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Potential and demand analysis of agricultural groundwater use

Regionalization of hydrogeological potentials and potential agricultural demand for groundwater in sub-Saharan Africa

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Executive summary

Food insecurity on the African continent continues to increase due to multiple crises such as the corona pandemic, wars and climate change. Sustainable agricultural irrigation using renewable groundwater resources within Africa can help to increase food production, strengthen resilience to climate change and reduce dependence on global food markets. Higher productivity in African agriculture not only promotes food security, but also the creation of jobs, poverty reduction and socio-economic development in the continent's rural areas.

In sub-Saharan Africa, the great potential of groundwater resources has hardly been exploited to date (Ford et al. 2022). In order to draw attention to this potential and identify potential target regions for the sustainable use of groundwater resources for agricultural irrigation, available hydrogeological data and land use data were examined in more detail. Criteria, for a sustainable use of groundwater resources for irrigation, were defined for two categories of use, “traditional subsistence farming” and “emergent small-scale commercial farming”. Spatial information available at continental level was merged and analysed in a GIS in order to identify the corresponding potential regions.

The renewability of groundwater resources is a key factor for their sustainable use. For a differentiated assessment of renewability, groundwater recharge, the size of the reservoir and the extent and type of its use should be considered, as well as the effect of climate change on groundwater recharge. Previous studies show areas with an increase in recharge as well as those with a decrease. For both “traditional subsistence farming” and “emergent small-scale commercial farming”, larger areas could be identified in which the conditions for the use of groundwater resources for agricultural irrigation are particularly favourable.

1. Introduction

According to the UN World Food Program (WFP), more than 345 million people were affected by food insecurity in 2023. That is more than twice as many as in 2020 (Rother et al. 2023). This primarily affects the African population. Here, especially climate change and a growing population pose new challenges for agriculture. In order to increase independence from developments in other regions of the world and improve food security and resilience to external shocks, such as the corona crisis or the Russian war against Ukraine, crop failures must be prevented and agricultural yields increased in order to achieve food sovereignty.

According to FAO estimates, agriculture must increase its production by almost 50% by 2050 in order to achieve the "Zero Hunger" goal (SDG 2) of the 2030 Agenda. As a contribution to this, the African Union (AU) has set itself the goal of increasing agricultural productivity through irrigation by 60% compared to 2013. This was stipulated in Agenda 2063. In the Alliance for Global Food Security (May 2022), Germany has committed to supporting "the long-term transformation of global agricultural and food systems towards greater resilience and sustainability". Local production and regional trade should be strengthened and unilateral dependencies and protectionism avoided preventing disproportional effects by natural disasters such as droughts and heavy rainfall or the loss of individual importing countries.

Water scarcity is one of the most common causes of crop failure and inefficient agricultural production, the effects of which particularly affect sub-Saharan Africa (SSA), where rain-fed agriculture is predominant. To date, only 3 % of agricultural land is irrigated, 95 % of which uses surface water (UN 2022 WWDR). At the same time, analyses show that there are large groundwater resources in SSA that are hardly used (Pavelic et al. 2013, Ford et al. 2022). Thus, there is great potential to increase the climate and drought resilience of agriculture and the rural population in general, increase agricultural yields and sustainably expand production without overexploiting groundwater resources.

For agricultural experts, irrigation is a key factor in adapting agriculture to climate change, increasing production and achieving food security in Africa (Malabo Montpellier Panel 2018). In an analysis of the approaches of the BMZ special initiative "A world without hunger", FAO experts looked at the effectiveness and efficiency of various food security measures. The promotion of smallholder irrigation in Africa was ranked fourth out of 24 measures evaluated in the cost-benefit analysis (ZEF & FAO 2020: 51). The agricultural sector in Africa employs an average of around 43% of the working population, with this figure exceeding 60% in countries in the Sahel region (World Bank 2023). Compared to this, its contribution to African GDP is relatively low at an average of 18%.

This gives an indication of the relatively low productivity; Africa's grain yields are only 41% of the international average (AfDB 2019). Against the backdrop of this great economic importance, increased irrigation with groundwater can not only lead to food security, but also to stronger socio-economic development, poverty reduction and job creation.

This study identifies regions with favourable hydrogeological conditions and a general need for agricultural irrigation. To this end, existing continental data sets on hydrogeology and land use data are combined to identify regions with irrigation potential and exploitable groundwater resources (Chapters 2 and 3). Subsequently, two key issues of sustainable groundwater use in agriculture - renewability and the effects of climate change - are discussed in more detail (Chapter 4).

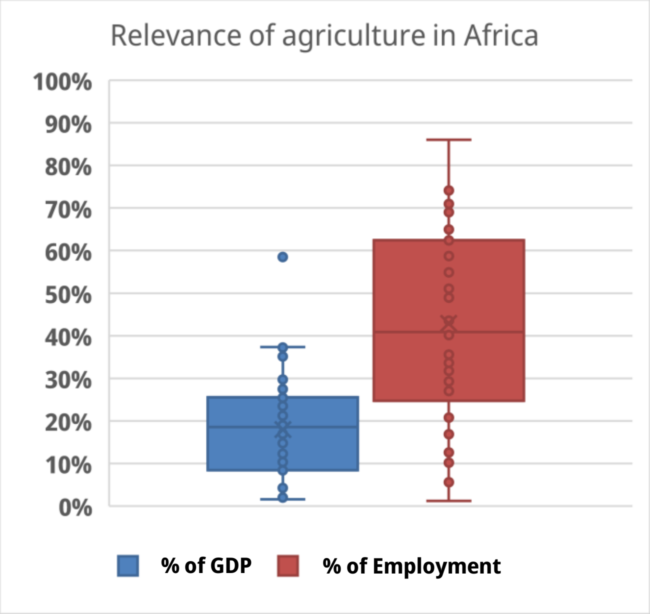

Figure 1: Share of the agricultural sector in GDP and employment in Africa. Data: World Bank 2023

A study at this scale cannot and should not be used to make statements about whether agricultural groundwater use at a specific location is ecologically justifiable, economically sensible and expedient in terms of social aspects. Rather, it could help to identify regions in which increased groundwater use for the purpose of food security should be examined as a priority.

2. Methodology and data basis

The study approach, the underlying data and the thresholds defined on this data are explained in more detail below.

2.1 Hydrogeological potential

For sustainable groundwater usage, no more water may be withdrawn in the long term than flows back into the groundwater body via rainwater or surface water infiltration. Therefore, for the sustainability assessment particularly the parameter "groundwater recharge" was of high interest. The parameters "groundwater storage", "depth to groundwater", "productivity" and "geology" were also taken into account. Since 2012, the British Geological Survey (BGS) has provided various pan-African data sets, which were used for the calculation here: a geological overview map of Africa and various pan-African maps on aquifer productivity, storage, depth to groundwater and groundwater recharge.

Aquifer productivity: Productivity describes the maximum quantity that can be extracted from an aquifer at a well, taking into account a sensibly limited drawdown. The hydrogeological properties of the aquifer, particularly its hydraulic conductivity, and the quality of the well design are the limiting factors here.

Storage: Storage is a measure of the amount of water stored in an aquifer. To determine this, the saturated aquifer thickness is multiplied by the effective porosity.

Depth to the groundwater table: The depth to the groundwater table indicates the depth at which groundwater can be found from the earth's surface.

Groundwater recharge: Groundwater recharge indicates how much new groundwater is formed each year. This is primarily dependent on precipitation, but also infiltration from surface waters such as rivers or lakes. Depending on the permeability of the subsoil, more or less water can infiltrate from the surface into the groundwater. In highly variable climatic zones, the multi-year average can also be considered a decisive factor.

The extent to which an aquifer has potential for sustainable agricultural use depends largely on the agricultural business model. For this reason, two categories with different criteria were considered when analysing the hydrogeological potential for groundwater-based irrigation: “traditional subsistence farming” and “emergent small-scale commercial farming”.

“Traditional subsistence farming” describes agricultural activities with a focus on self-consumption. This includes family farms and community structures. These farms in sub-Saharan Africa often have too little capital to drill deeper wells (> 30 m) and build large-scale irrigation infrastructure. Due to, the scope of their agriculture and a lack of access to land and additional labour, their potential water requirements are limited and can be met with a hand pump. These limitations and the correspondingly low water requirements mean, that sustainable groundwater use can often still be assumed even in aquifers with low productivity and relatively low recharge.

In this analysis, the “emergent small-scale commercial farming” category includes agricultural activities that have more means of production (land, financial resources). Besides self-consumption also commercial interests are of relevance. The areas used for agriculture are larger and the food produced is mainly traded on local and regional markets. The construction of deeper wells can also be financed within these structures. However, deeper and larger wells only make sense in aquifers with higher productivity and their use can only be considered sustainable with higher recharge rates.

Table 1 shows an overview of the parameters and the thresholds defined for both categories.

Table 1: Parameters and thresholds

Parameter	**Scale of values**	**Thresholds traditional subsistence farming**	**Thresholds emergent small-scale commercial farming**	**Data basis**
Groundwater recharge (mm/a)	0 - 295	>= 50 (green) >= 25 (yellow)	>= 50 (if storage >= 10,000) or >= 100 (if storage >= 1,000)	MacDonald et al. 2021
Depth to groundwater (m below surface)	Very shallow = 0 – 7 Shallow = 7 – 25 Shallow to medium = 25 -50 Medium = 50 – 100 Deep = 100 – 250 Very Deep >= 250	<= 25	<= 50	Bonsor and MacDonald 2011
Productivity (l/s)	Very high >= 20 High = 5 – 20 Medium = 1 – 5 Low to medium = 0.5 – 1 Low = 0.1 – 0.5 Very low <= 0.1	>= 0.1	>= 1.0	MacDonald et al. 2012

Storage (mm)	Low <= 1,000 Low to medium = 1,000 – 10,000 Medium = 10,000 – 25,000 High = 25,000 – 50,000 Very high >= 50,000	No exclusion criterion	>= 10,000 (if recharge >= 50 mm/a) or >= 1,000 (if recharge >= 100 mm/a)	MacDonald et al. 2012

Justification of the selection criteria

The defined thresholds of the different hydrogeological parameters for a sustainable and favourable agricultural use of groundwater resources are described below:

a) Groundwater recharge

The threshold value for groundwater recharge is intended to ensure sustainable use. In the "traditional subsistence farming" category, the limit value for groundwater recharge is already set at values of > 25 mm/a due to the relatively low water requirement. In the "emergent small-scale commercial farming" category, the water requirement is greater due to the larger farm size (more acreage), thus a higher recharge is required for sustainable use. Differentiated benchmark values were used in this analysis. As precipitation and therefore groundwater recharge can fluctuate greatly over years, this parameter was linked to the groundwater storage. This means that more water can be pumped from the reservoir in drier years, which can then be replenished to a greater extent in rainier years. If the aquifer has a large storage (>10,000 mm), it can still be managed sustainably even with moderate recharge rates of 50 mm/a. If the recharge rates are > 100 mm/a, we assume that aquifers with lower storage (>=1,000 mm) can still be used sustainably.

b) Depth to groundwater

In the case of “traditional subsistence farming” irrigation, farmers generally have significantly lower financial resources at their disposal. For this reason, the maximum depth to groundwater was set at 25 m for this category in order to keep the costs of well construction low. In the “emergent small-scale commercial farming” irrigation category, the groundwater depth was set at a maximum of 50 m, so that the groundwater can still be developed with relatively simple means, but higher costs are still required for drilling and well construction. Exploiting deep aquifers with deep boreholes requires considerable technical and financial effort, which could at best be realized by large companies or state institutions.

c) Aquifer productivity

The “traditional subsistence farming” structures considered in this study have a manageable water requirement. This can already be covered with the operation of a simple hand pump and with a very low productivity of 0.1 l/s or more. For "emergent small-scale commercial farming", we have assumed a greater water demand and thus a higher productivity of > 1 l/s to cover it. However, these withdrawal rates are only used during irrigation periods. Irrigation does usually not take place continuously, but in seasonal cycles and even then the water is usually not pumped throughout the day, but only at certain times of the day.

d) Groundwater storage

Storage capacity was not defined as an exclusion criterion for “traditional subsistence farming” structures. As already mentioned in the description of groundwater recharge, this parameter was not defined as a fixed limit value for "emergent small-scale commercial farming", but as a function of groundwater recharge. In regions with high precipitation and high recharge rates of > 100 mm/a, a lower storage (> 1,000 mm) was accepted, whereas for lower recharge rates > 50 mm/a, a higher storage (> 10,000 mm) was assumed for sustainable use.

2.2 Selection of potential areas according to land use, green water scarcity and protected areas

2.2.1 Selection of the agricultural area

The basic idea behind the increased use of groundwater to secure and expand agricultural production in SSA is to make the currently predominant rain-fed agriculture more productive and climate-resilient. The aim is not to expand agricultural land into previously unused areas or natural ecosystems. On the one hand, this is intended to reduce conflicts of interest with ecological concerns, while on the other hand, increasing the productivity of existing agricultural structures also appears to make more economic sense.

The designation of potential regions for agricultural groundwater use was therefore based solely on the existing arable land. The Global Food Security-support Analysis Data (GFSAD) @ 30-m for Africa: Cropland Extent- Product (GFSAD30AFCE) from 2017 (NASA GFSAD dataset) was selected as the data basis for this. The grid of the land use mapping (30 m) was then intersected with the grid of the hydrogeological mapping (~5 km or 3.125'). Statistics (zonal statistics) on the extent of agricultural land were calculated for each 5 km grid cell. In the designation of potential areas, only those grid cells with more than 10% agricultural land were taken into account, to exclude regions where arable farming has not been practised to date. The objective is to increase agricultural irrigation with groundwater in or around existing, larger agricultural areas.

2.2.2 Stock and demand for agricultural irrigation

The "Landsat-Derived Global Rainfed and Irrigated-Cropland Product (LGRIP)" from NASA/USGS (Teluguntla et al. 2023) was initially used to locate the current stock of agricultural irrigation. The high-resolution land use mapping is based on satellite images taken by the Landsat 8 satellite between 2014 and 2017 and shows the irrigated agricultural areas with a resolution of 30 m. The data covers irrigated areas in general, without distinguishing between surface water and groundwater.

Global data on the scarcity of plant-available water ("green water") was then considered in order to localize the need for irrigation. This occurs when the water requirements of crops cannot be met from the soil moisture replenished by rain. He and Rosa (2023) define green water scarcity (GWS) for conditions when the quotient of monthly irrigation water requirements (BWR - blue water requirements) and the crop water requirement (CWR - crop water requirement) is greater than 0.2.

According to He and Rosa (2023), 53% of the areas cultivated in rainfed agriculture are currently affected by a shortage of green water, meaning that the plants are under water stress and do not produce their full yield. Changing temperature and precipitation patterns will change the extent of green water scarcity. He and Rosa (2023) have performed global calculations for current climatic conditions, for a +1.5° and +3° warmer climate compared to pre-industrial times, with a spatial resolution of 5' x 5' arc minutes. Under a +3° warmer climate, 75% of global rainfed agriculture would already be affected, with the greatest increase expected in mid-latitude countries (USA, Russia, Ukraine, Argentina).

The relatively low-resolution grid information on the GWS was also transferred to the 5 km grid of the hydrogeological data sets using zonal statistics, whereby the respective mean values of the ~10 km GWS cell values were selected to determine the GWS value of the 5 km grid.

In view of the current climatic development and the international target agreements concluded in the Paris Climate Agreement, the GWS values for a 1.5° warmer climate have already been used to calculate the potential regions.

2.2.3 Protected areas

Many African countries have designated nature conservation areas that serve to protect nature and species and do not permit agricultural use at all or only with restrictions. These areas were therefore excluded from the potential regions. The location of the protected areas were taken from the World Database on Protected Areas (UNEP-WCMC and IUCN 2023). When mapping the potential regions, areas of all IUCN protected area categories were then excluded, although some categories do not generally exclude agricultural use (e.g. Cat. VI).

3. Results

As a result of the evaluations, the following maps show the hydrogeological potential regions for groundwater-based irrigation for the two categories “traditional subsistence farming” (figure 2) and “emergent small-scale commercial farming” (figure 4) as well as the existing irrigation areas surveyed by remote sensing. For both categories, these potential regions were then combined with the criteria of green water scarcity, protected areas and current agricultural use (> 10 %) (figure 3 and 5).

While the hydrogeological potential for “traditional subsistence farming” irrigation extends far beyond SSA except for southwest and east Africa (figure 2), these areas are significantly reduced after intersection with the protected areas, land use and green water scarcity. Larger contiguous potential regions for this irrigation type remain in western Africa (mainly Côte d'Ivoire, Togo, Ghana, Benin, Burkina Faso, southern Mali), in Ethiopia, and along a curved line from the Congo Delta via the southern DR Congo, Rwanda, Burundi and Tanzania to northern Mozambique. In the Sahel region and in southern Africa, the potential regions are primarily limited by the recharge criterion, so that larger areas here are only shown within recharge values between 25 mm and 50 mm (see figure 3).

As the category "traditional subsistence farming" also includes many very small agricultural activities, some of which are significantly smaller than 1 ha, it is likely that activities of this size are not included in the land use data with a satisfactory level of completeness due to a lack of resolution. Furthermore, due to the low water demand, the withdrawals are also very low, so that no effects on protected areas are to be expected here. In order to define potential regions for agricultural groundwater use for this category, it is therefore recommended to consider the pure hydrogeological potential (figure 2).

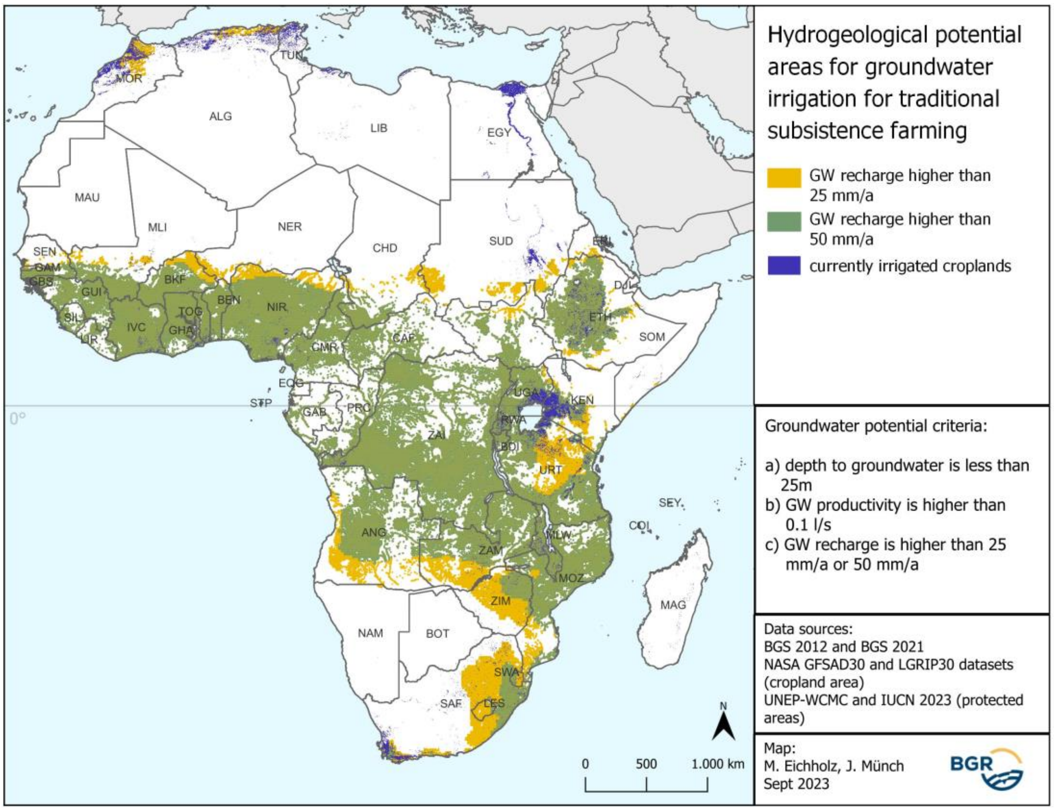

Figure 2: Hydrogeological potential regions for groundwater-based irrigation for traditional subsistence farming

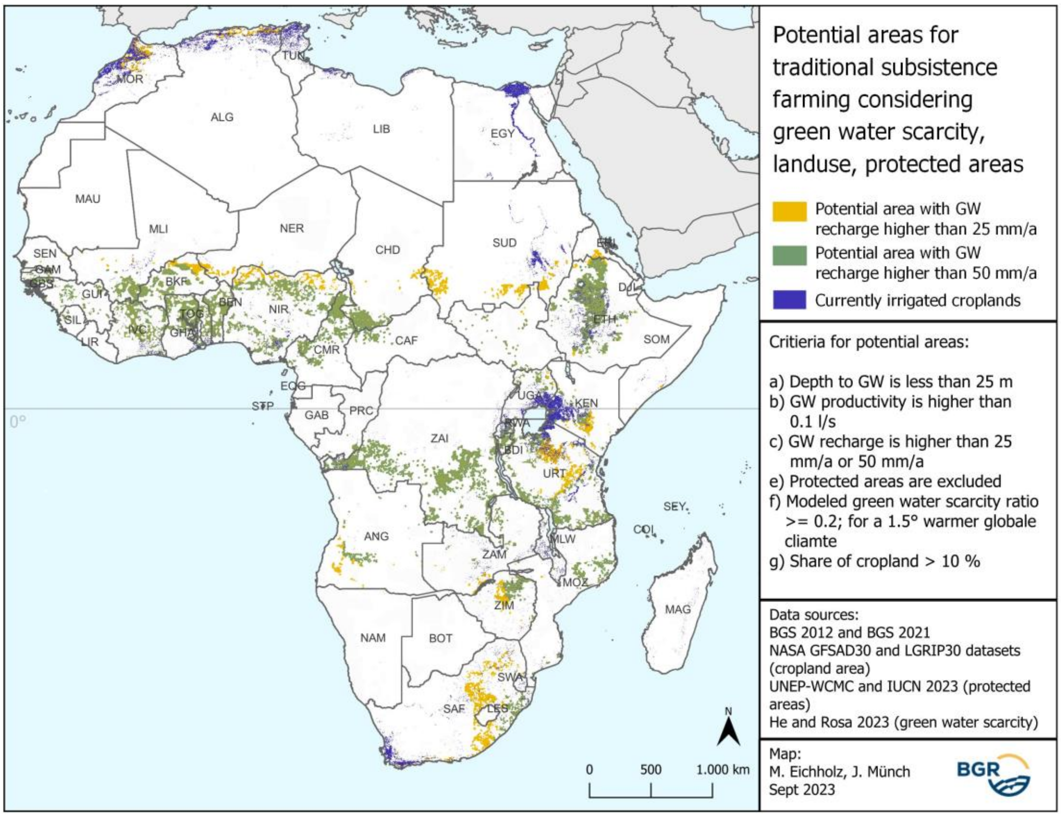

Figure 3: Potential areas for groundwater-based irrigation for traditional subsistence farming after considering green water scarcity, land use and protected areas

In the category “emergent small-scale commercial farming”, the hydrogeological potential is still quite extensive, but somewhat reduced compared to “traditional subsistence farming” (figure 4). After accounting for protected areas, land use and green water scarcity, the potential areas reduce. There are larger contiguous areas in the agricultural regions of central Ethiopia. In southern Chad (between the Logone and Shari rivers), in northern Cameroon (south of the Waza plain), in the north (east of Kano) and south of Nigeria (mainly west of the Niger River), in northern Ghana and in the northern border areas between Ghana and Togo as well as Togo and Benin. Further west, areas in Burkina Faso are designated on the border with Mali and in Mali on a line leading to the capital Bamako. There are individual, relatively small areas of potential in southern Senegal and Guinea Bissau (figure 5).

There are fewer contiguous areas of potential south of the equator. In the DR Congo, areas are identified on a line between the 4th and 5th latitude as far as Burundi, while smaller areas are still marked in southern Tanzania as well as on the coast in southern Mozambique and in the centre of Angola (in the south of Huíla province).

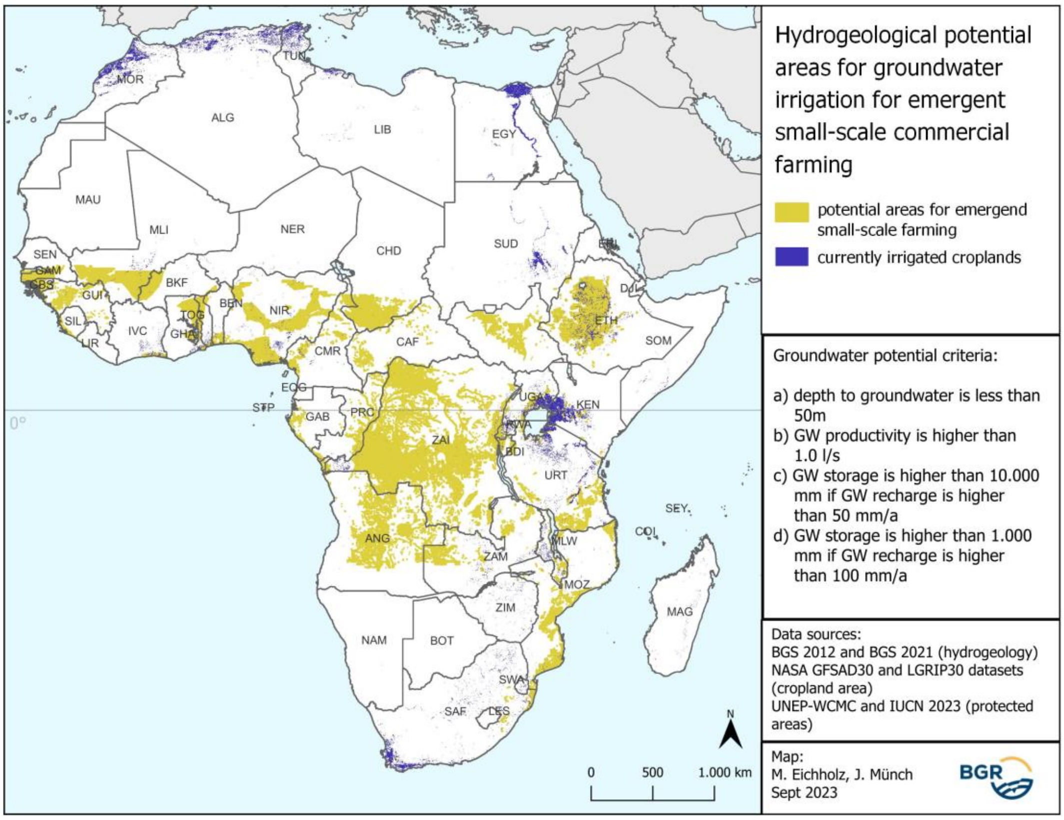

Figure 4: Hydrogeological potential regions for groundwater-based irrigation for emergent small-scale commercial farming

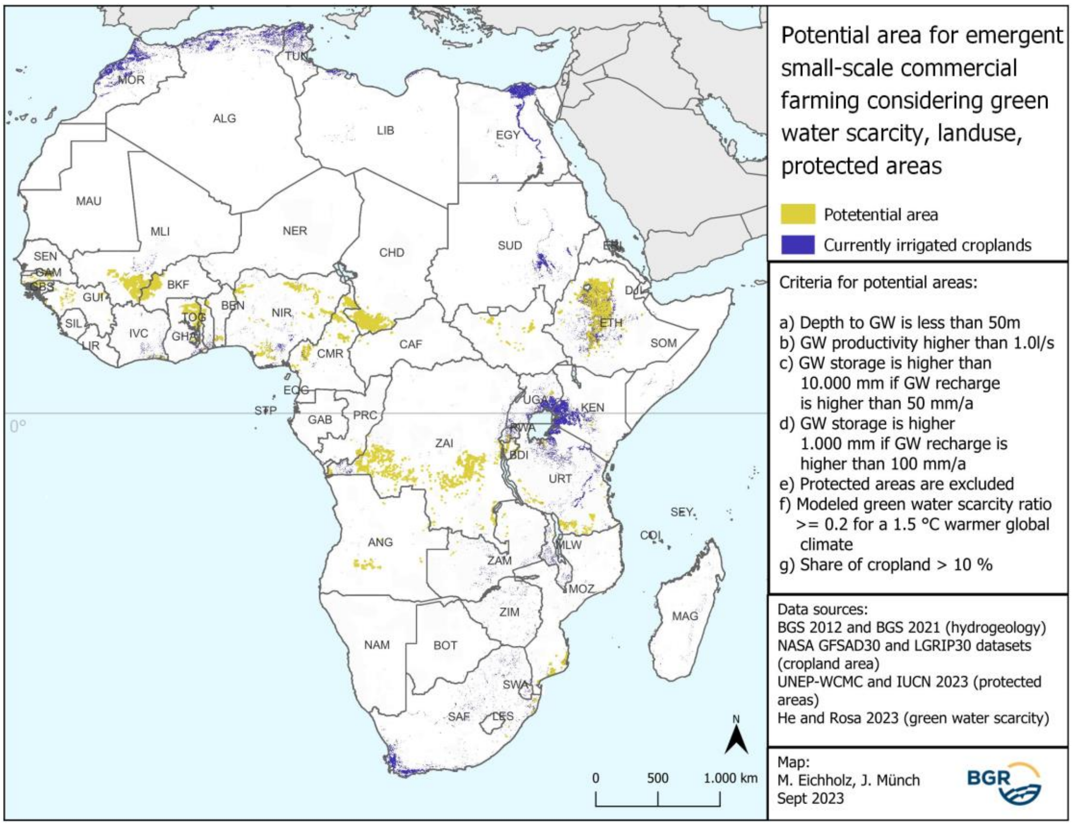

Figure 5: Potential areas for groundwater-based irrigation for emergent small-scale commercial farming after considering green water scarcity, land use and protected areas

4. Issues of sustainable groundwater use

4.1 Renewable groundwater and its sustainable use

The renewability of groundwater depends on the climatic conditions of the location and on the hydrogeological properties of the aquifer as well as the extent to which the resource is used.

For a differentiated assessment of renewability, both storage-based criteria and flux-based criteria should be considered. Accordingly, Cuthbert et al. (2023) define groundwater use as renewable if it enables a dynamic equilibrium of groundwater levels in human timescales. The "maximum extraction rate" (Q_R) is introduced here as a flux-based criterion and defined as the maximum extraction rate for which both the flow and the storage capacity of the aquifer are recovered with constant groundwater quality after extraction. The "groundwater response time" is introduced as a storage-based criterion in order to measure the time required to fully restore the system after extraction (t_c). This is related to a human timescale (t_h) as a reference value.

Systems in which the extraction rate (Q) is lower than the maximum extraction rate ($Q < Q_R$) and the time for complete recovery is within the range of a human timescale ($t_c < t_h$) are therefore described as renewable. If the extraction rate is lower than the maximum extraction rate ($Q < Q_R$) and at the same time the recovery time is greater than a human timescale ($t_c > t_h$), this is referred to as flux-renewable use. If the extraction rate is higher than the maximum extraction rate ($Q > Q_R$) and at the same time the recovery time is shorter than a human timescale ($t_c < t_h$), this is referred to as storage-renewable use. If both the extraction rate is higher than the maximum extraction rate ($Q > Q_R$) and at the same time the recovery time is greater than a human timescale ($t_c > t_h$), this is referred to as non-renewable use. According to Cuthbert et al. (2023), the different uses can be represented in a quadrant model (see Figure 6).

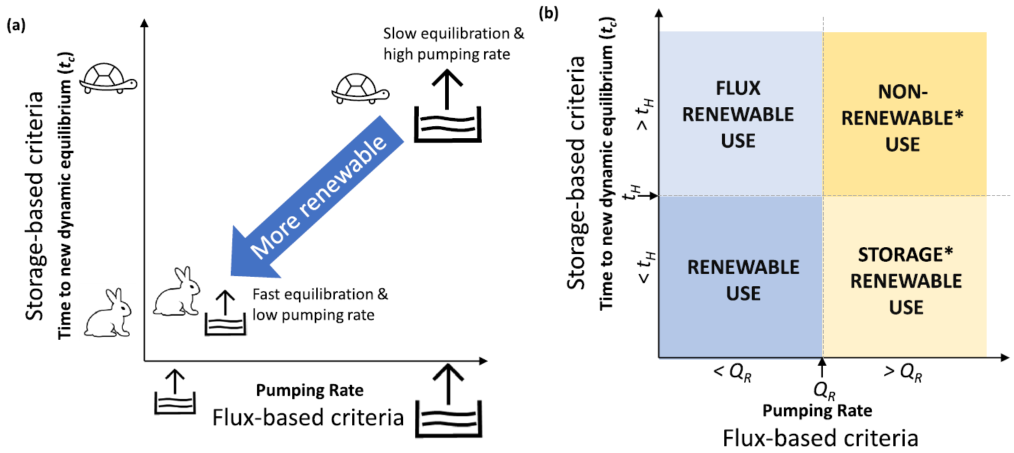

Figure 6: Criteria for renewable groundwater use (Cuthbert et al. 2023)

The lower quadrants of Figure 6 are groundwater systems with rapid response times (small t_c). Here, recharge and discharge rates are probably in equilibrium before groundwater abstraction. Excessive abstraction can cause problems to become apparent more quickly. This is a disadvantage when climatic shocks such as droughts occur, but conversely also means that problems associated with over-exploitation can be addressed and corrected quickly as the aquifer regenerates within human timescales. In the upper quadrants with slow response times (large t_c), it can take a very long time for problems due to overexploitation to become apparent. This can be an advantage when climatic shocks such as droughts occur, but conversely means that problems related to overexploitation are protracted as the aquifer is slow to respond.

Groundwater uses located in the right-hand quadrants have relatively high abstraction rates ($Q > Q_R$). These systems are sometimes managed in the sense of "strategic groundwater depletion". In this case, the aquifer is temporarily used or even temporarily overused, e.g. during a long period of drought, but in the knowledge that the groundwater levels and flow will return to their initial values once extraction has ceased (Cuthbert et al. 2023). Management strategies can therefore also be derived from the quadrant model. However, in order to implement these management strategies consistently, the aquifer and the abstractions must be known in detail.

The renewable groundwater use can therefore be defined solely according to the principles of hydrogeology and the physical properties of the aquifer. Although renewability plays a decisive role in determining sustainable groundwater use, it is only one of many criteria. Socio-political, economic, ecological and cultural criteria must also be taken into account for sustainable groundwater use (Cuthbert et al. 2023).

In this study, the selection criteria for the different categories were chosen in a way that the use of the resource should always lie within the three quadrants with renewable use. This was achieved by interpreting the criteria for the sustainability of groundwater resources (recharge and storage potential) more strictly as water demand increases.

However, in terms of renewability, the African continent shows that many countries with lower recharge rates have considerable storage potential, especially south of the Sahara, while many countries with lower storage potential have relatively high recharge rates (MacDonald et al. 2021). This means that groundwater resources in many countries are likely to be found in the "renewable use", "flux-renewable use" or "storage-renewable use" quadrants.

4.2 Impact of climate change on the renewability of groundwater resources

Climate change affects the water cycle via various complex feedback effects. Changes in air and sea temperatures, for example, influence evaporation rates and cloud formation and ensure that the amount and temporal distribution of precipitation changes. This in turn has an effect on groundwater recharge. In addition to climatic conditions, groundwater recharge depends on many other factors such as soil properties, land use and topography. While groundwater recharge in humid and semi-humid regions is mainly diffuse, i.e. due to infiltration of precipitation in the area, in arid and semi-arid regions infiltration from water bodies, including rivers that only carry water seasonally, is more significant.

According to the IPCC, Africa is particularly hard affected by climate change. An increase in average temperatures and extreme temperatures is predicted for most of Africa. Climate change will lead to an increase in heatwaves and droughts. It is also assumed that the frequency and intensity of heavy rainfall events will increase on the African continent, with the exception of North Africa and Southwest Africa. In addition, extreme fluctuations in precipitation and river discharge (-50% to +50% of the long-term average) are already being observed, which will have a negative impact on all water-dependent sectors (Trisos et al. 2022, IPCC 6).

A continental analysis and quantification of the impact of these changes in precipitation patterns on groundwater recharge is very complex due to the large number of influencing factors and is not currently available. Nevertheless, groundwater recharge processes are being investigated in various local and regional studies. In humid areas, heavier rainfall can lead to the infiltration capacity of the soil being exceeded, which increases surface runoff and thus soil erosion and flooding. In this case, the limiting factor for groundwater recharge is the infiltration capacity of the soil (Wang et al. 2015). In semi-arid and arid areas, on the other hand, heavy precipitation can lead to an increase in groundwater recharge, as in these areas only relatively intense precipitation does not evaporate directly, but also leads to infiltration (Hetzel et al. 2008). The effects of climate change on groundwater recharge must therefore be considered in a regionally differentiated manner.

For West Africa, for example, Cook et al. (2022) examined the potential impact of climate change on groundwater recharge. On average, a moderate to strong increase in groundwater recharge is expected here. Depending on the region, the projected change in the recharge rate varies between - 10% (West Sahel) and > +40% (in southern Burkina Faso). In eastern Africa, in Tanzania, heavy rainfall leads to increased surface runoff and ultimately to the formation of seasonal rivers. Here, despite increased runoff, focused (non-diffuse) recharge along rivers can increase (Seddon et al. 2015).

However, the increase and extension of dry periods and droughts also increases the need for water resources, especially those with a buffer function. In Aquifers water is protected against pollution and evaporation and thus groundwater can play a decisive role here and help to bridge dry periods. Increased groundwater abstraction during dry periods can be offset by reduced abstraction during rainy periods, during which the groundwater can then be replenished through recharge.

5. Conclusion and outlook

Agricultural irrigation plays an important role in adapting to climate change and improving food security in Africa - alongside other measures. In many regions of the continent, shallow and renewable groundwater resources are available and can be used to contribute to that aim.

Based on two different agricultural pathways, the study has identified potential regions for groundwater-based irrigation. Therefore, various exclusion criteria were formulated and calculated, to describe favourable conditions for sustainable use. According to Giller et al. (2021), many agricultural activities in SSA, more than 80 %, are so small-scale that their productivity is not even sufficient for the operators' food security. Irrigation could help these farmers to increase their agricultural productivity and outputs and thus to achieve food security. These farmers are included in “traditional subsistence farming” and the potential regions where groundwater can contribute to that purpose extensively extend across SSA except for southwest and east Africa (figure 2). For the category “emergent small-scale commercial farming” the majority of production is traded on local and regional markets and not self-consumed anymore. For that purpose, the required water demand for irrigation is higher. The potential regions for groundwater-based irrigation that could support this agricultural pathway are shown in figure 5. Both categories address key farmer groups if it comes to food security across SSA and the maps provided offer to identify potential favourable target regions to support groundwater development for agricultural irrigation.

The resolution scale of the data sets used and the criteria selected allow the identification of rather favourable regions for sustainable agricultural groundwater use. However, they do not allow absolute statements to be made about groundwater conditions at high resolution for a specific location and thus they cannot be used for implementation purposes. For example, a conservative approach was chosen by excluding grid cells with less than 10% agricultural land use from the potential areas. These regions were further blended with green water scarcity and protected areas (see figure 3 and 5). This also excludes, for example, areas that have been used only marginally for agriculture but still have sufficient groundwater resources for irrigation purposes, such as in South Sudan. The hydrogeological potential regions are thus generally much more extensive (see figure 2 and 4).

Following the identification of potential regions on the basis of this study, more detailed hydrological, agronomic and social investigations and feasibility studies need to be carried out for specific intervention regions in order to quantify the presumed potential for sustainable use more precisely. On this basis, decision-makers in the regions and international partners could make well-founded decisions on the costs, benefits and sustainability of investments in the promotion of agricultural irrigation with groundwater.

Although climate change will also have an impact on regional water cycles in Africa and therefore on groundwater recharge, this will vary from region to region and will by no means always be negative. Rather, groundwater will gain in importance as an adaptation resource due to its buffering function. This is because, compared to surface water, it is protected from evaporation and pollution underground. During prolonged periods of drought, the use of this resource can be intensified, while during rainy periods, surface water is increasingly used to conserve groundwater resources and allow extensive recharge. However, for this to be and remain sustainable, functioning groundwater management institutions and good knowledge of renewability and the nature and dynamics of the resource as well as consumption are required.

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