Memo

Subject:	Hydrologic corridor potential map Africa
Project number:	693 – hydrologic corridor Africa
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Re-greening is one of the ways how climate change can be mitigated, how livelihoods can be provided and how ecosystems can be restored. Re-greening can be achieved, by applying rainwater harvesting techniques, conservation methods and agroforestry together. When areas are re-greened, the process of evapotranspiration can start again, so that the hydrologic cycle is positively influenced. When - due to multiple re-greening projects - larger areas are covered, a so called hydrological corridor is made: they together recreate the local hydrological cycle and eventually impact the wider regional hydrological cycle.

In order to identify the areas where re-greening has the highest impact and therefore the hydrological corridor has the highest potential, an extended GIS analysis of the African continent has been carried out for Justdiggit. This analysis has resulted into 3 base maps and the final map with the hydrologic corridor potential:

- Map 1: Biophysical potential map
- Map 2: Local recycling map
- Map 3: Regional recycling map
- Map 4: Hydrologic corridor potential map

This memo explains which data has been used, and which activities have been carried out in order to make the maps. The online version of the map can be found at https://justdiggit.org/potentialmap/.

Map 1: Biophysical map

In order to determine the areas that are suitable for re-greening based on biophysical criteria, various data sources are used. Each source of information adds an aspect to be able to determine the suitability for re-greening. On continental scale, the following aspects have been taken into account:

- *Soil* suitability: Is the soil suitable for re-greening
- *Precipitation* suitability: is there enough rain water for the new plants to grow
- Current *vegetation* cover: is re-greening needed
- Land *use*: is it possible to re-green the area, within the current use
- *Altitude* suitability: at very high altitudes, re-greening becomes very difficult to carry out

These five aspects are the main aspects that are used to determine the biophysical potential on continental scale. When detailed maps for selected areas are made, other data can be taken into account as well, for example:

- Population (density)
- Steepness and direction of the slope of the landscape
- Trend in change of vegetation cover (is vegetation cover increasing or decreasing)
- Geology in combination with soils to specify different possible interventions

On the scale of the African continent the five mentioned aspects are used. For this the following data sources have been used:

- *Soil* data: Soil atlas Africa 2013, shape file
- *Precipitation* data: TRMM data, between 2000 to 2015, raster file with 0.25 degrees resolution
- Current *vegetation* data: MODIS NDVI (Normalized Difference Vegetation Index) between 2000 to 2015, raster file with 1 km resolution
- Land *use*: Globcover 2009, raster file with 1 km resolution
- *Altitude* data, GMTED 2010, raster file with 1 km resolution

For the determination of the biophysical map, each layer is reclassified between 0 and 1 to a map showing the potential of each aspect. Next all five data sources are summed without any weighing factor and divided by 5 in order to determine the total biophysical potential.

In the next paragraphs it is explained how every dataset is reclassified.

Soil data

Based on the descriptions of the soils in the Soil Atlas of Africa (EU 2013), all soils are reclassified based on suitability of re-greening. Fertile soils are classified as suitable for re-greening such as Andosols, young volcanic depositions and chernozems, black deeply developed soils. Very bad soils, such as loptosols, shallow soils and plinthosols, soils with an accumulation of iron, have been classified as less suitable.

Table 1: Scoring of the different African soils for re-greening

Soil code	Soil type	Description	Score
AC	Acrisols	Strongly acid soils with a clay enriched subsoil and low nutrient holding capacity	0.5
AL	Alisols	Very acid soils with a clay enriched subsoil and high nutrient holding capacity	0.5
AN	Andosols	Young soil development in volcanic deposits (from Japanese an, back and do, soil)	1
AR	Arenosols	Soils developed in residual sands, in situ after weathering or as usually quartz-rich soil material or rock. Loamy sand or coarser texture to at least 100 cm from the surface, at least 35% rock or coarse fragments.	0.5
CH	Chernozems	Soil with a deep, dark topsoil that is rich in organic matter (from Russian chern black and zemlja, earth)	1
CL	Calcisols	Calcisols are common in highly calcareous parent materials and widespread in arid and semi-arid environments. Formerly used international soil names for Calcisols include 'Desert soils' and 'Takyrs'.	0.6
CM	Cambisols	Cambisols are characterized by the absence of a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides. Texture of the subsurface horizons are sandy loam or finer, with at least 8 percent clay by mass and a thickness of 15 cm (6 inches) or more. Generally well drained. They differ from Leptosols and Regosols by their greater depth and finer texture and are often found in conjunction with Luvisols.	0.9
Du	Durisols	Soils with accumulation of silica (from latin durus, meaning hard); ph can be above 8	0.3
FL	Fluvisols	Soils developed in alluvial deposits, in periodically flooded areas of alluvial plains. Texture can vary from coarse sand in levee soils to heavy clays in basin areas.	0.5
FR	Ferralsols	Strongly weathered soils with low nutrient holding capacity (from latin ferrum, iron and alumen, alum)	0.3
GL	Gleysols	Soils saturated by groundwater for long periods (from Russian gley, mucky mass)	0.5
GY	Gypsisols	Soils with significant accumulation of gypsum, generally found in dry areas (from greek, sypsos, gypsum)	0.3
HS	Histosols	Soils with a large amound of organic material generally developed under excess water or cold conditions	0.4
KS	Kastanozems	Soil with an organic-rich surface horizon and calcium carbonate or gypsum accumulation in the subsoil	0.8
LP	Leptosols	Generally young soils. Very shallow soils over hard rock or highly calcareous material, but also deeper soils that are gravelly and/or stony.	0.2
LV	Luvisols	Soils in which clay is washed down from the surface soil into an accumulation horizon at some depth. Potential for shallow groundwater.	0.8
LX	Lixisols	Lixisols consists of strongly weathered soils in which clay has washed out of an eluvial horizon (L. lixivia is washed-out substances) down to an argic subsurface horizon that has low activity clays and a moderate to high base saturation level.	0.5
NT	Nitisols	Deep red soils with a well-developed, nut shaped structure (from latin nitidus, shiny)	0.7
PH	Phaeozems	Phaeozems are much like Chernozems and Kastanozems but are more intensively leached in wet seasons. Consequently, they have dark, humous surface soils that, in comparison to Chernozems and Kastanozems, are less rich in bases and Phaeozems have no (signs of) secondary carbonates in the upper metre of soil.	0.8
PL	Planosols	Soils having an eluvial horizon or materials having loamy sand or coarser textures. Stagnic soil properties. Mature soils are chemically strongly degraded. The surface has become acid and lost (much of) its clay; ion exchange properties have deteriorated.	0.6

PT	Plinthosols	Soils with accumulation of iron that hardens irreversibly when exposed to air and sunslight	0.3
PZ	Podzols	Acid soil with a bleached horizon underlain by an accumulation of organic matter, aluminium and iron	0.5
RG	Regosols	Deep, well drained, medium textured, non-differentiated mineral soil that has minimal expressions of diagnostic horizons	0.4
SC	Solonchaks	Soils having a salic horizon starting within 50 cm from the soil surface Solonchaks are largely confined to the arid and semi-arid climatic zones and to coastal regions in all climates. Common international names are 'saline soils' and 'salt-affected soils'.	0.1
SN	Solonetz	Soils with a high content of exchangeable sodium and/or magnesium ions.	0.2
ST	Stagnosols	Soils with periodic water stagnation	0.3
TC	Technosols	Soils that are sealed or contain a significant amount of artefacts	0.4
UM	Umbrisols	Acidic soil with a dark surface horizon rich in organic matter	0.5
VR	Vertisols	Clay rich soils that develop deel, wide cracks upon drying (from latin vertere, to turn)	0.3
WR	Water	Water	0

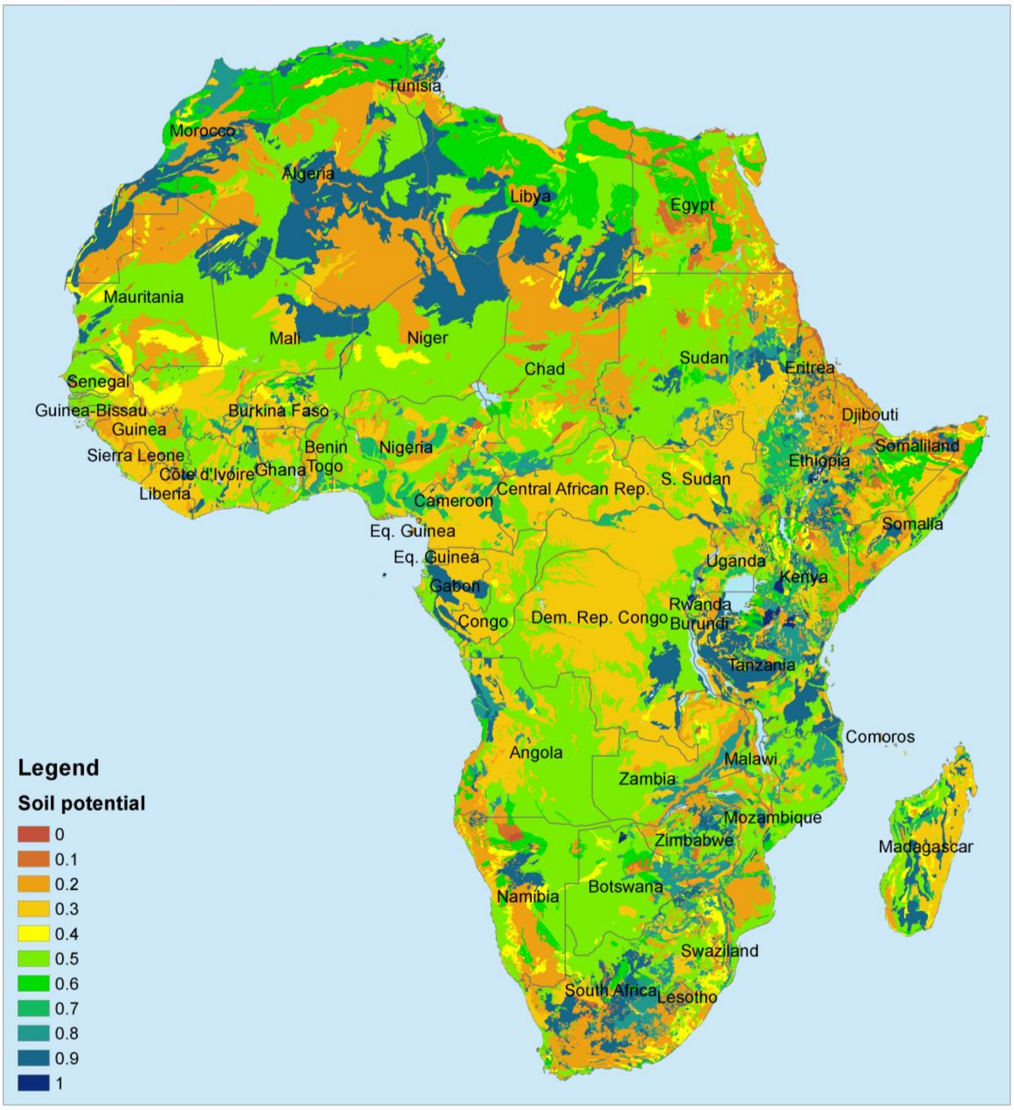

Figure 1 Soil potential for re-greening

Precipitation data

Precipitation data is used to determine where there is enough rainfall, so that re-greening is possible. Experiences from other re-greening projects show that the type of re-greening that Justdiggit is focussing on, is extremely difficult in areas with an annual rainfall below 200 mm, because of that areas with less than 200 mm are excluded. Re-greening in areas with annual rainfall between 200 and 400 mm is possible, but starting the re-greening is a big effort; additional water resources might be needed to support the growth of the roots of the vegetation, until the root network has become large enough. Due to this, areas with annual precipitation between 200 and 400 mm has received a lower score, then the areas with an annual precipitation above 400 mm.

Table 2: Precipitation scoring

Precipitation [mm]	Score
< 200	Excluded
200 – 400	0.5
400 and more	1

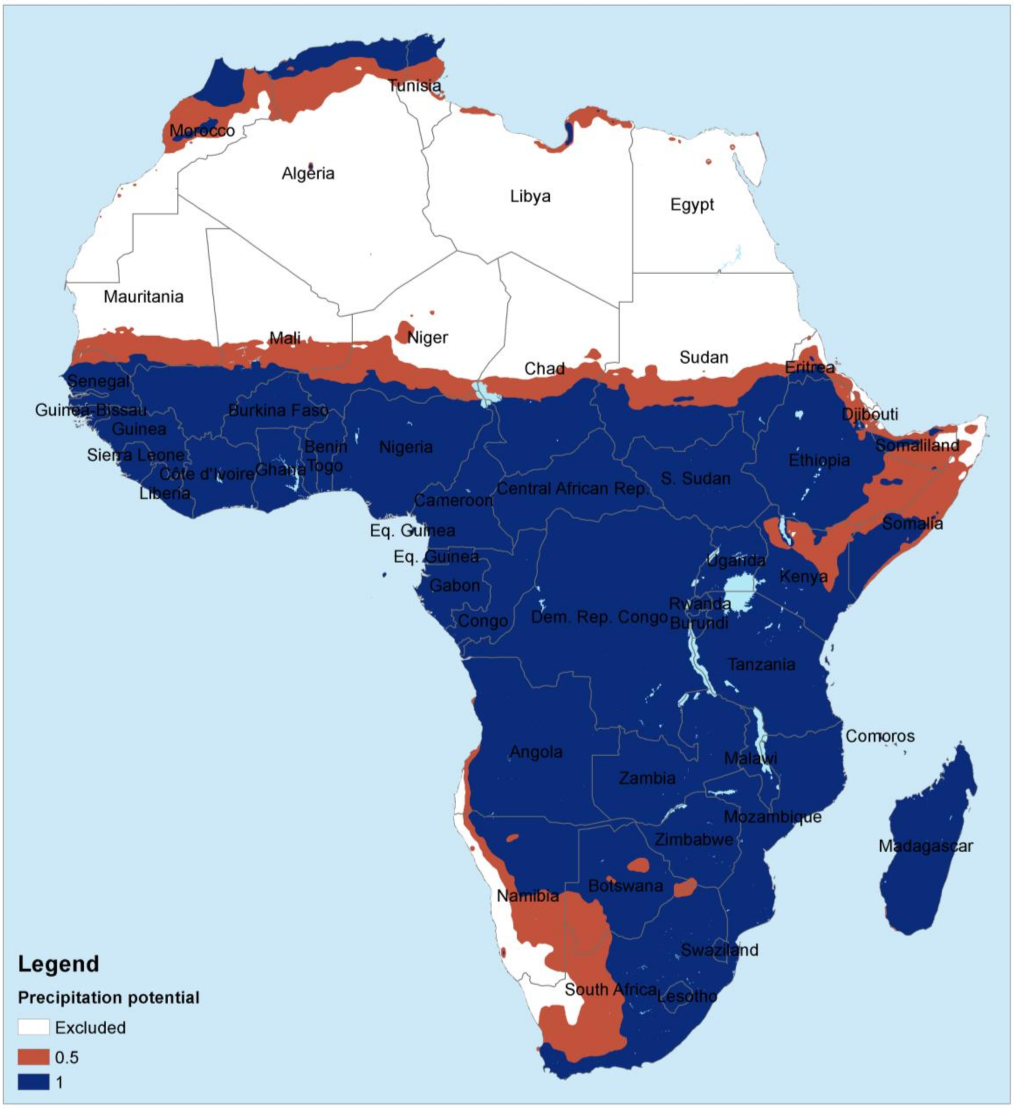

Figure 2 Precipitation potential for re-greening

Vegetation data

The NDVI data is used to determine the average vegetation index over the period of 2000 to 2015. This average NDVI map is reclassified using different scores for different NDVI values.
Areas that have an higher potential for re-greening have received an higher scoring, areas with a low potential a lower one: in areas with hardly any vegetation (NDVI below 0.1) it is quite hard to re-green but necessary; in areas where a bit of vegetation is growing re-greening can be achieved much quicker (NDVI between 0.1 and 0.26); areas that are green part of the year need less re-greening, so NDVI above 0.26 the higher the NDVI, the lower the score. Areas with a NDVI above 0.6 are excluded: these areas are already so green that re-greening is not needed.

Table 3: Scoring of the NDVI variation

NDVI	Score
0 – 0.1	0.5
0.1 – 0.26	1
0.26 – 0.43	0.6
0.43 – 0.6	0.3
> 0.6	Excluded

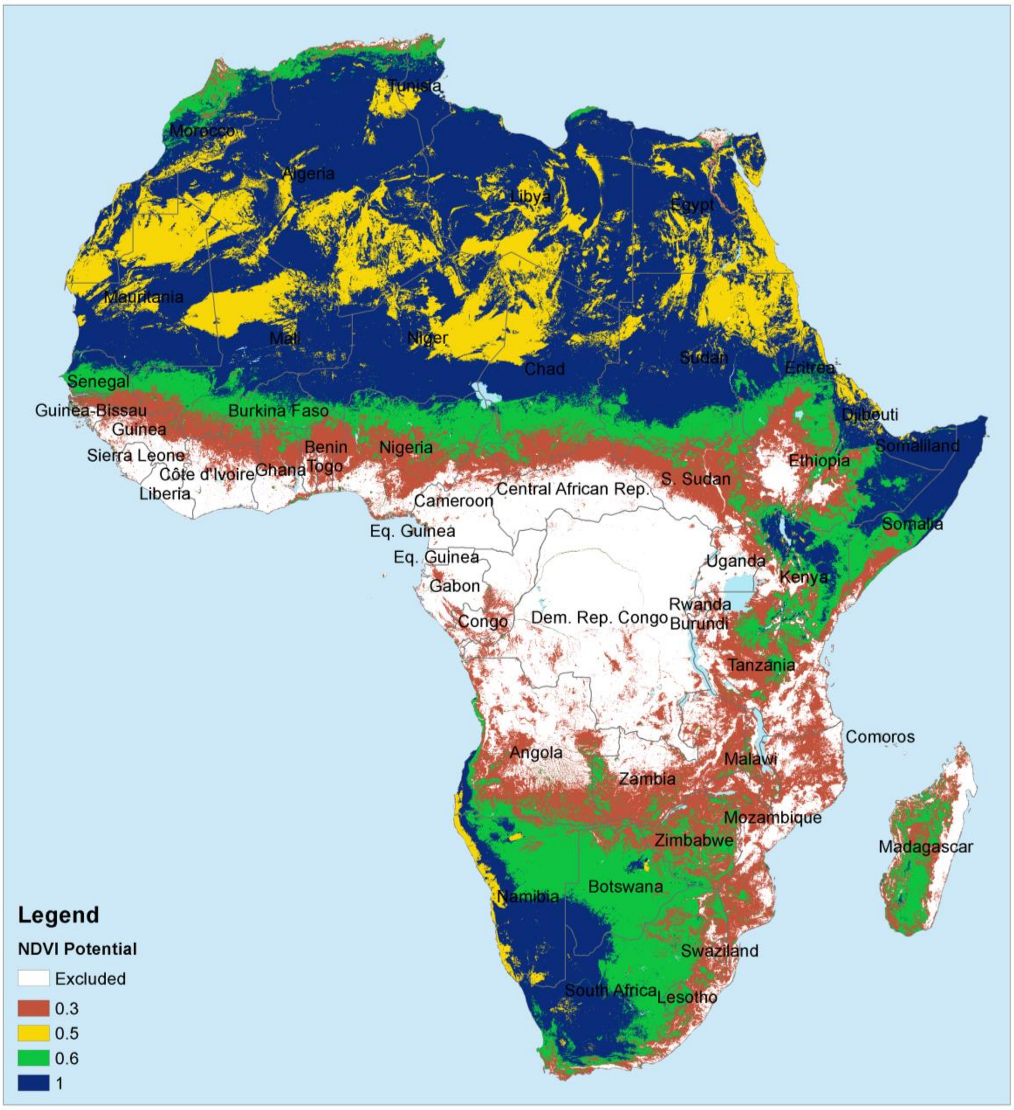

Figure 3 NDVI potential for re-greening

Land use

The land use map of Globcover is a raster file with a land use code. Each code stands for a certain land use (see Table 4). The land use map of Globcover 2009 is reclassified on re-greening potential. This reclassification is based on experience gained in other projects.
Low potential land use in Globcover 2009 has received a lower scoring. Low potential areas are for example areas with permanent forests that are regularly flooded or waterlogged, or deciduous forests, which are already green. High potential land use are areas with mixed grassland / forest / shrub land and mosaic vegetation.

Table 4: Scoring of the various land uses in Africa for re-greening

Land use code	Description	Score
11	Irrigated croplands	0.4
14	rainfed croplands	0.6
20	mosaic croplands / vegetation	0.7
30	mosaic vegetation / croplands	0.9
40	closed to open broadleaved evergreen or semi deciduous forest	0.4
50	closed broadleaved deciduous forest	0.3
60	Open broadleaved deciduous forest	0.5
70	closed needleleaved evergreen forest	0.3
90	Open needleleaved deciduous or evergreen forest	0.4
100	Closed to open mixed broadleaved and needleleaved forest	0.4
110	Mosaic Forest-Shrubland/Grassland	0.6
120	Mosaic Grassland/Forest-Shrubland	1
130	Closed to open shrubland	0.6
140	Closed to open grassland	0.8
150	Sparse vegetation	0.6
160	Closed to open broadleaved forest regularly flooded (fresh-brackisch water)	0.2
170	Closed broadleaved forest permanently flooded (saline-brackish water)	0.1
180	Closed to open vegetation regularly flooded	0.1
190	Artificial areas	0
200	Bare areas	0.5
210	Water bodies	0
220	Permanent snow and ice	0
230	No data	0

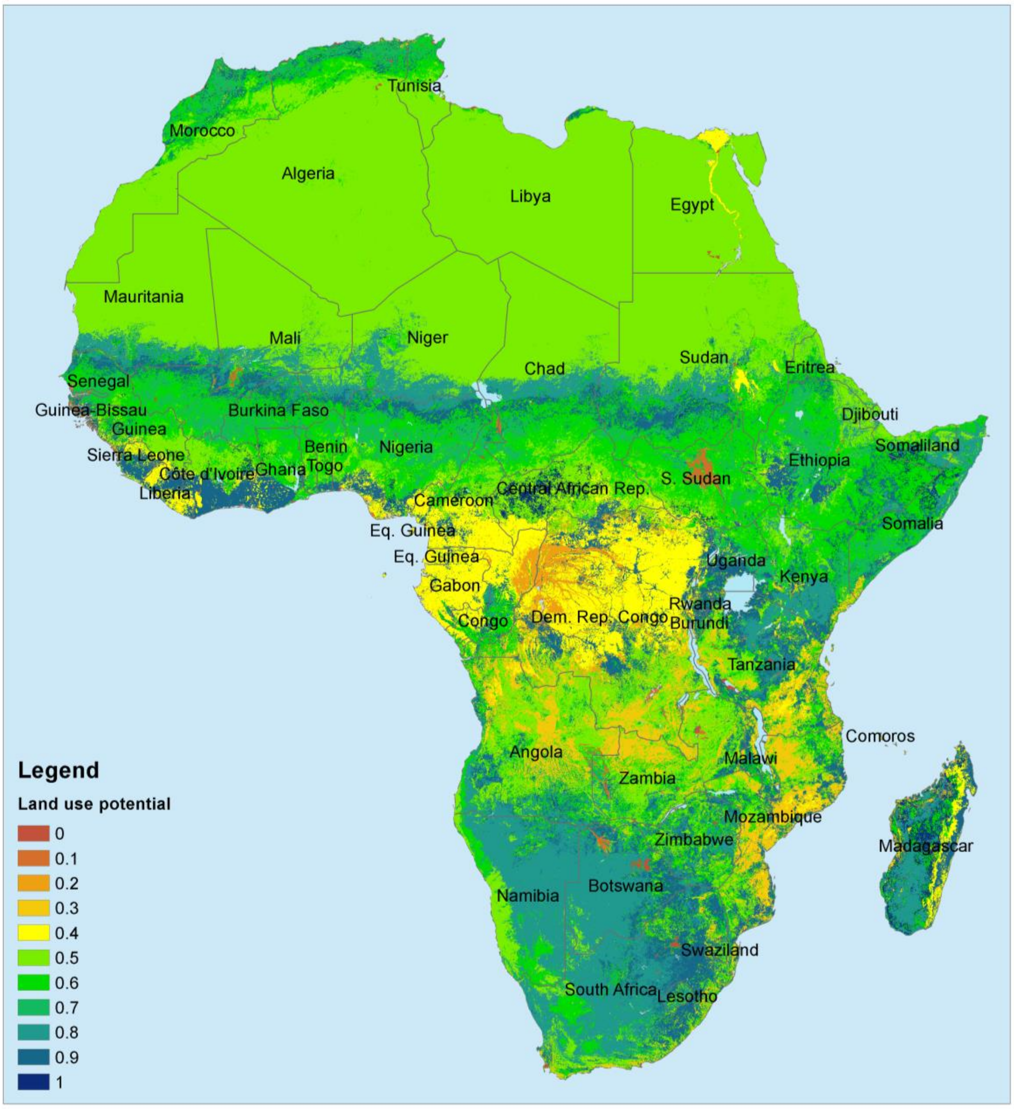

Figure 4 Land use potential for re-greening

Altitude data

Re-greening at very high altitude is difficult to carry out. Because of this, areas higher than 3000 m above sea level are excluded. When detailed maps within a hydrologic corridor are made, more detailed data sets will be used. For that analysis slopes will be taken into account as well. At this point excluding areas above 3000 m is providing a good basis for determining the potential for re-greening with a hydrologic corridor.

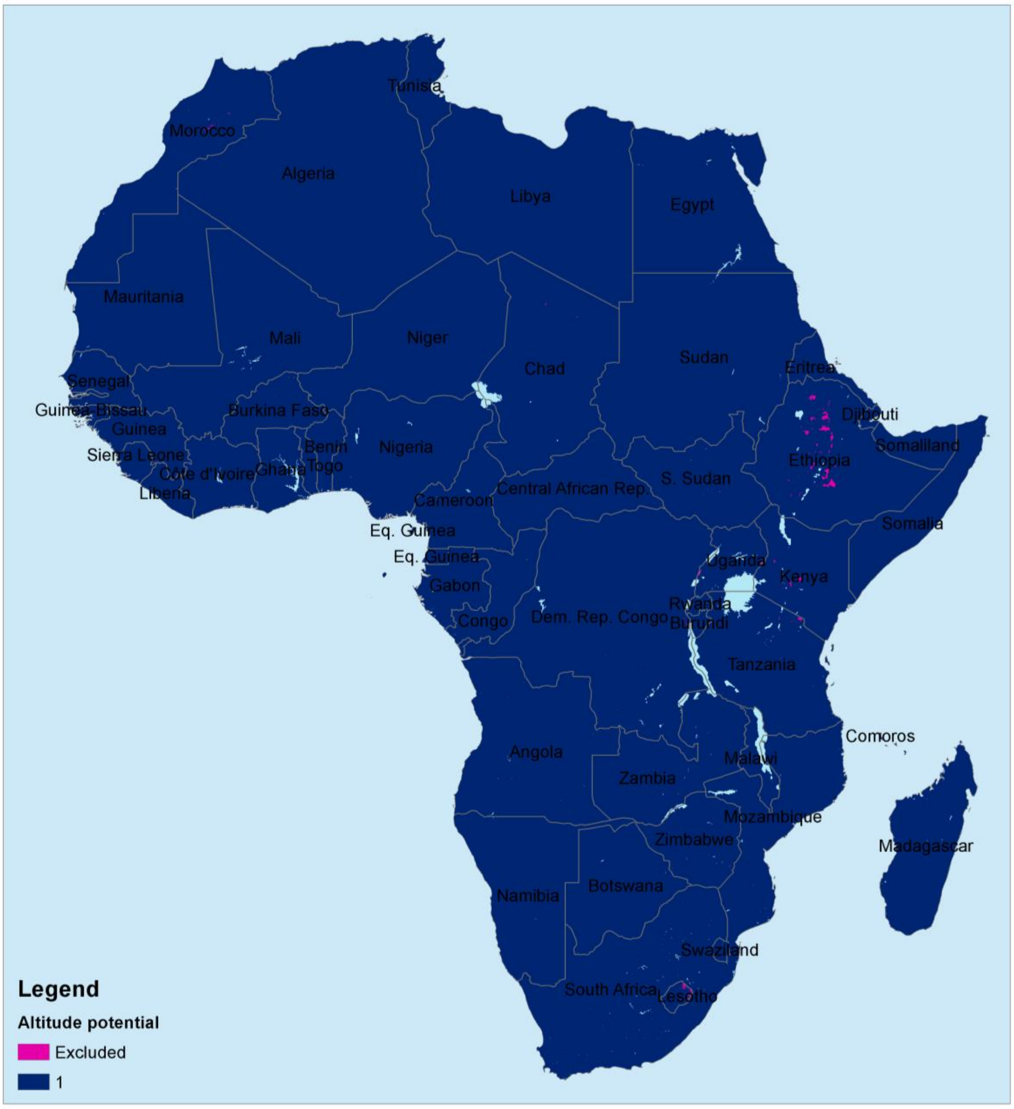

Figure 5 Altitude potential for re-greening

Biophysical potential map

The five maps, (soil, precipitation, vegetation, land use and altitude) are combined into the biophysical potential map. In the vegetation, precipitation and altitude maps certain areas are excluded. If in one of these maps an area is excluded, this area is excluded in the biophysical map. In the remaining areas there is a biophysical potential for re-greening. For each grid cell the average score is calculated to determine the potential. The resulting map shows the biophysical potential in the African continent. Areas with a low score (0) have a low potential. Areas with a high score (1) have a high biophysical potential.

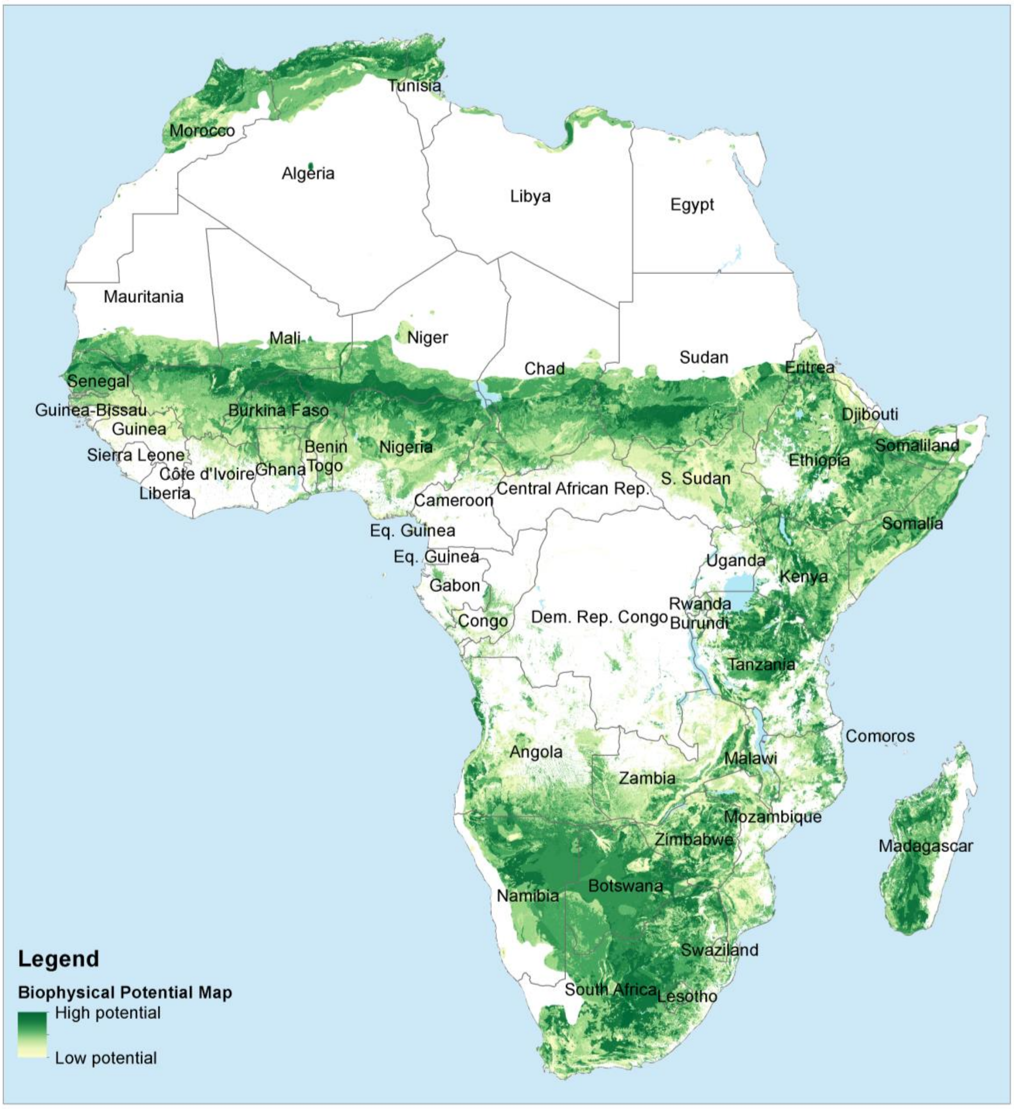

Figure 6 Combined biophysical potential for re-greening

Map 2: Local recycling map

The local recycling map quantifies the effects of wetter land surfaces, hence indicates the impact that more vegetation will have on the local hydrological recycling. Transforming the landscape from a bare soil situation to a vegetated situation generally increases the amount of evaporation and decreases the amount of sensible heat that enters the atmosphere from the land surface. This change in the form of energy that enters the atmosphere influences the local meteorology. Whether this can lead to a change in precipitation or not depends on the atmospheric conditions. Under certain conditions a wetter (more vegetated) land surface with more evapotranspiration leads to more precipitation, while under different conditions it will lead to less precipitation or the land surface conditions do not influence precipitation at all. These conditions were determined using the CTP-Hilow framework (Findell et al., 2003, Tuinenburg et al., 2011), based on ERA-interim atmospheric reanalysis data.

The map shows the frequency of days that the atmospheric conditions are such that wetter (more vegetated) land surface conditions lead to more precipitation minus the frequency of days that a wetter land surface leads to less precipitation. In blue zones more evaporated water is expected to lead to a lot more rain, in red zones more water will hardly lead to more precipitation.

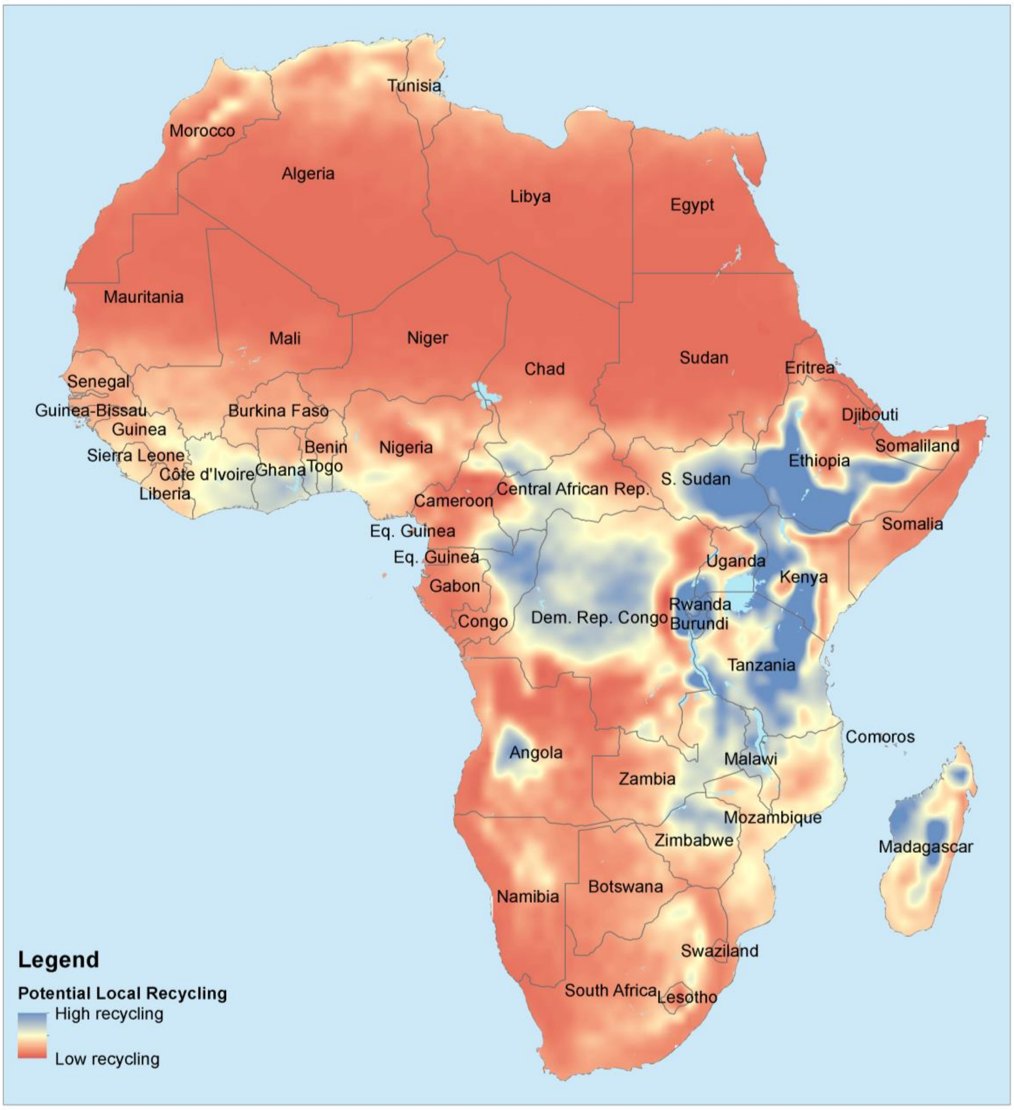

Figure 7 potential local recycling due to re-greening

Map 3: Regional recycling map

The regional recycling map quantifies the effect of an increased evaporation on the downwind precipitation. The downwind location where the evaporated water from a certain location precipitates can be close by or far away (even more than 3000 km) and can differ through the year. For each location, the evaporation that enters the atmosphere has been tracked and followed to its subsequent precipitation location using the 3D atmospheric moisture tracking model (Tuinenburg et al., 2012), based on ERA-interim atmospheric reanalysis. This has been done for all months from 1990-2015. This dataset on where the evaporation from each location is precipitation for each month is combined with an estimation of the difference in evaporation between bare soil and vegetation. This estimate is acquired from the PCR-GLOBWB (van Beek et al, 2011) model. This hydrological model takes into account the large scale hydrology and produces estimates of evaporation for different land use classes.

By combining these products, the effects of a land use change, via evaporation on downwind precipitation is determined. The map shows the fraction of this extra evaporation that precipitates in drier regions than where it evaporated. So in the blue zones water evaporating at that location has a potential to lead to more rainfall in a drier area. In the red zones this is not the case.

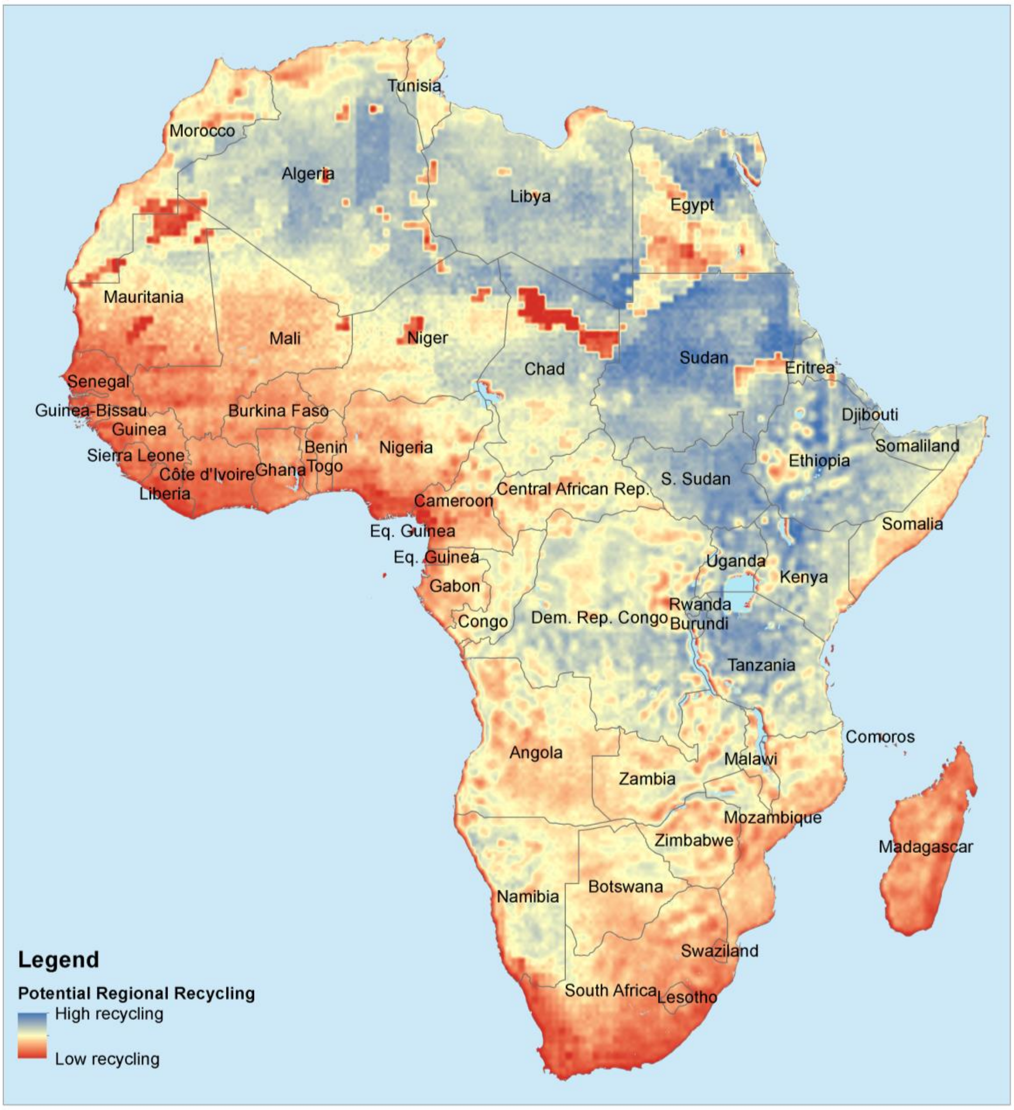

Figure 8 potential regional recycling due to re-greening

Map 4: Hydrologic corridor potential map

The 3 previous discussed maps have been combined with a weighted average. The weighing factors are presented in the table below. In order to give biophysical the same weight as the climatological impact, biophysical potential map is given a weighing score of 0.5. The 2 climatological maps are both given a weight of 0.25.

Table 5: Weighing factors of the resulting hydrologic corridor potential map

Map	Weight
Biophysical potential	0.5
Local recycling	0.25
Regional recycling	0.25

The resulting map shows the hydrologic corridor potential in Africa. This potential is the highest in the north west of Africa, in the middle and eastern part of the Sahel, continuing into the east of Africa and the south and south east of Africa.

Western side of the Sahel is less suitable for re-greening with a hydrologic corridor, partly because of biophysical reasons, but also because here the re-greening can result in a lower water availability due to the fact that the increased evaporation after the rainy season is blown into the ocean: the winds have a different direction in the dry and in the wet season.

However, areas that have a low potential for a hydrologic corridor could still be suitable for re-greening. The chance of having a climatological spinoff might be smaller, or re-greening might be more challenging.

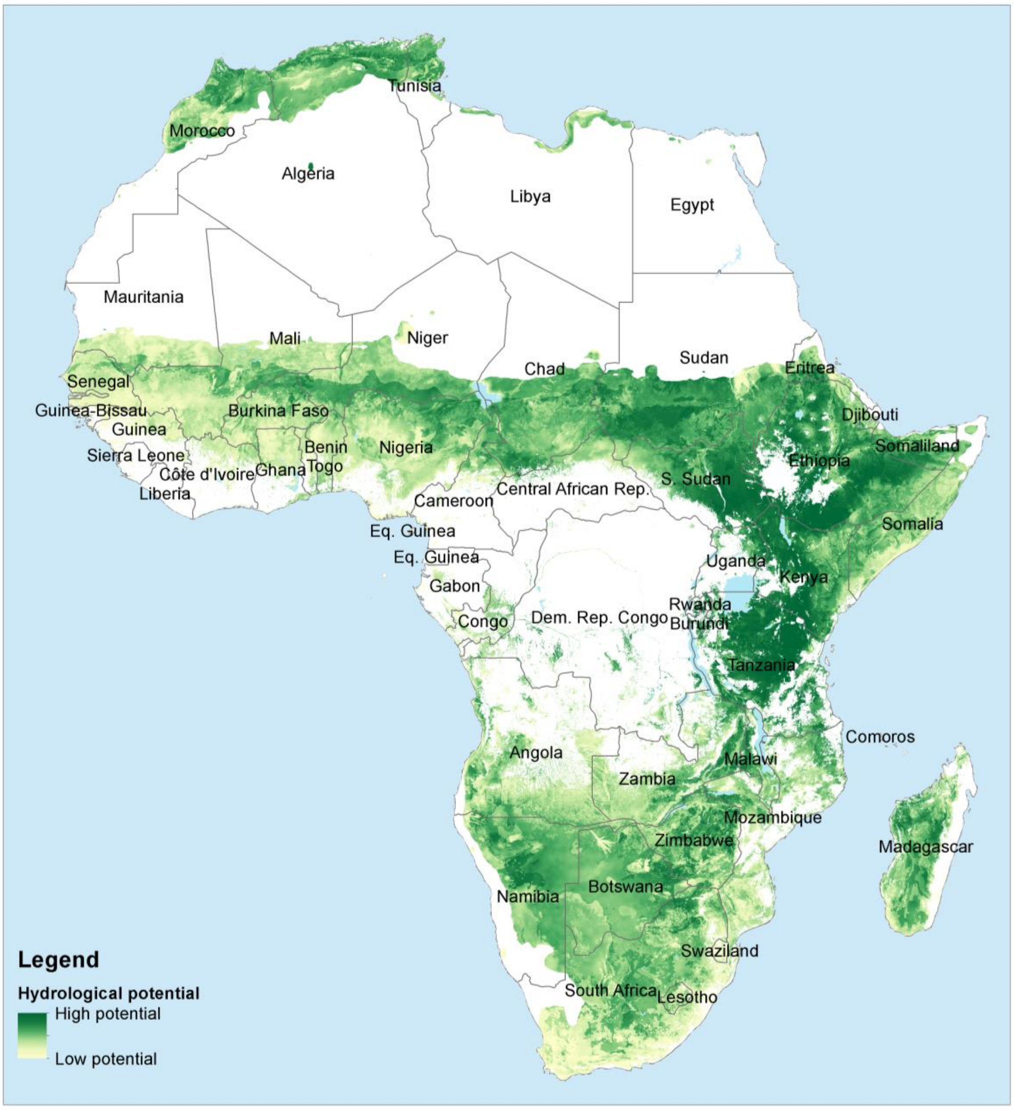

Figure 9 potential regional recycling due to re-greening

References:

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Tuinenburg, O. A., R. W. A. Hutjes, and P. Kabat. "The fate of evaporated water from the Ganges basin." *Journal of Geophysical Research: Atmospheres* 117.D1 (2012).

Findell, Kirsten L., and Elfatih AB Eltahir. "Atmospheric controls on soil moisture-boundary layer interactions. Part I: Framework development." *Journal of Hydrometeorology* 4.3 (2003): 552-569.

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