 % of the entire carbon stock of the Nile Basin. The other systems, while smaller, still represent a great potential for collaboration. It should also be noted that because of the different factors used in the estimation process, a system like Mara may contain as much carbon as the ones in Sango Bay (upper limit to lower limit respectively). Hence, development plans will require further investigation of each system of interest to get a better grasp of their stocks and actual potentials. Probability maps for area estimation of the above-mentioned transboundary peatlands are in annex 5.

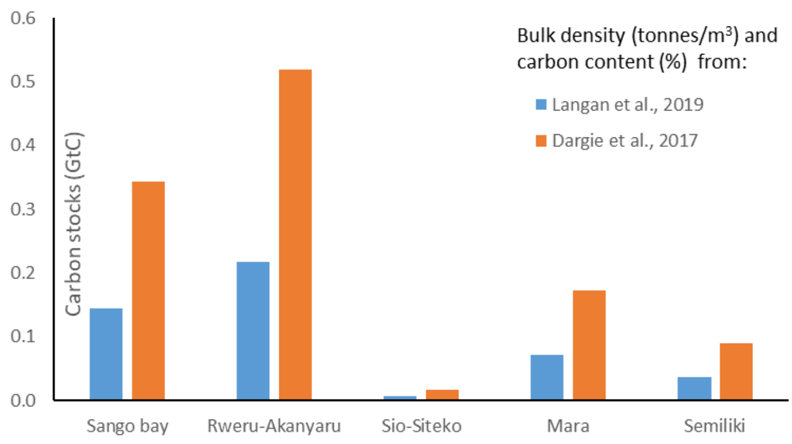

Figure 19. Carbon stocks (GtC) of some of the transboundary peatlands in the Nile Basin.

3.4 Peatland degradation and land use

Carbon storage and other ecosystem services may be affected significantly by land use. Assessment of land use intensity (e.g. presence of drainage ditches, fire scars, …) using satellite and aerial imagery showed that many peatlands and organic soils areas were still unaffected by human activity in 2010 - 2014 (Figure 20). In Rwanda and Kenya approximately half of the organic soils were found to be drained and degrading, including 552 km^2 (46 % of the total) in Rwanda, and 207 km^2 (46 %) in Kenya. Uganda and Tanzania were found to have the lowest land use impact on peatlands. The major 2010-2014 degradation hotspot was Burundi (Figure 20), where slightly and heavily drained organic soils covered 600 km^2 (91 % of the total organic soil area), and only 57 km^2 (9 %) had remained untouched.

Land use may involve total destruction (i.e. by peat extraction, burning and infrastructure and housing construction), drainage for agriculture and forestry, grazing, fishing ponds, and tourism (Namaalwa et al., 2013, Hakizimana et al., 2016; Langan et al., 2019). Further analysis of land-use types, assessment approaches and a rapid assessment of land-use change impact on GHG-emissions is presented in annex 6. Our field survey

2019 revealed that since 2010-2014 an accelerated conversion of undisturbed peatlands has taken place in Uganda, mainly by draining and recurrent burning of papyrus and sedge stands during the dry season and their subsequent conversion to various types of land use (Figure 21). A major recent conversion hotspot is found in the south-eastern tributaries of Lake Kyoga (Figure 22). Since much peat here seems to be shallow, these practices will lead to the complete loss of peat and its inherent ecosystem services such as water storage and water provision during the dry season. Degradation usually starts at the margins of the peatlands and where new or expanding road infrastructure provides access. The increasing rice cultivation is a severe threat because of the change of traditional low intensity and peat-conserving use of mainly papyrus in the peat filled valleys into a high intensity and peat degrading production type. Moreover, a prolonged dry season probably leads to the burning of the peat underneath the papyrus in the Lake Kyoga and Sio Siteko regions (Figure 11 g, h, m; Figure 20).

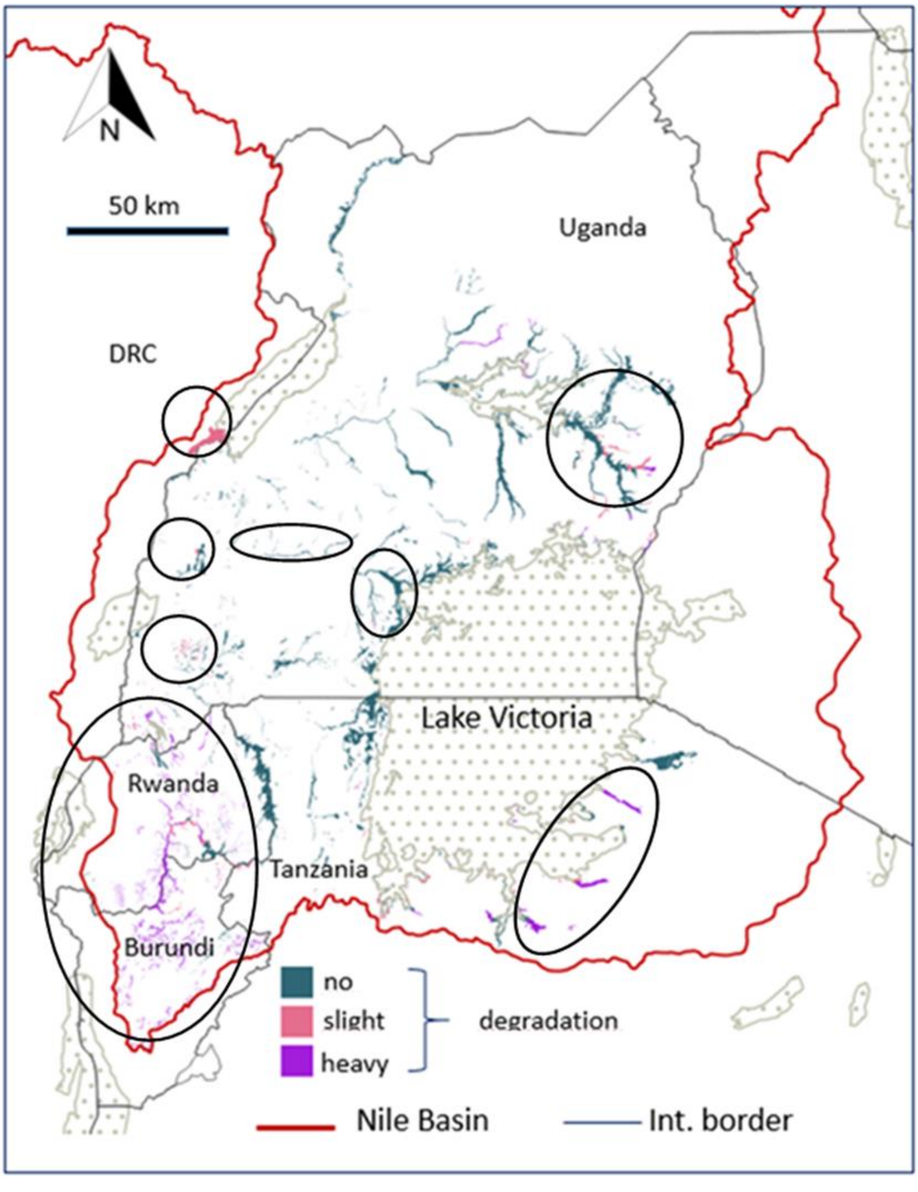

Figure 20. 2010-2014 drainage and degradation status of organic soils in the NEL region countries based on satellite imagery compared with major current (2019) degradation hotspots (black ellipses). The degradation status is overlying the cumulative coverage of confirmed, probable and possible peatlands and organic soils.

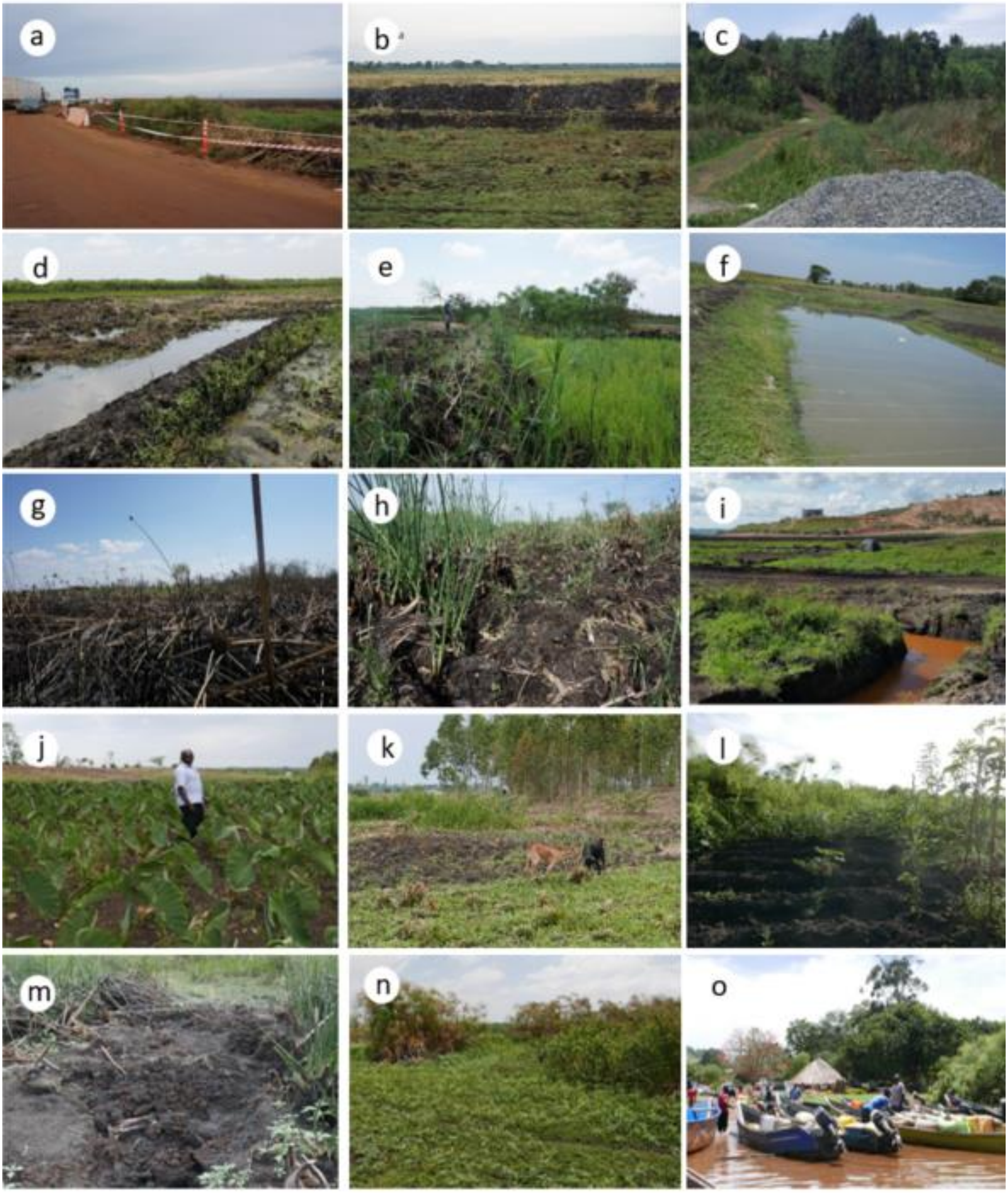

Figure 21. Examples of land use of peatlands in the Nile Basin: a-c) road construction[3]; d, e) developing rice fields from *Papyrus* swamps; f) fish pond; g) freshly burned *Papyrus*; h) burned *Papyrus* and peat; i) peat extraction; j, l) cropland on former *Raphia* palm stand; k) grazing; m) multiple times burned peat; n) abandoned land with mineralised peat and dense weed cover; o) domestic transport and bird watching/tourism. Photos made during the 2019 field work by Alexandra Barthelmes, Hans Joosten and Samer Elshehawi.

[3] a,b,d,e,f: Pallisa (Uganda); c: Fort Portal (Uganda), g,h: Mbale (Uganda); i: Gisagara (Rwanda); j,k: Tororo (Uganda); i: Kagera region (Tanzania); m,n: Sio Siteko (Uganda); o: Mabamba Bay (Uganda)

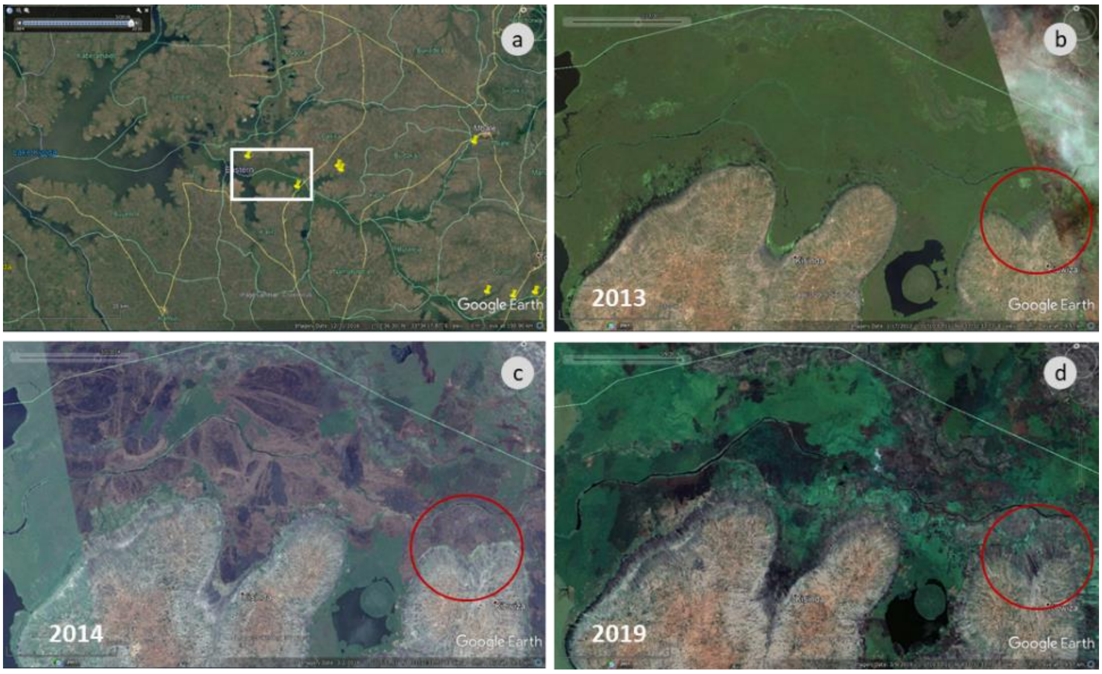

Figure 22. Development of an area close to Lake Kyoga. (a): general location; (b): undisturbed peatland in 2013 (red circle); (c): many probably human-made fires in 2014; (d): recurrent burning until 2019 has led to the loss of shallow peat layers at the margins.

3.5 CO_2 emissions avoidance potential

CO_2 emissions avoidance can be reached by

1. stopping the increase of emissions by stopping the expansion of drainage.
2. reducing existing emissions by rewetting already drained areas.

In the business-as-usual scenario the peatlands would in our model from 2015 to 2050 lose 0.22 GtC (Figure 23). This would lead to a net emission of 804 Mt CO_2 over that period for the NEL area. Compared to the business-as-usual scenario the 'no new drainage' and 'rewet all' scenarios would lead to an emission avoidance of 362 and 678 Mt CO_2 until 2050, or 9.03 and 19.4 Mt CO_2 per year, respectively (Figure 23). The emission avoidance here is determined by the time of stopping drainage and/or rewetting, hence the lower emission avoidance estimated in this scenario model. If all the drained peatlands are to be rewetted in 2020, the reduction could be higher than 678 Mt CO_2.

CO_2 emissions continue in the scenario of 'no new drainage'. The reason is that already drained peatlands continue to emit CO_2, even without expansion of drainage as carbon stocks keep decreasing and cumulative emissions keep increasing over time (until the total carbon stock is depleted). In contrast, stopping deforestation in forests leads to an immediate decrease in GHG emissions (Figure 24, Wibisono et al., 2011).

It should be noted that the values available from the scenario are based on an assumed overall initial proportion of drained peatland of 25 %, which was done for the sake of simplicity of the model. Carbon stock losses and associated emissions are proportionally higher in areas with heavy drainage, e.g. in Burundi and Rwanda (see Figure 20), where many peatlands have been in use since 1975 (FAO, 2017). Calculations based on a more differentiated estimation of the initial (2015) drained area per country arrives at higher emissions avoidance potential for the NEL countries of 885.5 Mt CO_2 (annex 7).

The CO_2 emissions avoidance potential from the Nile Basin's transboundary peatlands follows the same trends as observed in Figure 23. The magnitude of these potentials differs as per drained area in each peatland. The current proportion of drained peatland in Rweru-Akanyaru is in the range of 50-75 %, while it is likely less than 10 % for Sango Bay-Minziro. This means that the current carbon stock losses in the Rweru-Akanyaru complex are already high and that urgent rewetting is required to avoid further CO_2 emissions. Meanwhile the emissions from Sango Bay-Minziro are currently lower than the average, but accelerating land-use change under the business-as-usual scenario was also observed there during our field trip in Tanzania in 2019.

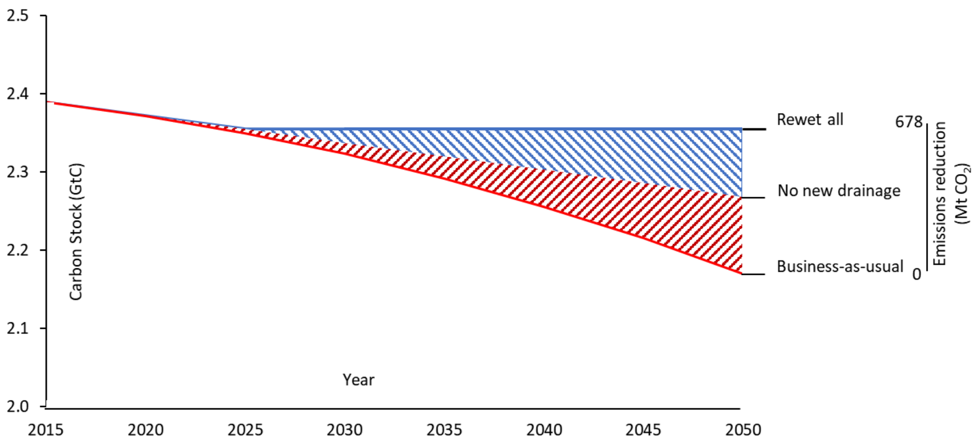

Figure 23. Cumulative Carbon stock changes and CO_2 emissions reduction potential under different scenarios. The **red line** shows the change in carbon stock (see axis left) in the business-as-usual scenario with an annual increase of drained area of 1 % of all peatlands. The **blue line** shows the change in carbon stock when all drained peatlands are rewetted in 2025. The **red hatched area** shows the cumulative emissions avoided (see axis right) when no new drainage takes place after 2020, the **red and blue hatched areas together** show the cumulative emission avoidance if all drained peatlands are rewetted in 2025.

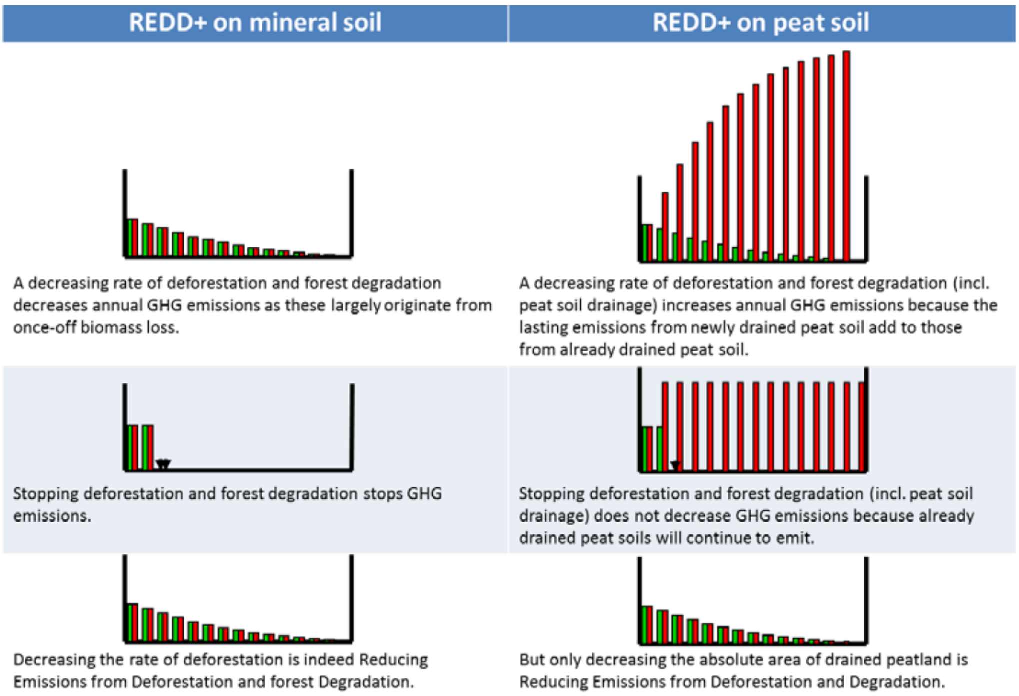

Figure 24. Effects of reducing deforestation (left) and reducing new peatland drainage (right) (green) on emissions (red) from forests and peatlands, respectively (Wibisono et al., 2011).

3.6 Loss of peatland ecosystem services and socio-economic implications

Peatlands form under permanently waterlogged conditions, which prevent the complete decomposition of dead biomass resulting in the accumulation of carbon rich soil organic matter. This organic matter is rapidly decomposed when the soil is no longer water-saturated, causing huge GHG emissions. Some 15 % (650,000 km²) of the organic soils worldwide have been drained, mainly for cropland, grazing land, and forestry. This 0.4 % of the global land area is responsible for some 5 % of all global anthropogenic GHG emissions.

In East Africa, peatlands and organic soils occur in many river valleys, in the headwater areas of higher altitudes, in large filled-in lakes and in the coastal lowlands near river mouths. These peatlands provide vital ecosystem services: they sequester and store carbon, regulate local and regional climate (cooling effect), host rare and specialized biodiversity, control floods, increase groundwater availability, retain nutrients, remove pollutants, supply drinking water, and provide livelihoods to millions of people. Thus, climate change is merely one of many societal damages related with peatland drainage (Figure 25).

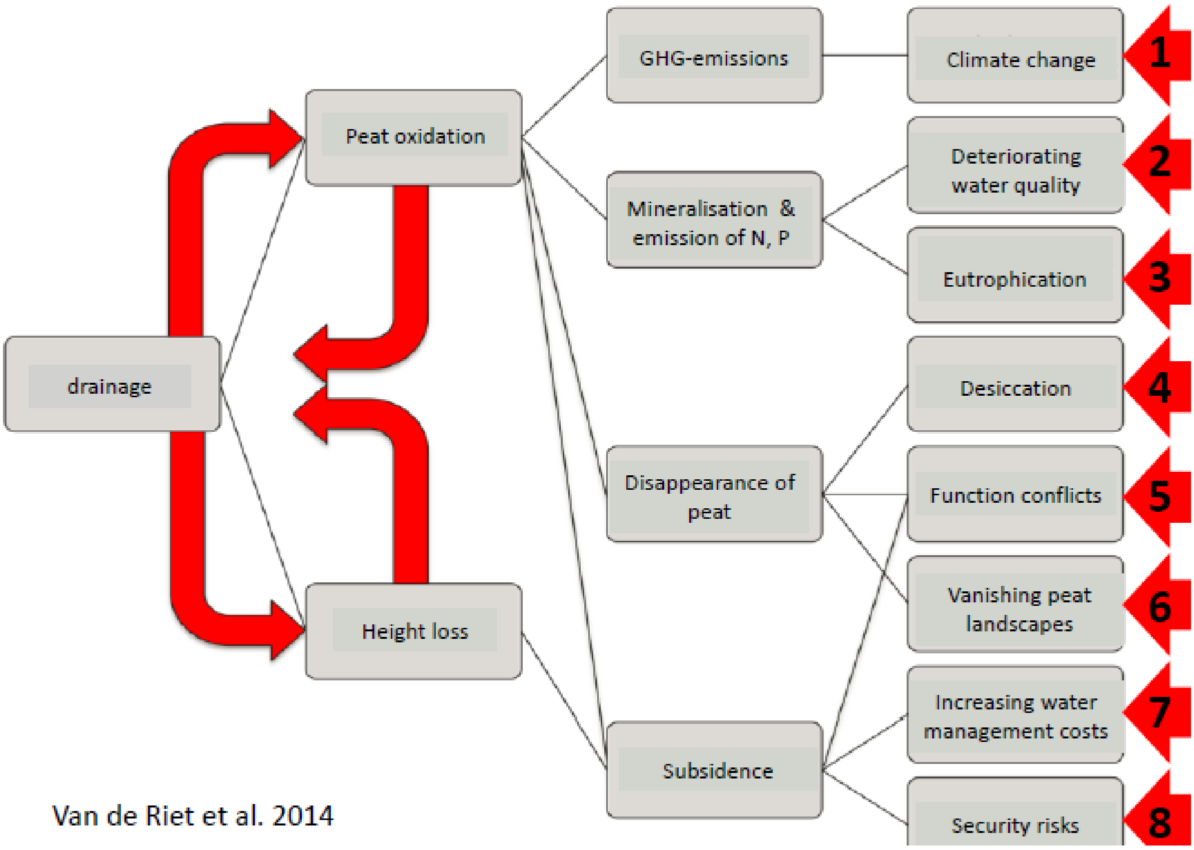

Figure 25. Societal damages of peatland/organic soil drainage and degradation (after van de Riet et al. 2014).

4. Further research

Our pilot research in the framework of the NBI-GIZ project has uncovered various strategic knowledge gaps for the development and implementation of sustainable land use in the Nile Basin peatlands, especially with respect to transboundary peatlands. This final chapter shortly describes these gaps and comes with first ideas how these gaps could be effectively filled.

4.1 Peatland mapping

Our peatland mapping in 2019 has resulted in an estimated peatland area for the Nile Equatorial Lakes (NEL) region of >12,000 km^2, for the Sudd of >16,000 km^2 and for the Ethiopian highlands of >1,000 km^2. This translates to 4 - 10 Gt of Carbon, depending on the assumed depth and carbon density of the peat. The most reliable estimates are for the NEL region, where more than 50 % of the peatlands are located in the Kagera subset of the Lake Victoria sub-basin. This area may also contain more than 70 % of the total carbon stock of the NEL region, because of the thick peat layers encountered in Burundi, Rwanda and southwest Uganda (own fieldwork in Tanzania, see Figure 26; Hamilton & Taylor, 1986; Pajunen, 1996; Langan et al., 2019). In the Sudd, the peatland extent requires further investigation; initial research indicates that the Sudd could be one of the largest peat carbon stocks of all wetlands in Africa (Figure 17). Strategic areas for further studies that comply with the NBI strategic goals include:

1) The Kagera subset as a large transboundary peatland system, covering Burundi, Tanzania, Uganda and Rwanda (Figure 26, left),
2) The Sudd as a peatland system of regional importance: (Figure 12).
3) The peatlands in the Ethiopian highlands, which are smaller in extent, but provide vital ecosystem services related to water security by suppling and regulating by far the most water of the Nile River through the Blue Nile (Figure 26 right) (Sutcliffe & Parks, 1999).

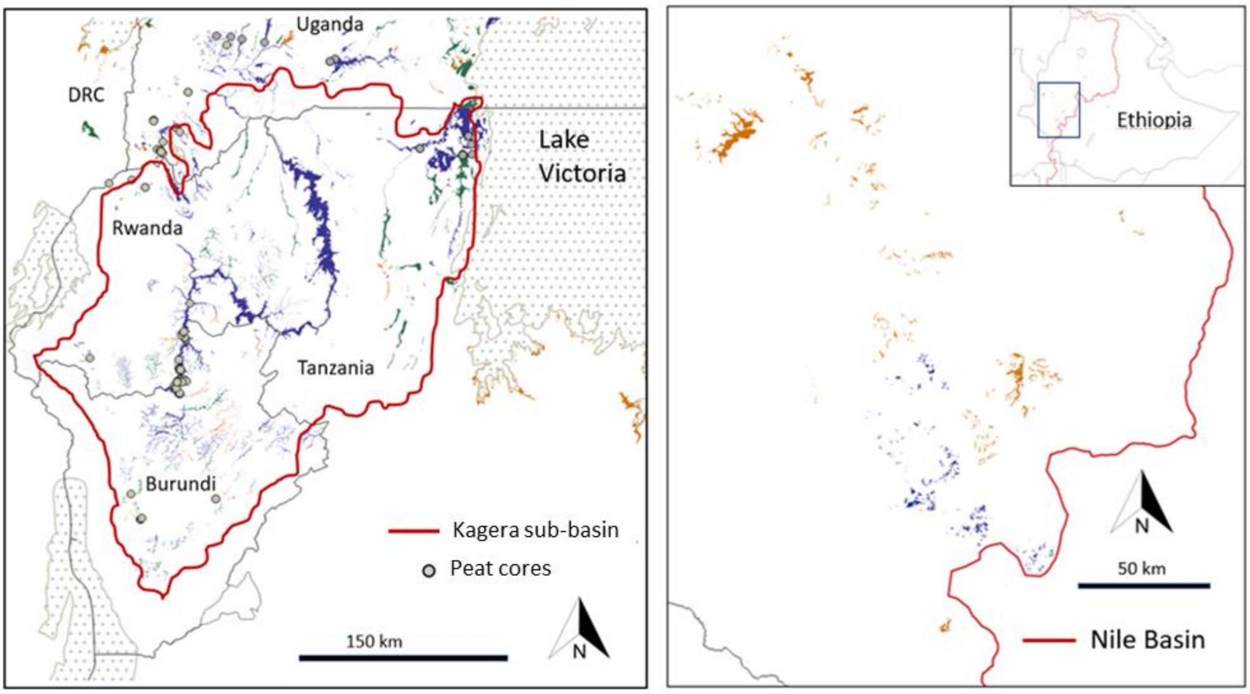

Figure 26. Peatland probability maps for the Kagera subset (left) and the Western Ethiopian highlands (right). Green=confirmed peatland; blue=probable peatland; orange=possible peatland.

Further exploratory peatland mapping and field validation needs to continue in the Sudd and the Ethiopian Highlands, preferably by further capacity building of South- Sudanese and Ethiopian counterparts. The skills required include site position registration (i.e. GPS operation), peat recognition, vegetation description (indicative species) and water sample collection (to facilitate hydrological understanding).

Our field work indicated that field observation is indispensable for the identification of areas with peat (and other organic soil). While the validity of *a priori* formulated peat indicating vegetation types (*Cyperus papyrus* and other Cyperaceae species) was confirmed, the fieldwork also showed that *Raphia* palm forests (often accompanied with rushes and ferns) often had a peat soil (Figure 27). The latter types require further mapping to identify under which conditions they indicate peat.

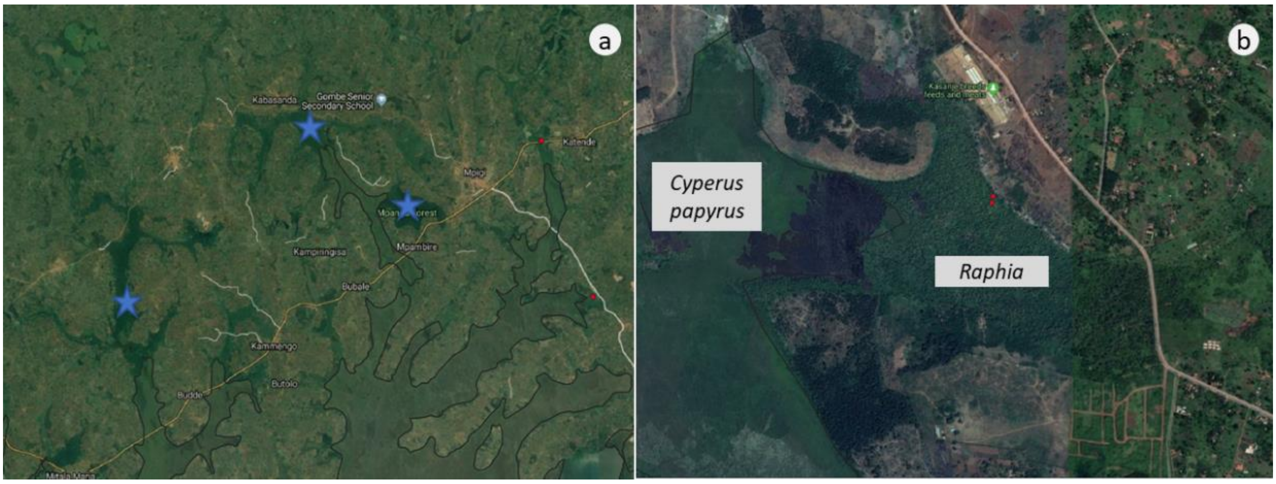

Figure 27. Example of satellite-based peatland delineation around Mabamba Bay near Mpigi town in Uganda (black outlines). Raphia palm forests on the edge (blue stars, a) were missed by the satellite delineation, but were shown to be peat-underlain during fieldwork (red dots; b).

4.2 Eco-hydrological modelling

Eco-hydrological knowledge (on origin, quality and quantity of water supply) of the functioning of the Nile Basin peatlands is necessary for developing and implementing sustainable peatland conservation, management and restoration plans. Such knowledge is still largely missing. This gap urgently needs to be filled by an interdisciplinary eco-hydrological approach that combines 1) the reconstruction of past hydrological conditions (in the light of previous human disturbance and former climate conditions) and 2) the analysis of the present hydrological components, i.e. surface-ground water interactions (Grootjans & Jansen, 2012). To cover peatland diversity in the Nile Basin, 3-4 pilot areas have to be selected for an eco-hydrological study that includes vegetation surveys, hydrological observations (over at least an entire hydrological year) and simple groundwater modelling.

4.3 Land-use change and greenhouse gas emissions

The fieldwork in 2019 has revealed rapid developments, especially in Uganda, with direct impact on the areal extent and carbon stock of peatlands (see Figure 21). Studies into land-use change in peatlands are still limited in the Nile Basin and mostly focus on subsistence farming, biodiversity, wildlife and non-sustainable use of wetlands for energy production (cf. annex 6; e.g. Hakizimana et al., 2016; Donaldson et al., 2016; Langan et al., 2019). Very little attention is paid to the climate services of peatlands. Langan et al. (2019) indeed quantified the peat carbon stock under various types of land use, but only accounted for the upper two meters of soil, and consequently arrived at the methodologically wrong and strategically dangerous conclusion that cultivated peatlands score higher in climate services than unused areas. It is necessary to combine fundamental research on the eco-hydrological setting, carbon stocks and GHG-emissions of peatlands in the Nile Basin under changing land-use practices with cutting-edge applied research into the potential of socio-economically beneficial but sustainable land use options for peatlands, e.g. paludiculture.

Land use and land use change should be covered by 1) remote sensing for land use classification and mapping, 2) fire maps for the past 10 years using the Fire Information for Resource Management System (FIRMS) of NASA (https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms) and the Global Fire Emissions Database (https://www.globalfiredata.org/data.html), and 3) GHG-measurements. For the Kagera subset, the recent land use map of FAO (2017) can be used as a base-map, but higher resolution and more peatland focussed maps need to be created for the pilot areas. Remote sensing of peatland occurrence can then be combined with global fire data to assess the impact of fires on (shallow) peat layers (cf. Sio Siteko, Uganda; Figure 20). GHG-measurements have to measure actual emissions from peatlands under different intensities of land-use.

4.4 Ecosystem services and paludiculture

The traditional use of peatlands and papyrus in East Africa is manifold and widespread (e.g. van Dam & Kipkemboi, 2016) and had over centuries no fundamental negative impact. Nowadays, increasing land use pressure through growing population, accelerated infrastructure, industry and agriculture development (e.g. growing rice for export), combined with the consequences of climate change (e.g. prolonged dry season) is about to damage the peatlands of East Africa considerably (by drainage, burning, overgrazing, growing crops, pollution; cf. annex 6). This will reduce the ecosystem services that intact peatlands provide - such as water provision and purification and flood control – considerably. Strategies to avoid these negative impacts but allow to use peatlands productively need to be developed and their feasibility shown in demonstration sites. Paludiculture is the productive use of wet and rewetted peatlands in a way that preserves the peat stock and minimizes greenhouse gas emissions (Wichtmann et al. 2016). The aboveground biomass is used as a renewable resource, which can be used for construction, enhanced handicraft[4], energy and charcoal production, or fodder. In the Nile Basin, *Papyrus* is already used on a local level for several applications (van Dam et al., 2014; Pacini et al., 2018). Experiences from the temperate zone with other wetlands plants like

[4] https://www.birdlife.org/africa/news/sustainable-use-papyrus-saves-wetlands-and-boosts-income

Phragmites, *Typha* or tall sedges may be transferable to East Africa. Useful plants may be found in the Database of Potential Paludiculture Plants (DPPP) of Greifswald Mire Centre[5].

A paludiculture feasibility study should

- define the criteria for sustainable use (connected to LUC),
- spot promising sites,
- identify suitable crops,
- assess their suitability for large-scale use with respect to cultivation, harvest strategies, and value chain development (cf. paludiculture strategy for Mecklenburg-Vorpommern[6]).
- identify potential obstacles and provide recommendations for implementation and legal frameworks,
- provide for networking and knowledge transfer, awareness raising and capacity development for a wide range of stakeholders,
- develop concepts for implementation projects, and
- target NELSAP Transboundary Wetlands to test whether paludiculture could be applied in Sango Bay Minziro or Semiliki Delta (see Annex 5).

5. Acknowledgement

We would like to appreciate the Ministry of Environment, Nature and Nuclear power in Germany, the International Climate Initiative (IKI) and the German Cooperation Agency (GIZ) coordination and financial support, which was made available through Malte Grossman and Juan Carlos Sanchez. Leonard Akwany and the other staff from the Nile Basin Initiative are most acknowledged for supporting and facilitating our work and travels. We would also like to thank Arthur Neher, Tatiana Minayeva, Stephan Flink, Julie Mulonga and Lorna Kobusingye from Wetlands International for their contribution to some of the project activities. We are grateful for Asadhu Ssebyoto and Leonard Cherop for supporting and participating in our fieldwork trip in Uganda and Tanzania. Other wetland officers from Uganda are thanked for guiding us in the field, namely: Patrick Juma, Lillian Taaka, Abram Dmasa, Charles Wakebe, Geoffrey Gokaka, Emmanuel Bwengye, James Tiberindwa, Judim Bwenye and Herbert Kamuhanda, as well as our guides in Tanzania are thanked namely: Bernard Mwigwu. Our colleague in Rwanda Olivier Ngabonziza is thanked for guiding us to Gisagara and Gishoma peat extraction sites. We would also like to thank our Ethiopian colleagues Genetu Tafere and Elias Dogiso Dagne for their participation and support in Ethiopia fieldtrip. We are grateful for our S. Sudanese colleagues John Ater and Samuel Kenyi for joining the field training in Ethiopia and carrying out the preliminary ground-truthing in the Sudd wetlands. Georg Petersen of Hydroc is most appreciated for sharing mapping data on the Sudd with us. Jenny Farmer of the Uganda Carbon Bureau is also appreciated for

[5] https://www.greifswaldmoor.de/dppp-109.html

[6] https://www.regierung-mv.de/serviceassistent/download?id=1598259

facilitating a small workshop to exchange ideas on peatlands and land-use in Uganda. We are grateful to our colleagues at the Greifswald Mire Centre for supporting the research and administrative activities, namely: Achim Schäfer, Michael Rühs, Christiane Schnick, Jan Peters, Susanne Abel, Mira Kohl, Karen-Doreen Barthelmes, Cosima Tegetmeyer, Pim de Klerk and John Couwenberg.

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Annex 1: Country profiles

Nile Basin country mire massif profiles (AA= Afro Alpine, CVB= Channelled valley-bottom, UCVB= Un-channelled valley-bottom, LP= Lacustrine floodplain, RP= Riverine peatlands) (Minayeva et al., 2017), and available literature.

Country	Peatland types	References (chronologically)
Burundi	AA- CVB- UCVB	Bonnefille & Riollet, 1988; Jolly & Bonnefille, 1992; Bonnefille et al., 1995; Aucour et al., 1999; Bonnefille, 2000, 2002; Kiage & Liu, 2006; Marchant & Hooghiemstra, 2004; Hamilton & Taylor, 2018
Dem. Rep. Congo	AA- LP	Burton, 1859; Livingstone, 1967; Livingstone, 2008; van Damme & Eggermont, 2011; van Geest & Coesel, 2012
Egypt	RP	Peters, 1988; Zalat, 1995; Ayyad et al., 1992; Stanley et al., 2004; El-galladi et al., 2007; Pennington et al., 2017
Ethiopia	AA- CVB- UCVB	Hedberg, 1964; Bonnefille, 1983; Hamilton & Taylor, 1986; Umer et al., 2007; Dullo et al., 2015; Dullo et al., 2017; Lanckriet et al., 2017
Kenya	AA- RP- LP	Sallskapet, 1964; Hamilton & Perrott, 1981; Hamilton & Taylor, 1986; Muthuri et al., 1989; Maitima, 1991; Muthuri & Jones, 1997; Mworia-Maitima, 1997; Jones & Humphries, 2002; Taylor et al., 2005; Owino & Ryan, 2007; Morrison & Harper, 2009; Muiruri et al., 2009; Rucina et al., 2010; Gherardi et al., 2011; Okello & Kioko, 2011; Terer et al., 2015; Ondiek et al., 2016; Behn et al., 2018; Githumbi et al., 2018
Rwanda	AA- CVB- UCVB- RP- LP	Gilson & Van Wambeke, 1956; Sys, 1960; Bouxin, 1974; Hamilton & Taylor, 1986; Pajunen, 1996; Hategekimana & Twarabamenya, 2007; Kersting, 2010; Fischer et al., 2011; Hamerlynck, 2013; Cambrezy, 2014; Roche et al., 2015; Morris et al., 2016; Hakizimana et al., 2016; Wood & Scholz, 2017; Grundling et al., 2018; Jolly et al., 2018
South Sudan	RP- LP	Buursink, 1971; The Jonglei Team, 1953; Rzóska, 1974; Sutcliffe, 1974; Denny, 1984; Conway & Hulme, 1993; Mohamed et al., 2006; Petersen et al., 2008; Petersen, 2008; Green & El-Moghraby, 2009; Petersen & Fohrer, 2010; Rebelo et al., 2012; Kebede et al., 2017; Wilusz et al., 2017
Sudan	RP	Buursink, 1971; Ritchie, 1994; Ayliffe et al., 1996; Blanchet et al., 2015
Tanzania	CVB- UCVB- RP	Mumbi et al., 2008; Finch et al., 2009; Heckmann et al., 2014; Bergonzini et al., 2015; Kempen et al., 2019
Uganda	AA- CVB- UCVB- RP LP	Burton, 1859; Morrison, 1968; Hamilton, 1972; Morrison & Hamilton, 1974; Hamilton & Perrott, 1981; Hamilton et al., 1986; Taylor, 1992; Taylor, 1993; Taylor & Robertshaw, 2000; Hamilton et al., 1996; Marchant et al., 1997; Marchant & Taylor, 1998; Taylor et al., 1999; Kansiime & Nalubega, 1999; Lands & Box, 1999; Kansiime, 2000; Taylor & Robertshaw, 2000; Jones & Humphries, 2002; Marchant & Hooghiemstra, 2004; Lejju et al., 2005; Kiage & Liu, 2006; Hategekimana & Twarabamenya, 2007; Kansiime et al., 2007; Saunders et al., 2007; Ministry of Water, Lands and Environment Uganda, 2010; van Damme & Eggermont, 2011; Saunders et al., 2012; van Geest & Coesel, 2012; Bastawesy et al., 2013; Namaalwa et al., 2013; Republic of Uganda, 2014; van Dam et al., 2014; Hamyrlink, 2013; Government of Uganda, 2016; Murungi et al., 2017; Behn et al., 2018; Inogwabini et al., 2018; Jolly et al., 2018; Kayendeke et al., 2018; Langan et al., 2019

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Annex 2: Reliability assessment for delineated peatland polygons.

A: Simplified reliabillity assessment for delineated peatland polygons based on point data, integrated additional information and satellite/aerial imagery (after Barthelmes et al. 2015).

- peat, Histosol or organic soil point data = **confirmed peat point**
- area with homogenous vegetation around peat point features (on satellite and aerial images) = **confirmed peatland area**
- area in the same region without peat point data, but with *the same*:
    - geomorphological setting
    - indication from landscape constraints
    - appearance on satellite or aerial images = **probable peatland area**
- area in the same region without peat point data, but with *a comparable*:
    - geomorphological setting
    - indication from landscape constraints
    - appearance on satellite or aerial images = **possible peatland areas**

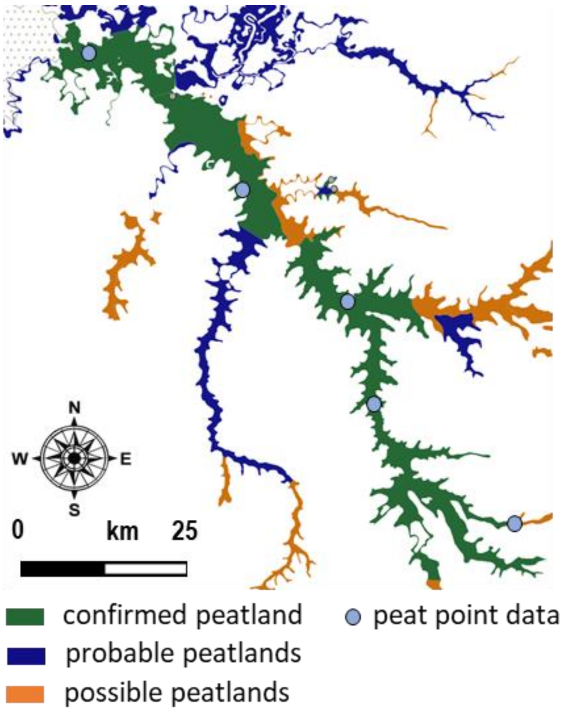


Figure: Delineated peatland polygons across several districts in Eastern Uganda.

B: Simplified reliabillity assessment for delineated peatland polygons based on peat geospatial data/maps, integrated additional information and satellite/aerial imagery (after Barthelmes et al. 2015).

- peat, Histosol or organic soil geospatial data/map in high and medium resolution = **confirmed peatland area**
- area in the same region as a confirmed peatland with *the same*:
    - geomorphological setting
    - indication from landscape constraints
    - appearance on satellite or aerial images = **probable peatland area**
- area in the same region as a confirmed peatland with *a comparable*:
    - geomorphological setting
    - indication from landscape constraints
    - appearance on satellite or aerial images = **possible peatland area**

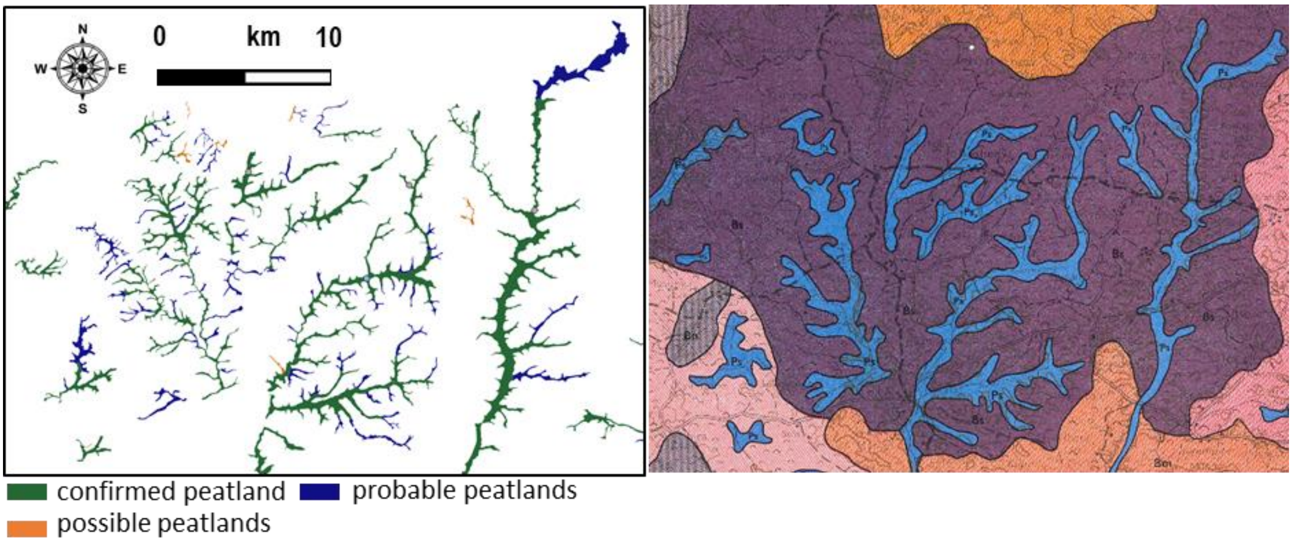


Figure: Left delineated peatland polygons in the southern parts of the districts Bushenyi and Sheema in SW-Uganda. *Right*: the same region depicting ‘Papyrus peat’ in a medium-resolution soil map (Land and Surveys Department of Uganda (1959). Mbrarara Soils. 1:250,000, Entebbe, Uganda.

Annex 3: Sudd remote sensing data

1: Confusion Matrix for accuracy assessment of vegetation classification.

	Papyrus	River	Lake	Reed	Floodplain	Grassland1	Road	bare soil	Savannah	Grassland2	Grassland3	Total	U_Accuracy	Kappa
Papyrus	21	0	0	0	0	0	0	0	0	0	0	21	1,000	0,000
River	0	10	0	0	0	0	0	0	0	0	0	10	1,000	0,000
Lake	0	0	56	0	0	0	0	0	0	0	0	56	1,000	0,000
Reed	0	0	0	30	0	0	0	0	0	0	1	31	0,968	0,000
Floodplain	0	0	0	0	58	0	0	0	0	0	0	58	1,000	0,000
Grassland1	0	0	0	0	0	34	0	0	0	0	0	34	1,000	0,000
Road	0	0	0	0	0	0	8	0	0	1	0	9	0,889	0,000
bare soil	0	0	0	0	0	0	1	9	0	0	0	10	0,900	0,000
Savannah	0	0	0	0	0	0	0	0	21	0	1	22	0,955	0,000
Grassland2	0	0	0	0	0	0	1	1	0	84	8	94	0,894	0,000
Grassland3	0	0	1	0	0	0	0	0	0	2	171	174	0,983	0,000
Total	21	10	57	30	58	34	10	10	21	87	181	519	0,000	0,000
P_Accuracy	1,000	1,000	0,982	1,000	1,000	1,000	0,800	0,900	1,000	0,966	0,945	0,000	0,967	
Kappa	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,960

2: Wetland classes and relation to wetland maps from Rebelo et al., 2012 and Hydroc, 2009.

	Area (km^2)	Area overlying Rebelo (km^2)	not overlying Rebelo (km^2)	Overlying hydroc (km^2)
Papyrus	5879,3581	1893,4225	3985,9356	739,9344
Reeds	2687,7099	943,91	1743,7999	227
Sum	8567,068			

3: Class verification for classification.

class	ground truthing (g)/ optical interpretation (o)
Papyrus	g
Reed	g
Floodplain	o
Grassland1	o
Grassland2	o
Grassland3	o
Savannah	o
bare soil	o
River	o
Lake	o
Road	o

Annex 4: Report on the sudd wetland field trip in Bor and Jonglei state

Prepared by: John Ater and Samuel Kenyi

7th August 2019

INTRODUCTION:

Nile Basin Initiative in partnership with German Development Agency (GIZ) are currently implementing the Nile Basin Transboundary Wetlands Project aimed at strengthening technical and institutional capacities for sustainable management of wetlands of transboundary relevance in the Nile Basin region.

The Ministry of Environment and Forestry in collaboration with the Ministry of Water Resources and Irrigation and with funding from the Nile Basin Initiative (NBI) had been tasked with conducting peats samples collection within the Sudd area of Jonglei State between the period from 22nd July 2019 to the 30th July 2019 as part of study entitled, "Assessment of Carbon (CO2) emissions avoidance potential of the Nile Basin wetlands." Three officials from both Institutions were selected and assigned with this great and quite very difficult task of collecting peats samples from the Sudd area within designated sites (Coordinates Points) both within Bor South and Bor North locations along the river Nile. While in the field, two individuals were also selected for the work mainly a field assistant and a security guard.

A consultancy team from Greifswald Mire Centre in Germany was contracted by GIZ to conduct the peatlands assessment of the Nile Basin. The team inception work was launched in February 2019 and had so far completed peatlands assessment in some parts of Tanzania, Uganda, Rwanda and Ethiopia. The team could not come and carried out the same work in South Sudan due to possible insecurity threat within the Sudd region and climatic conditions as rainfall season will coincide with the team's presence in the Sudd area per their scheduled work plan. The team finally opted to train South Sudanese officials to gain knowledge and skills to undertake the peatlands survey in the Sudd wetlands.

OBJECTIVES:

Assessing the Nile Basin's wetlands and peatlands' role on avoidance of CO2 emissions release by calculating the current carbon stock in the basin and estimating the CO2 emissions from drained use;

Developing a discussion paper which can serve as the backbone for further technical and policy discussions on emissions avoidance from wetlands and peatlands in the region;

Undertaking financial modelling for developing business or economic case for investing on peatlands investment plan and mapping requisite financial flows under overall NBI Investment Plan. This will consequently reinforce Nationally Determined Contribution (NDC) and provide baseline information for peatlands conservation and designation as peatlands Ramsar sites.

SAMPLES COLLECTION:

As previously mentioned, samples were to be collected from ten transects from both Bor South and Bor North locations respectively, however, due to accessibility constraints in reaching to the intended sites/points, the team could not manage to cover all those sites. The coordinates of those transects which were to be visited are as follows:

Transect 7: N 6° 53' 6,302" E 31° 31 35' 7,843", Transect 8: N 6° 52' 46,455" E 31° 16'17,909", Transect 9: N 6° 52' 28,549" E 30° 59' 58,697, Transect 10: N 6° 42' 48,265" E 31° 15' 22,011" Transect 11: N 6° 42' 52,149" E 31° 15' 38,525", Transect 12: N 6° 42' 57,571 E 31° 16" 19,526" , Transect 15: N 6° 43' 7,660" E 31° 16' 44,923", Transect 16: N 6° 43' 8,955 E 31° 16' 50,246, Transect 17: N 6° 33' 53,742" E 31° 24' 33,031", Transect 18: N 6° 33' 50,990 E 31° 24' 34,497".

The team managed to collect samples from the following locations/coordinate points:

- Kuala village (Panpandier site): Transect N 06° 01' 865" E 031° 37' 240". Two samples were collected from 2 points at coring depths of zero – 50 cm and 50 – 100 cm respectively. Further coring was not possible due to the tramped soil conditions by grazing cattle especially during the dry season.
- Pariak village: Transect N 05° 58' 265" E 031° 39' 544". One sample was collected at coring depth of zero - 50 cm. Again, further coring was impossible due to the hardened soil conditions.
- Leudier area (a point near the main steamers port): Transect 06° 13' 004" E 031° 32' 867". One sample was collected at coring depth of 50 cm (at 32 cm point).
- Agutdier area, Point 1: N 06° 17' 709" E 031° 29' 655". Three samples were collected at coring depth of zero – 50 cm (between depth 25-30 cm), 50 cm -100 cm, 100cm – 150 cm (between depth 105cm-110cm and 140cm-145 cm) and 150 cm – 200 cm (between depth 165 cm- 170cm) respectively.

CHALLENGES AND DIFFICULTIES ENCOUNTERED:

- The field trip was conducted during the peak time of the rainy season as such most roads, areas and villages were quite inaccessible due to visible flooding and muddy situations within and outside Bor town surroundings.
- Reaching or accessing most of the transects would have been quite easier on land from the western side of the Nile, however, that wasn't possible due to flooding, mud and ferrying of a vehicle across the Nile.
- Most of the transects suggested for peat samples collection seem to be very far on motor boat at times motor boat owner/driver complains of the distance and docking of the motor boat by the river side as in some places where there is absence of the local community/inhabitants, docking is quite difficult always.
- The team worked on transects which are quite close and of similar surroundings, nature and vegetation type.
- The motor-boat is not equipped with safety procedures such as floating vest and in the event of unforeseen accident, quick rescue plans are lacking.
- Some cored points were under trodden soils by grazing cattle during the dry season making coring extremely difficult.
- At some of the places, the height of the grasses and the papyrus is quite very tall, wet and swampy making penetration quite difficult.

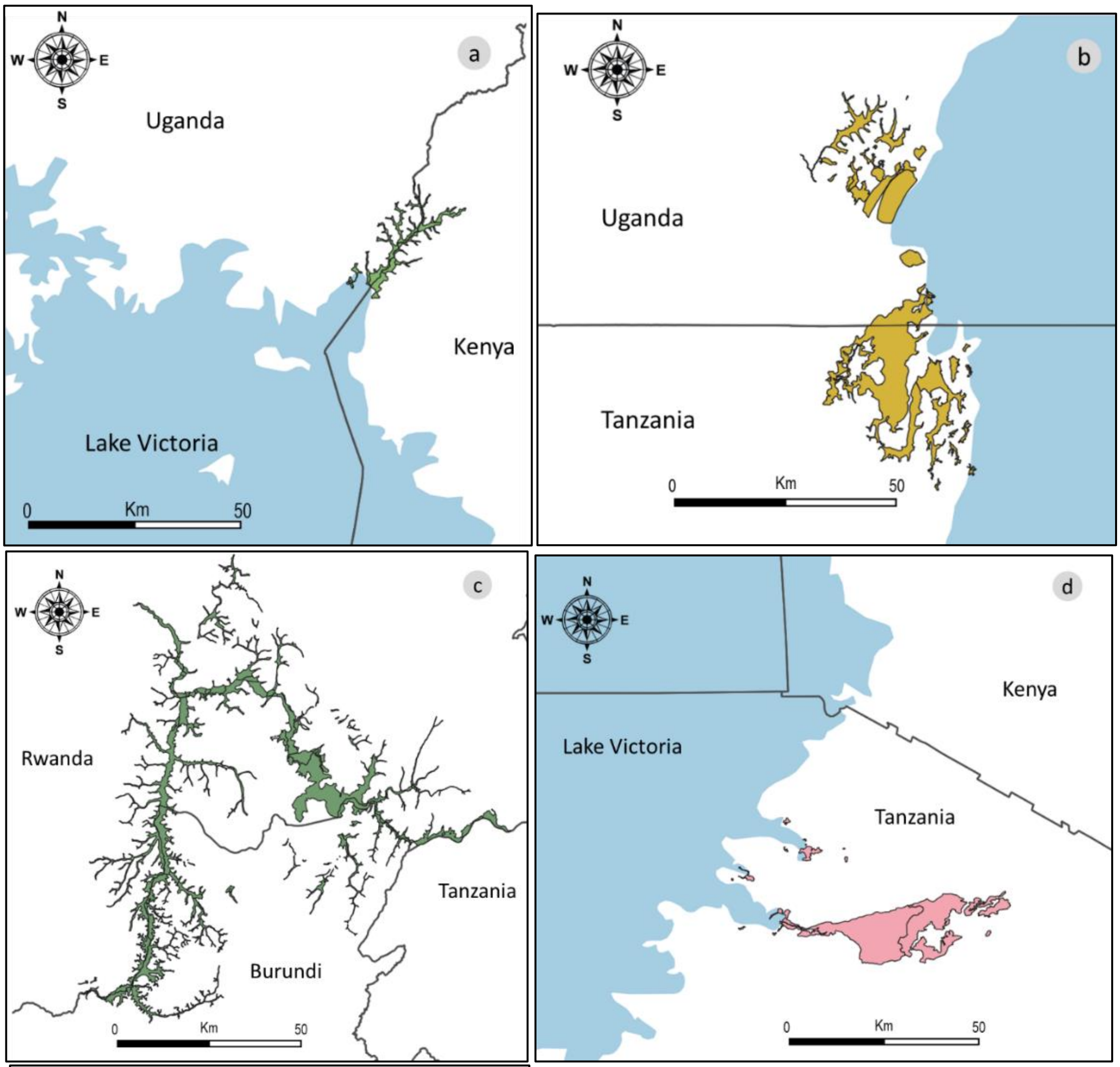
- The team could not manage to travel to Shambe due to distant factor; as a motor-boat takes two days journey to reach Shambe area, except on land which is easily accessible from the western bank of the Nile.

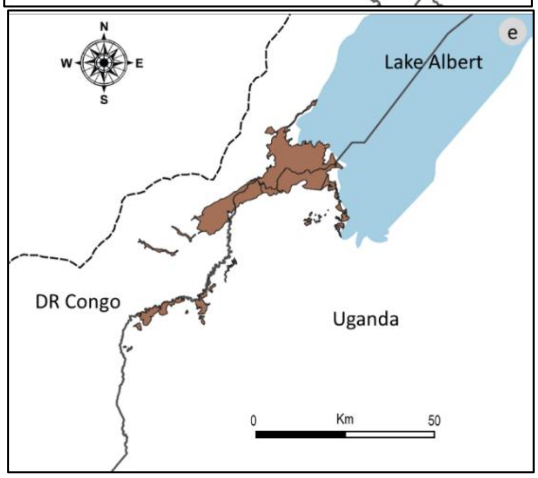
WAY FORWARD:

- The present short field trip recommends that for any field work in the Sudd area in the future should only be executed during the period of the dry season, which normally ranges from November to March. Most areas and villages could be accessed on land or by river transport; in addition, many places will also be less wet and swampy.
- There is also be need of the inclusion of important stakeholders of the area with significant and valuable knowledge on the history of the Sudd area and its surroundings e.g. economic, social, aesthetic and spiritual values.

Annex 5: Probability maps of peatland delineation in priority transboundary areas in the Nile Basin

The figures show the peatland delineations for a) Sio-Malaba (green), b) Sango Bay- Minziro (yellow), c) Rweru-Cyahoha-Akanyaru (green), d) Mara (pink) and e) Semiliki (brown). The blue colour is for lakes. The following table shows the peatland areal estimates for each area.





Transboundary area name	Area (km²)
Sango bay	533.84
Rweru-Akanyaru	804.97
Sio-Siteko	71.40
Mara	385.11
Semiliki	399.93

ANNEX 6: Land-use change in peatlands of the Nile Basin and options for minimising and avoiding GHG emissions

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24-11-2019

1 Background for land use impact assessment in the Nile Basin

Peatlands are significant storage of carbon and potential source of land use based green house gases (GHG) emissions. Peatlands provide a number of other ecosystem services enhancing resilience of ecosystems and communities to climate change and increasing their adaptation capacity. The Contracting Parties to several Multilateral Environment Agreements (UNFCCC, CBD, Ramsar Convention of Wetlands, UNCCD, CMS) agreed to develop relevant national policies to maintain peatlands for climate change mitigation and adaptation. The Nile Basin countries are jointly implementing its Wetlands Programme, addressing among others the development of climate friendly land use regional policy.

A significant part of this process is to:

- conduct strategic and environment impact assessments of various land uses considering peatlands,
- to assess the carbon losses and emissions derived from land uses
- to map and indicate peatlands in land use inventories
- to develop strategies for minimising land use impacts by avoidance, mitigation and restoration.

The current rapid assessment of the impact of the land use on peatlands' climate change mitigation and adaptation capacity is based on **the ecosystem services approach**. The options for minimising and avoiding negative impacts are considered based on **the "allowance envelope" approach**.

1.1 Ecosystem services approach

Land use planning is a compromise in most cases between getting different services from different ecosystems. The ecosystem services concept was adopted by the Millennium Ecosystem Assessment (2003)7 and developed in the TEEB Synthesis Report (2010), TEEB Water and Wetlands report (Russi et al., 2013; Mitsch et al., 2015) and further directing countries documents.

The concept of ecosystem services helps to set up incentives for climate change mitigation and adaptation based on an integrative approach.

In the current annex, land use impacts are assessed through the potential losses of current ecosystem services. The information should help countries to influence land use types in a way that no losses but gains are the result.

Ecosystem services are those natural functions of ecosystems which are directly or indirectly used (eg. protection function against avalanches) or appropriated (eg. Production function for timber) by the human society. The ecosystem services of peatlands are usually regionally and locally very specific as they are driven by the social and economic situation and specific uses. They depend the one side on the natural features and functions of the ecosystems, and on the other - on their use by different stakeholders.

Peatland ecosystems around the world, including the Nile Basin, carry unique **natural features and functions**:

In their natural state, peatlands ecosystems (also known as mires):

[7] https://www.millenniumassessment.org/en/Synthesis.html

- preserve and accumulate organic carbon produced by plants in long term, and therefore store it in amounts larger than the biomass of all forests of the world,
- accumulate and store a large amount of water – larger than rivers and lakes can and
- maintain habitats of various and unique ecosystems, species and maintain genetic diversity.

The ecosystem services of the current rapid assessment of land use in peatlands of the Nile Basin are grouped along three main groups of natural functions: **carbon related, water related and biodiversity related.**

The particular qualitative and quantitate characteristics of these features and functions differ in each peatland type. Considering the ecosystem services and impacts specifically for each peatland type would help to solve the problem of the natural variability. The current rapid assessment was carried out **without consideration of natural variabilities**.

The ecosystem services should be assessed considering not only differences in natural features, but **also national and local socio-economic conditions**. The national differences are partly addressed in the description of land use impacts and drivers and in the NDC reporting part.

The focus of this document lies on those ecosystem services, which help people of the Nile Basin countries on the one side to reach their targets for climate change mitigation and, on the other side, to support communities and individuals to maintain and improve their livelihoods despite climate change in-line with adaptation targets.

The latest overview on wetlands ecosystem services of the entire Nile Basin was presented 2012 (Rebelo and NacCartney, 2012) and includes case-studies from Sudan, Ethiopia and Egypt. The NBI project on wetlands economic valuation started in 2018. Only very few studies focused specifically on peatlands with their specific ecosystem services. The presence of peat increases the number and enhances the quality of ecosystem services compared to other wetland types. In many cases these serves are not known locally because their benefits are not directly associated with them (e.g. sustainable water supply) and because their benefits become obvious later or in larger distances.

Abundant information on ecosystem services of wetlands is available for Uganda (Mafabi, 1998; Emerton, 1999; Kaggwa, 2009) including two studies focusing on peatlands (Hedman, 2019; Langan, 2019). Some data on wetlands ecosystem services are available for Tanzania (Omolo, 2018); for Ethiopia either very general (Seid, 2017) or with focus on the lake Tana (Wondie, 2018), and a fragmented analysis for Kenya (Ajwang', 2016). For Rwanda there are two very valuable unpublished sources as a master (Willetts, 2008) and PhD (Nsharwasi, 2012) thesis. The WetWin project on twinned case studies in Europe, Africa and South America funded by EU in the 7th Framework Programme of the European Union (2017-2013) gives several good examples how data could be analysed and presented.

The current report is a rapid assessment, based on literature review and short field visits in early 2019. An in depths evaluation of peatland ecosystem services could form a solid base for involving the market mechanisms supporting climate-smart land use and the economy in general (Siedenburg, 2015; Barnes, 2017; Langan, 2019) and help to overcome the "market failures to regulate demand and supply for wetland goods and services, as well as the failure to understand the consequences of land use, water management, pollution and infrastructure on wetlands" (Schuyt 2005). The Natural Capital Accounting was used to assess the biodiversity 'no net loss' on infrastructure development in Uganda (Backer, 2019).

More investigations and larger investments are needed to address the issues of land use impacts on peatlands ecosystem services and specifically their capacity for climate change mitigation and adaptation in all Nile Basin countries.

1.2 "Allowance envelope" approach

The "allowance envelope" is an approach to address negative land use impacts in order to find the best solutions for minimising and avoiding them.

Land-use is not a hazard in itself. Unadapted land use may create hazards, which can be drivers for negative impact/effects. In the course of negative impact effects ecosystems losses are the consequence (fig. 2).

Measures to avoid or minimise the hazards, impacts and losses are relevant at any stage of the land use cycle. After losses take place – restoration and compensation measures should be implemented.

This concept is widely used in responsible business. It gives impulses for developing the so-called "allowance envelope" – a set of limitations and conditions minimising losses based on the mitigation hierarchy approach. The "allowance envelope" – is a road on which developers and conservationists are working together on the way to sustainability.

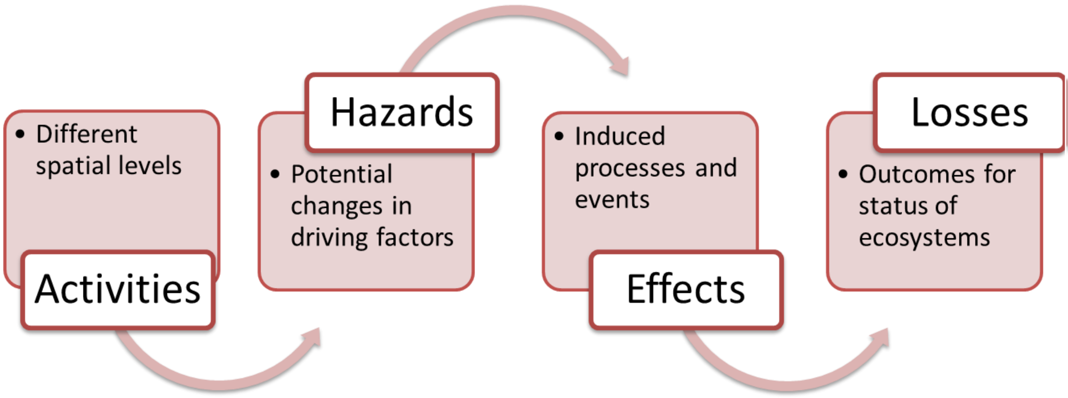


Figure 2 The scheme of land use stream as background for the "allowance envelope" (Minayeva et al., 2016).

Below we address the land-uses which are hazards to peatlands or turn to drivers of peatland degradation with main consequences for carbon loss and an increase GHG emissions. Other ecosystem services and uses are addressed wherever possible.

For most of the land use types a preliminary "allowance envelope analysis" is carried out: hazards, impacts, losses and mitigation options are identified.

The main target of this assignment is to identify how land use is changing peatlands ecosystem capacity for climate change mitigation and to provide adaptation ecosystem services.

2 Land-use in peatlands in the Nile Basin countries

Below the land use types description for the peatlands of the Nile Basin include:

- Short information on land use history and economic role
- Changes in natural features and ecosystem services caused by land use practices
- An "allowance envelope" analysis
- Potential solutions for impact minimising and avoidance

The summary of land use types includes a rank-based assessment of ecosystem services losses based on the literature review. The land uses covering larger areas, such as pasturing, biomass production, crop production and forestry are addressed in more details.

2.1 Pastoralism

History and economy:

In lowlands, peatlands had been used for pasturing actively before the 20th century. In highlands, peatlands used to serve as pastures in certain seasons of the year. Livestock always was a significant part of the livelihood of Africans, and many were maintaining a nomadic lifestyle till the end of the last century. The Nile basin contains various systems of animal husbandry. In some areas, the availability and quality of pastures has decreased increasing the pressure of pastoralism on peatlands.

In a long-term perspective, all countries show an increase in livestock with the dominance of cattle and poultry (FAO, 2010). In some cases (the Tana lake wetlands, Ethiopia) the cattle density decreased due to rice cultivation (Desta, 2019). Grazing is the dominant land use occupying about 60% of the total land in the Nile Basin (Amede, 2011). The highest cattle and small ruminant densities (50 TLU km–2) are found close to water, around Lake Victoria in mixed farming systems in Kenya, in pastoral and mixed farming systems in Tanzania and in mixed farming systems in Burundi, Rwanda and Uganda.

The land use practices and hazards

The access for cattle to the area is possible only after burning the previous papyrus areas. That also affects upper layers of peat. This procedure is repeated when the papyrus regenerates. The burnt area is taken over by young papyrus shoots and small sedges and reeds, very suitable for intensive pasture. However, this newly created ecosystem with high numbers of animals is neither stable sustainable. When the vegetation is destroyed, the peat degradation is accelerated.

There is no or very limited practice of draining peatlands by ditches for pasture improvement. In some of the Nile Basin countries people are fencing their individual pasture plots. Due to the peat subsidence the stripe of ground carrying fences soon is forming a ridge changing the water flow with subsequent draining of the peatland. For watering of cattle and other livestock, people dig ponds. Large numbers of animals are moving to these ponds. The numerous paths start to work as drains.

The impact minimising, avoidance and restoration

In general, the use of peatland for pasture is more sustainable than for crop cultivation. Creating of incentives for sustainable management of livestock including movable watering points, movable fences and other techniques. The self-restoration of abandoned pastures is quite effective in the lowlands. In highlands active restoration measures are demanded.

Summary for pastoralism:

Hazards:	burning, overgrazing, overuse of water		
Impacts:	peat is burning together with vegetation, the vegetation disappearing, subsistence of former peat area, bare dry peat exposed for decay, drainage by paths, change of vegetation		
Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	moderate	Moderate	moderate
Emissions sources	Burning biomass, burning upper layer of peat, drying up of peat (emissions of CO_2 in-situ due decomposition), flood-based erosion (emissions of methane from the dissolved organic matter)		
Minimising and avoidance	awareness of other ecosystem services than pasture, spatial and temporal planning of pasture, involving modern techniques for pasture management and supporting policies (Financial or tax incentives by the state, introduction of new income options like tourism, where possible, awareness building and training).		

2.2 Using the biomass in natural peatlands

The biomass harvest is a traditional and widely spread use of peatlands in the Nile Basin. The main product is papyrus. This type of peatland use can be considered as sustainable in case it does not involve massive burning. However, burning is used for a “better regeneration” of the papyrus and for opening access to the new areas.

Donaldson et al. (2016) demonstrated in a special study that a low-intensity use of papyrus wetlands by people is compatible with the conservation of specialist bird species, and highlighted the potential benefits of traditional human activities to conserve biodiversity in the tropics.

Summary for biomass use:

Hazards:	burning, overusing		
Impacts:	peat is burning together with vegetation, the vegetation disappearing, bare periodically dry peat exposed for decay		
Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	moderate	low	low
Emissions sources	Burning biomass, burning upper layer of peat, drying up of peat during dry periods (emissions of CO_2 in-situ due decomposition)		
Minimising and avoidance	awareness building on other ecosystem services than biomass, spatial and temporal planning of harvest, introduction of other fertilizing schemes, like dung		

2.3 Crop cultivation

History and economy:

The agriculture set up in the Nile Basin is complicated and varies from the indigenous shifting cultivation to very large plantation systems, nowadays industrialised farms. Some authors are distinguishing agriculture systems between substantial (farming for their own household needs) and commercial (farming for market). This classification does not reflect the economic drivers nowadays. The improved connectivity and mobility of people also allow small-scale agriculture being part of external markets.

The use of peatlands for crop production was developing very slowly. Even if people were aware of the high organic content of peat soils, the use of peatland for agriculture demanded quite large labour investments for drainage. In the lowlands, the crops are limited to those species, which can stand growing on the peat and are adapted to the periodic flood situation by short ripening periods. Those are for example yam, cassava, sugar cane, some variations of matoke and mainly rice.

In the 20th century the use of peatlands for crops was limited to rice production in the shallow peat lacustrine and riverine peatlands in combination with mud fields Benneh (1972).

Yam and cassava cannot cover the livelihood needs of a household alone, neither are they profitable commercially. Cash returns from yam/maize intercrops are quite low for commercial farming (Field crop production, 1991). The expected best net return will be only about 50% of that of sole yam.

Cassava is the most important staple food crop in certain areas of the Nile Basin where tubers and leaves are used, the former being the major source of energy and the latter a major source of protein, vitamins and minerals. Cassava, cultivated as a key component of shifting cultivation systems, allows great flexibility in cultural practices. During the last years, there is a tendency of expansion of cassava onto marginal soils such as peatlands.

Matoke (banana palm) is actively cultivated at the edge of peatlands around the lakes in former palm belt.

Sugar cane being traditionally cultivated in peatlands in South America, just started to shift to peatlands in tropical Africa. The main sugar cane areas on peat soils are found around Lake Victoria.

The largest cultivation hazard for peatlands is rice (Nwanze et al., 2006). During the last 20 years, there was a clear increase in rice production. FAO published in 1999 a large research on the need and capacity of African countries to increase rice production. The main capacity was designated as the availability of wetlands for rice production (http://www.fao.org/3/x2243t/x2243t05.htm) It was real strong call to use wetlands for rice cultivation.

The land use practices and hazards

From the point of view of the impact on peatlands the croplands could be defined as lowland crops, rainfed crops and irrigated crops.

The modern agriculture scheme used in traditional villages in the uplands (rainfed and irrigated) is still similar to the 1960th. The differences lie in the increase of applying of mineral fertilisers and pesticides and more irrigation due to decreasing precipitation. The large plantations in the drylands have the same impact. Fertilisers and pesticides are responsible for wetlands eutrophication and the increase of N2O and methane emissions. Irrigation systems are competing with wetlands for water.

The lowland crops practices include burning of vegetation and partly peat, clearing remaining vegetation, drainage by ditches. Once bare of protective vegetation and exposed to wind and rain, cultivated peat soils erode bit by bit, slowly enough to be ignored by local planners but fast enough to cause significant CO2 emissions. Also their water storage decreases along with the water quality, as well as other natural functions of peatland supporting adaptation capacity of local communities. The preliminary assessment shows that the conversion of wetlands to arable lands has had long term negative impact on the local, national and the Nile Basin level, first in shortage of water. The global consequences lie in additional significant emissions from the degraded peatlands.

The impact minimising, avoidance and restoration

When the peat layer still remains in crop areas, peatland restoration could be achieved only by termination of its use. The ditches do not function shortly after they are stopped to be maintained. No other active interventions are needed. However, the regeneration of abandoned cultivated peatlands was not studied sufficiently for wetlands in the Nile Basin.

In case peat layer is gone, the changes are irreversible and restoration is possible in the long term after peat starts to accumulate.

As impact minimising measures could be recommended limitation and wise application of fertilisers, pesticides and other chemical mediators. and other measures, like the control of surface flow and water discharge from peatlands. Generally, the strategy should be to avoid crops on peatlands in the Nile Basin.

Summary for crop production:

Hazards:	Burning, drainage, using fertiliser, pumping water out of wetland or upstream		
Impacts:	peat is burning together with vegetation, the vegetation is cleared out, bare periodically dry peat exposed for decay, waters are polluted, flood waters erodes bare peat and carry out organic material through the ditches to rivers and lakes.		
Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	high	Moderate to high	high
Emissions sources	Burning vegetation, burning upper layer of peat, drying up of peat during dry periods (emissions of CO_2 in-situ due decomposition), emissions from ditches and other water bodies polluted by dissolved organic matter.		
Minimising and avoidance	awareness on other ecosystem services than crops, preferably - avoidance of crops on peats, spatial planning of the crop's turnover; introducing restoration practices		

2.4. Forestry and peatlands

The Nile Basin economy used to have a significant sector of wood production. The deforestation also affected peat forests and forested peatlands. There is no statistic about the percentage of peatlands related forests cut to forests on mineral soils. The latest assessment of Aleman (2018) reports that West and East African forests have undergone almost a complete decline (~ deforestation level for 83.3 and 93.0%, respectively).

The progressive deforestation became a challenge for the economy. Several climate related policies supported rapid afforestation. Unfortunately, many foresters of the Nile Basin decided to choose from 600 species of Australian eucalyptus and invasive neem (*Azadirachta indica* L.), rather than focusing on the 5000 native species. The problem with eucalyptus is that this genus is known for pumping ground water in enormous amounts to support its fast growth. A three-year-old tree needs 20 litres of water per day, gradually the consumption increases for a tree 20 years old up to 200 litres water daily. Eucalyptus plantations are absolutely unwanted in the neighbourhood of peatlands.

There is no data on the direct afforestation of peatlands by unwanted species in the Nile Basin. Activities, which could cause significant GHG emissions are:

- Deforestation of peatlands leading to peatlands drainage, damage of peat layer and fires
- Afforestation of peatlands, causing drainage if not suitable species. Possible ditching, peat fires
- Eucalyptus plantation in the adjacent areas causing pumping water, peatlands drainage and peat fires

Summary for forestry:

Hazards:	Fires, drainage, competing for ground water		
Impacts:	Peat burning, drainage and peat decomposition, subsidence, drop of ground water level habitat lossesLoss of water storage capacity		
Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	high	moderate	moderate to high
Emissions sources	Burning of wood and upper layer of peat, emissions of CO_2 in-situ due to decomposition from dry peat, emissions from ditches.		
Minimising and avoidance	awareness on the connections between peat and forests; planting native peatlands tree species; avoiding deforestation of peatlands; banning eucalyptus in surroundings of peatlands		

2.5 Fishery

Peatlands play a crucial role in the inland waters' fisheries in the Nile Basin. Peatlands are important for the fish reproduction serving as spawning and breeding grounds of certain fish species like Protopterus, Clarias, ground and several others. Peatlands are the habitat of the mud-fish traditionally known as Enshoonzi joining several species of the genus Clarias. Mud-fish are an essential part of local livelihoods. In the past, one fisherman could catch between 500 to 1000 fishes a day what yielded 20-30 USD. Currently the harvest dramatically decreased as is reported due to the drop of the water level in wetlands/peatlands.

The peatlands suitable for mudfish are riverine peatlands in large valleys and large lacustrine peatlands. Fishermen dig special ponds in peatlands to harvest mudfish. Very often they burn papyrus stands to have access to the central part of the peatland. In case the harvest is planned considering the natural functions of peatlands, this peatland use could be sustainable.

Hazards: burning, creation of deviated system of ponds.

Impacts: peat is burning together with vegetation, the system of ponds causes drainage, open water evaporates fast during dry season causing drainage and eutrophication, N_2O and methane emissions.

Losses: losses of habitats; losses of peat by burning and decomposing, GHG emissions, water level drop and drainage.

Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	high	moderate	moderate

Emissions sources: Burning of vegetation and upper layer of peat, emissions of CO2 in-situ due decomposition from dry peat, emissions from ditches.
Mitigation and Restoration: awareness of other ecosystem services than fishery, sustainable methods.

2.6 Tourism

Information on the economic tendencies and statistics on tourism development is not available for the region. However, future land use planning should take into account options and aspects of developing sustainable tourism for improving local livelihoods without affecting peatlands. Tourism affects peatlands at the sure line of the Lake Victoria by the construction of the beach facilities, landing sites with relevant infrastructure, clearing vegetation for boat routs. The rapid growth of tourism in mountainous area already is a serious threat to Afroalpine peatlands. The special tourist wooden trails are not common practice in the region. The trampling and infrastructure development in highlands cause ruining of the vegetation and peat soil erosion followed by carbon loss and GHG emissions.

Summary for tourism:
Hazards: clearing of lakeshores for beach, clearing riparian vegetation in lakes and rivers for boat routes, trampling and construction of touristic facilities in alpine peatlands.
Impact: vegetation and peat clearing (initially by burning), pollution, changing of hydrology and destroy of peat layer
Losses: peat degradation, loss of carbon and GHG emissions, losses in habitats

Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	moderate	low	low

Mitigation/restoration: impact assessment and recognition of peat as value, spatial planning, avoidance of housing on peatlands, protection of peatlands by walking boards.

2.7 Charcoal and bricks production

Most of the poor population rely heavily on biomass sources for energy - firewood, charcoal, agricultural residues, and dung - and will probably continue to do so. The charcoal production involves burning wood in stoves. Very often bricks are produced from loam underlying peat, as it is of better quality. Peat itself is used to enhance the temperature of burning during the charcoal production. In some areas people burn peat in the process of the brick production. Very often the brick/charcoal producing areas occupy entire small valleys with peat. In several years such peatland is lost as entire ecosystem – including vegetation, water and peat.

Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	high	moderate	moderate

Mitigation and Restoration: avoid peatlands in bricks/charcoal production, use solar and wind energy

2.8 Palm oil

Palm oil is considered here apart from other agriculture uses. It is commercial land use, mainly carried out industrially. There are very few areas in the Nile Basin where palm oil was part of the household economy. It is common in Congo Basin.

Palm oil is one of the most rapidly expanding crops in Africa, and has been lauded as a valuable contributor to poverty alleviation and food independence in developing countries and is claimed as part of climate change adaptation national strategies by several governments. Unsustainable palm oil industry practices are the result of large-scale land acquisitions across Africa's tropical belt. The land claims at the end cause a shift of the small-scale agriculture to wetlands/peatlands and increase in drained areas. From the Nile Basin countries, only Tanzania and Uganda are currently involved in oil palm production. In 2018, Uganda started allotting land for Bidco's Second Palm-Oil Estate. The company expects to manage 4,000 hectares on Buvuma Island.

The impact of oil palm production on the carbon storage, GHG emissions and other ecosystem services depends if the production goes on directly on peatlands or in the adjacent industrial areas.

Several sustainability initiatives have already been introduced in response to the social and environmental concerns, including the Roundtable on Sustainable Palm Oil (RSPO), which grants Certified Sustainable Palm Oil (CSPO) if the oil is produced in-line with certain criteria. These include not draining peatlands, not clearing primary forests, or areas which contain significant concentrations of biodiversity or fragile ecosystems, minimizing erosion, and protecting water sources, reduced use of pesticides and fires, fair treatment of workers according to local and international labour rights standards, and the need to inform and consult with local communities before the development of new plantations on their land.

Summary for palm oil:

Hazard: when on peat - Burning, Drainage, long term maintenance in drained conditions; when out of peat - shifting households with small scale agriculture practices to peatlands with relevant impacts.

Impact: burning and clearing of vegetation, peat decomposition with emissions, and peat subsidence.

Loss: habitats, carbon storage, water regulation capacity

Losses of ecosystem services (direct palm oil on peat)	Carbon related	Water related	Biodiversity related
	high	high	high

Mitigation: No plantations on peat; relevant land use planning policy; certification under RSPO or similar

2.9 Housing and construction

Housing directly on wetlands both in rural and urban areas is a very active process in many countries of the Nile Basin. Before wetlands turned to be protected legally in the Nile Basin countries the land in peatlands was cheap and not recognised as something valuable. People with limited funds were setting up their houses and gardens in peatlands. Even after the ban to settle in peatlands, the process was going on illegally.

People were adjusting the areas for their needs, by draining, clearing, burning and by other means.

This process is very difficult to reverse as authorities have legalised many of the settlements on peatlands. Those parts of peatlands should be counted as lost, and the areas should be counted as GHG sources in the national inventories. The settlement administrations should be aware of the process of soil subsidence in these areas due to peat decomposition and undertake measures for the security of people.

Fig. 3 Housing and garden expansion to Nakivubo peatland, Kampala, Uganda

The construction of industrial buildings takes place often in the peatlands of mountainous countries. The reason is that peatlands provide vast flat areas. A recent example is the expansion of Kasese Airstrip. The usual practice is to destroy the peat layer and transform it to technogenic soil. The same takes place often in cities. Mitigation techniques are available and could be a part of construction rules.

Roads and other linear constructions are changing the hydrology of peatlands if constructed without taking into account the special features of peatland, in particular their hydrological characteristics.

Summary for housing and construction:

Hazards: Burning, long term maintenance in drained conditions; peat pollution, change in hydrology.

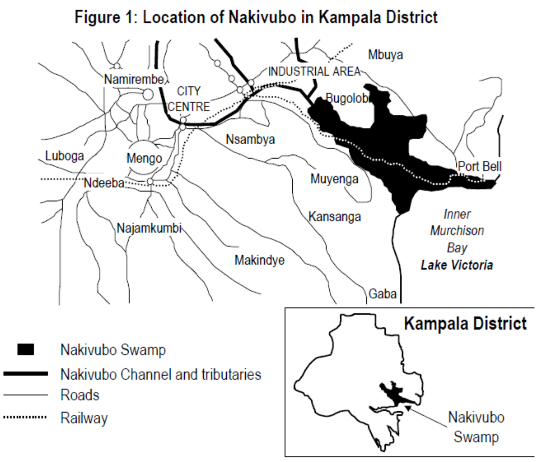
Impact: vegetation clearing and burning, peat decomposition, and peat subsidence, change in peat chemistry.

Loss: habitats, carbon storage change, water regulation capacity, emissions.

Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	high	high	high

Mitigation/restoration measures: avoidance, technical solutions for minimising impact

2.10 Water cleaning and supply



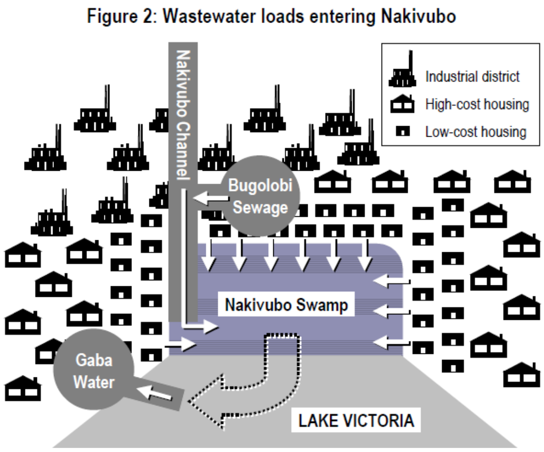


Fig.4 The concept of Nakivubo wetland use for water cleaning IUCN, 2003 (no permission requested).

The Nakivubo wetland in Kampala is mentioned in several case studies as a good example of water cleaning. The Nakivubo wetland is peatland with a peat deposit varying from 0,4 to 3 m. The cleaning capacity depends on the status of peat deposit and peatland area. The peat will lose its cleaning capacity when its physical and chemical properties change under the influence of pollution.

Fig. 5 Nakivubo wetland, March 2019

Many settlements in the Nile Basin have the habit to use peatlands for water supply. On a small scale the water is accumulated in simple ponds which are dug out in the peatland. On a large scale artificial reservoirs at the edge of peatlands are used.

Numulema (2016) calculated the economic benefit for the nearby community of the Kiyanja-Kaku peatland. The estimated price of clean water from the National Sewage Corporation for one household ranges from UGX. 612,174 to 4,054,733 (US 168.0-1095.0) per year. The estimated economic value of clean water (ecosystem service) from the Kiyanja-Kaku peatland ranges from UGX. 2,732,133,000.0 to 18,096,274,000.0 (US 775,228.0-4,885,994.0) for the entire community.

Each project on water supply from peatland has to include hydrological modelling to define the limitations in quantity of discharged water and the variation in time to avoid impact on peatland.

Summary for water cleaning and supply:
Hazard: Input of the polluted water to peatlands, water discharge
Impact: Changes of the biogeochemistry of water and peat deposit;
Losses: Larger emissions of N_2O and methane, losing cleaning capacity of peatland, changing habitats

Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	moderate	moderate	moderate

Mitigation/restoration: Projects of water cleaning by peatlands should be strategically well planned and designed.

2.11 Peatlands and hydropower

Peatlands maintain the water level in rivers, and this function increases upstream. The Nile Basin hosts as minimum 15 major dams (Fig. 6). Some of them have periodic or permanent water shortages. The positive role of peatlands for water supply for hydropower stations was recognised only in Rwanda.

As Rwanda's hydroelectric potential decreased and the cost of accessing electricity increased, the Ministry of Environment, Lands and Mines approached the Cabinet to make the case that restoring the Rugezi Wetlands would help address the situation. Rwanda's National Environment Policy was subsequently released in 2003, and entails a series of policy statements and options for the restoration of the natural environment through land-use management, natural resource management, and other measures (MLRE, 2003). Rwanda's Organic Law N° 04/2005: "Determining the Modalities of Protection, Conservation, and Promotion of the Environment in Rwanda" or the Environment Law (GoR, 2005a) entails a number of specific measures aimed at reversing the degradation of wetlands. That is driven by shortage of water for hydropower.

Flood regulation by large dams leads to water shortages for peatlands. Drying out of peatlands leads to further shortage in water and to additional GHG emissions. Flooding of peatlands by reservoirs in the course of large dam construction leads to a large portion of dissolved organic matter in the waters and hence additional emissions of N_2O and methane. These impacts of large dams are not usually assessed and considered.

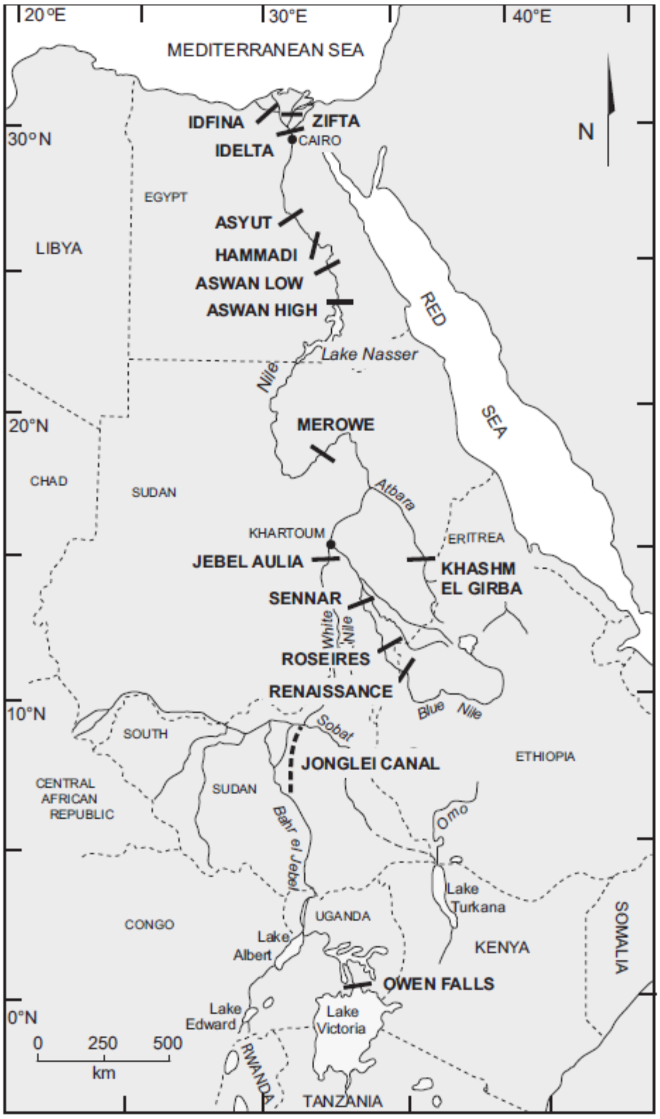


Fig.6 The location of major dams in the Nile Basin. Williams, M. (2019) – permission not requested.

Hazard: flood regulation, flooding of peatlands
Impact: Changes of the biogeochemistry of water and peat deposit; losses of habitats
Losses: Larger emissions of N_2O and methane in flooded peatlands; CO_2 in dry peatlands, changing in habitats

Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	high	Moderate to high	Moderate to high

2.12 Peat extraction

Till now peat extraction at industrial scale is known from Burundi and Rwanda only, some plots are known in Uganda, where more areas are under discussion.

In the year 2004, the Government of Rwanda decided to diversify the national energy portfolio through the increased use of its methane gas, geothermal, peat, solar and biogas resources. In 2016 the Government of Rwanda signed a Power Purchase Agreement (PPA) and a Concession Agreement with HAKAN MADENCILIK

VE ELEKTRIK URETIM SAN. TIC. A.S. to design, build, finance, own, operate and transfer an 80MW Peat power plant to produce electricity from peat extracted from the South Akanyaru peat prospect in Southern Province, Gisagara District, Mamba Sector. Peat Energy Co. (PEC) (a subsidiary of Rwanda Investment Group S.A.) mined peat at Gishoma for use in the cement production[8]. Another Plant was constructed by RUNH Power Corporation Ltd in the Bugarama Sector in Rusizi District.

In Burundi, the Office National de la Tourbe, a branch of the Burundi government, is responsible for peat production which is extracted notably in the Akanyara Valley near Buyongwe and in 2005 unmined resources of peat were stated by the Burundian government to total around 36 million metric tons.

The peat extraction from any type of peatlands in tropical and subtropical Africa for energy production needs a good economic background. The losses of ecosystem services are irreversible and very significant. The peat extraction is subject to reporting under the UNFCCC already since 2006. The losses of carbon store and connected emissions are tremendous. Any development of peat industry in the region should be based on strategic impact assessments.

The impact analysis is clear – peat extraction leads to a complete loss of all peatlands ecosystem services, including the loss of carbon store. The National Reporting under the UNFCCC in case of peat extraction for the needs of energy includes reporting both on LULUCF and industrial sectors.

Summary for peat extraction:

Hazard: drainage and removal of peat deposit

Impact: Changes of the biogeochemistry of water and peat deposit; losses of habitats

Losses: Larger emissions of N_2O and methane in flooded peatlands; CO_2 in dry peatlands, changing in habitats

Losses of ecosystem services	Carbon related	Water related	Biodiversity related
	high	high	high

2.13 Oil and gas extraction, mining

The petroleum potential of the Nile Basin Countries is uneven. Several mountain ridges are known for oil deposits since the beginning of 20th century. One of them -the Albertine graben has since been subdivided into ten Exploration Areas. http://chein.nema.go.ug/wp/?page_id=214. The Area contains the most valuable Afroalpine peatlands - the unique phenomenon of nature and water towers of Africa. Peatlands of Albertine mountain ridge are the main source of water for the White Nile.

The oil and gas industry development may have significant negative impacts on peatlands ecosystem services, including turning peatlands to a source on GHG emissions. The concerns regarding oil and gas development impact to wetlands is clearly presented in the recent Ramsar mission report (Infield et al., 2018). The indirect impact on peatlands is expected through the social processes (Mawejje, 2019; Ogwang & Vanclay, 2019)

The exploration plans should be a subject of the Strategic Impact Assessment and special concern.

3 Rapid assessment of land-use impact on GHG emissions

An assessment of GHG emissions derived from land uses is based on the understanding of functional characteristics of peatland ecosystems and mechanism of land use impact. As demonstrated above, the practices of land use are changing carbon storage and other ecosystem features and services in a specific way. The strength of the impact also differs (Table 1).

[8] https://www.usgs.gov/centers/nmic/africa-and-middle-east

Table 1 Summary of the impact rank of the various land uses driving to the losses in the capacity of peatlands to provide climate change mitigation and adaptation services

	Loss of mitigation capacity			*Loss of adaptation capacity*						
Land use:	*Direct emissions CO_2*	*Emissions of N_2O and CH_4*	*Emission form DOM*[9]	*Loss of carbon storage*	*Soil subsidence*	*Losses of productivity*	*Species and ecosystem losses*	*Invasive and alien species*	*Losses of water storage capacity*	*Losses of water discharge capacity*
Pastoralism	**2***	**2**	**1**	**1**	**2**	**1**	**1**	**2**	**2**	**1**
Biomass in situ	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**1**	**1**	**1**
Crop production	**2**	**3**	**3**	**2**	**2**	**3**	**3**	**2**	**2**	**2**
Forestry	**2**	**1**	**1**	**2**	**2**	**2**	**2**	**1**	**1**	**1**
Fishery	**1**	**2**	**2**	**2**	**2**	**1**	**1**	**2**	**1**	**1**
Tourism	**2**	**1**	**1**	**2**	**1**	**1**	**2**	**2**	**1**	**1**
Charcoal and bricks production	**2**	**1**	**1**	**2**	**1**	**2**	**2**	**1**	**1**	**1**
Palm oil	**2**	**3**	**2**	**2**	**2**	**3**	**3**	**2**	**2**	**2**
Housing and construction	**2**	**1**	**2**	**2**	**2**	**2**	**2**	**1**	**2**	**2**
Water cleaning and supply	**2**	**3**	**3**	**1**	**1**	**1**	**2**	**1**	**1**	**1**
Hydropower	**1**	**2**	**2**	**2**	**1**	**1**	**2**	**2**	**2**	**2**
Peat extraction	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Oil and gas	**2**	**2**	**2**	**2**	**1**	**2**	**2**	**2**	**2**	**2**

*rank of impact 1- low; 2 - moderate; 3 – high

[9] DOM – dissolved organic matter;

The potential emissions of CO_2-equivalents can be estimated **for a certain point** from the description of its land use type. The following background information on peatland and land use is used for the estimation of GHG fluxes at the point:

- Carbon pool characteristics: biomass production; peat depth, carbon and nitrogen content in peat;
- Carbon pool transformation activity: burning of biomass; burning of peat; peat decomposition; peat water erosion; peat wind erosion etc.

The further assessment for larger areas is based on extrapolation techniques. The indication by land cover is the basic approach for the Proxy based assessment of CO_2 equivalent emissions derived from land use.

4 Conclusion

The largest impact in the past was the practise to irrigate drylands with significant water discharge from wetlands or often directly from peatlands. Thus, peatlands had to compete for water with irrigated areas, and in many areas of the Nile Basin, this competition was lost by peatlands already several centuries ago (Williams, 2019).

The land use structure in Africa generally and in the Nile Basin in particular, was changed rapidly during the last 50 years. The changes are driven by several complicated socially, economically and politically unpredictable processes. Climate change enhances the impact unpredictability.

The later industrial development of The Nile Basin countries affects peatlands via the energy sector – hydropower and peat mining, as well as infrastructure development and construction.

The extension of unsuited land use to peatlands is a development known from the 20th century due to the establishment of large plantations on drylands. In the 21st century, the international markets are actively incentivising this process by introducing rice, sugar cane, oil palm, and other plantations, driven by global demands, mostly from industrialized countries. In this case, small households are shifting their cultivated plots to peatlands. In the 90-th of the last century FAO was actively supporting this process and initiated the inventory of wetlands, suitable for a "sustainable agriculture" (FAO, 1998). Nowadays FAO also recognises the high ecosystem values of wetlands and calls for a balanced approach.[10]

Uses, which are considered as traditional or sustainable (fishing, biomass harvesting, tourism development), also become hazardous due to their upscaling.

Most of the land-uses in the Nile Basin are affecting peatlands by causing strong GHG emissions. The land use practices could be modified accordingly in order to avoid and minimise the effect of land use on GHG emissions. Strong incentives should be developed to introduce climate-smart land use practices.

There are many political aspects behind land-uses in the Nile Basin (Barnes, 2017). A unified and coordinated policy of the Nile Basin countries for climate change mitigation and adaptation could help to develop a mitigation and adaptation strategy based on peatland friendly land uses in line with agreed by countries strategy (Nile Basin Initiative, 2013). The political framework for such a policy could be the implementation of the Paris Agreement based on the National Determined Contributions.

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[10] http://www.fao.org/3/x6611e/x6611e03.htm#P52_137

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Annex 7: Possible CO_2 emission reductions from drained peatlands for the individual NEL countries within the Nile Basin

The following table shows the possible CO_2 emission reductions from the drained peatlands within the Nile Basin in the NEL countries. The percentage drained peatland in 2015 is based on the 2010-2014 observation (Figure 20). The possible cumulative emission reductions (in Mt CO_2) are expressed as the difference in emissions between the two scenarios (1. No new drainage, 2. Rewet all drained peatland) and the business as usual scenario.

drained peatland in 2015	**Country**	**Scenario**	**Reduction potential (Mt CO_2)**								
			2015	2020	2025	2030	2035	2040	2045	2050	**Avg. per year**
25 %	Uganda	No new drainage	0.00	0.00	0.00	34.05	68.11	102.16	136.21	170.27	4.86
		Rewet all	0.00	0.00	9.29	61.92	123.83	195.03	275.52	365.30	10.44
10 %	Tanzania	No new drainage	0.00	0.00	0.00	5.21	10.41	15.62	20.83	26.04	0.74
		Rewet all	0.00	0.00	1.42	9.47	18.94	29.82	42.13	55.86	1.60
75 %	Rwanda	No new drainage	0.00	0.00	0.00	27.51	55.01	82.52	110.02	137.53	3.93
		Rewet all	0.00	0.00	7.50	50.01	100.02	157.53	222.54	295.06	8.43
10 %	Kenya	No new drainage	0.00	0.00	0.00	0.69	1.37	2.06	2.74	3.43	0.10
		Rewet all	0.00	0.00	0.19	1.25	2.50	3.93	5.55	7.36	0.21
90 %	Burundi	No new drainage	0.00	0.00	0.00	14.62	29.25	43.87	58.49	73.12	2.09
		Rewet all	0.00	0.00	3.99	26.59	53.18	83.75	118.32	156.87	4.48
10 %	DR Congo	No new drainage	0.00	0.00	0.00	0.47	0.94	1.41	1.88	2.35	0.07
		Rewet all	0.00	0.00	0.13	0.86	1.71	2.69	3.81	5.05	0.14