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Mapping the Risk Posed to Groundwater-Dependent Ecosystems by Uncontrolled Access to Photovoltaic Water Pumping in Sub-Saharan Africa

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Abstract

Photovoltaic-powered groundwater pumping offers a transformative solution for water services in underserved areas. However, without proper regulation, this technology could overexploit groundwater resources, threatening the groundwater-dependent ecosystems that rely on them. Often overlooked in development planning and water allocation, groundwater-dependent ecosystems hold significant socioeconomic and environmental importance. This study maps the risk to groundwater-dependent ecosystems in Sub-Saharan Africa from uncontrolled access to photovoltaic groundwater pumping using the analytic hierarchy process. It evaluates risks using data on irradiance, groundwater, and population, and novel data on groundwater-dependent ecosystems. Two scenarios are analyzed to improve the robustness of the findings. The results show that 92 percent of Sub-Saharan Africa's groundwater-dependent ecosystems risk overexploitation if photovoltaic water pumping is implemented without proper controls. Groundwater-dependent ecosystems in Southern and Eastern Africa, particularly in South Africa and Namibia, are found to face higher risks, while those in Gabon, the Republic of Congo, and southern Nigeria tend to be less at risk. Comparing these results with populations relying on unimproved water sources highlights regions like southern Nigeria and South Sudan, which could be prioritized for potential photovoltaic water pumping system investments due to their higher groundwater development needs and lower risks to groundwater-dependent ecosystems. Conversely, areas like Namibia and South Africa, with lower groundwater development needs but higher risks to groundwater-dependent ecosystems, should require targeted investments and very close groundwater monitoring. These findings can help policy makers in targeting investments in photovoltaic water pumping systems and identifying regions needing careful monitoring to ensure sustainable groundwater use and minimal impact on groundwater-dependent ecosystems.

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Mapping the Risk Posed to Groundwater-Dependent Ecosystems by Uncontrolled Access to Photovoltaic Water Pumping in Sub-Saharan Africa

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This paper is related to the Planet Vice-Presidency's flagship report "The Hidden Wealth of Nations: The Economics of Groundwater in Times of Climate Change" (2023) produced by the Water Department. The report was led by Aude-Sophie Rodella (TTL, Lead Economist) and Esha Zaveri (co-TTL, Senior Economist).

JEL codes: Q25, Q42.

Keywords: Groundwater-dependent ecosystems, Photovoltaic water pumping systems, Analytic Hierarchy Process, Sustainable groundwater management, sub-Saharan Africa

1. Introduction

Expanding access to electricity and expanding access to water are key development priorities, closely related in the regions where access gaps are most pronounced, such as in the case of Sub-Saharan Africa (SSA). The World Bank estimates that currently, 600 million people in SSA lack access to electricity, creating significant barriers to health care, education, productivity, digital inclusivity, and ultimately job creation (IEA, IRENA, UNSD, World Bank, WHO., 2024). Those barriers are compounded by a lack of access to clean water: 400 million people in SSA lack access to safely managed drinking water services (UNICEF, WHO, 2022). Progress in photovoltaic technologies has enabled a lowering of costs (Chandel et al., 2015; Global Solar Atlas, 2024), which can be a game changer in expanding access. Multilateral development partners such as the World Bank and the African Development Bank Group are partnering to provide at least 300 million people in Africa with electricity access by 2030. The expansion of photovoltaic energy at scale will also enable an expansion of solar pumping for irrigation.

This is promising for SSA where less than 5 percent of agricultural land is irrigated, and less than 7 percent of irrigated lands uses groundwater (Rodella, Zaveri and Bertone, 2023). This could also present challenges in terms of impacts on groundwater-dependent ecosystems (GDEs) and overexploitation if access to groundwater resources is not appropriately controlled, a scenario well-documented in regions such as South Asia and the Middle East (Lezzaik et al., 2018; Mukherjee, 2018).

There is growing recognition of the importance of those GDEs, from their socio-economic to their environmental value, including for carbon storage (Esteban and Dinar, 2016; Mendonça et al. 2017; Murray et al., 2003, 2006; Rohde et al., 2024). For instance, Mendonça et al. (2017) estimate that perennial lakes, mainly GDEs, trap some 0.33 billion tons of CO_2 per year, corresponding to about 1% of the present global CO_2 emissions.

GDEs play a crucial role in supporting the livelihoods of some of the most vulnerable populations in Sub-Saharan Africa, such as pastoralists (Rohde et al., 2024). The role of GDEs can often be indirect, for instance, through the hydraulic lift provided by certain tree species. However, GDEs are not consistently identified and mapped on a large scale, especially in developing countries. This data gap is significant, as GDEs, particularly in arid regions, are highly susceptible to even minor fluctuations in groundwater levels, which can jeopardize their survival.

A new World Bank database of GDEs in Sub-Saharan Africa shows their diversity and importance to people living in poverty (Rodella, Zaveri and Bertone, 2023). The database was compiled using a wide range of sources reflecting local and academic knowledge and identifies more than 200 GDEs across four main geographic types—inland surface waters (riverine, lacustrine, and wetland ecosystems); coastal and marine ecosystems (coastal and near-shore marine ecosystems), terrestrial springs (near spring and springs influenced zone ecosystems; includes oases); and terrestrial vegetation (sparse vegetation ecosystems and forests and woodlands ecosystems).

This dataset allows for novel analysis of the potential impacts of intervention affecting groundwater directly and indirectly. For instance, water extraction from aquifers by pumping systems can lead to the overexploitation of groundwater resources and a decrease in groundwater storage, which can, in turn, cause a loss of discharge from groundwater to wetlands, springs, streams/rivers, or coastal areas (McCallum et al., 2013). In addition, a decline in groundwater storage can lead to a decrease in the water table (Wada et al., 2010), rendering groundwater inaccessible to terrestrial vegetation (Barron et al., 2014).

To the authors' knowledge, this is the first paper looking at the potential impacts of the extension of photovoltaic water pumping systems (PVWPS) on GDEs. Even though several articles have studied the suitability of photovoltaic water pumping systems (PVWPS) in different regions of Sub-Saharan Africa (e.g., Gebrezgabher et al., 2021; Schmitter et al., 2018; Soenen et al., 2021; Xie et al., 2021), no article has investigated the risk posed to GDEs by the uncontrolled access to groundwater through photovoltaic water pumping across the continent. The potential to scale up shallow groundwater irrigation in the SSA region is undeniable and could be a game changer for poverty, food security, and climate adaptation (Rodella, Zaveri and Bertone, 2023). However, the analysis seeks to illuminate the unintended consequences of unfettered access and highlight the need for preventive measures to be in place prior to scaling up photovoltaic pumping.

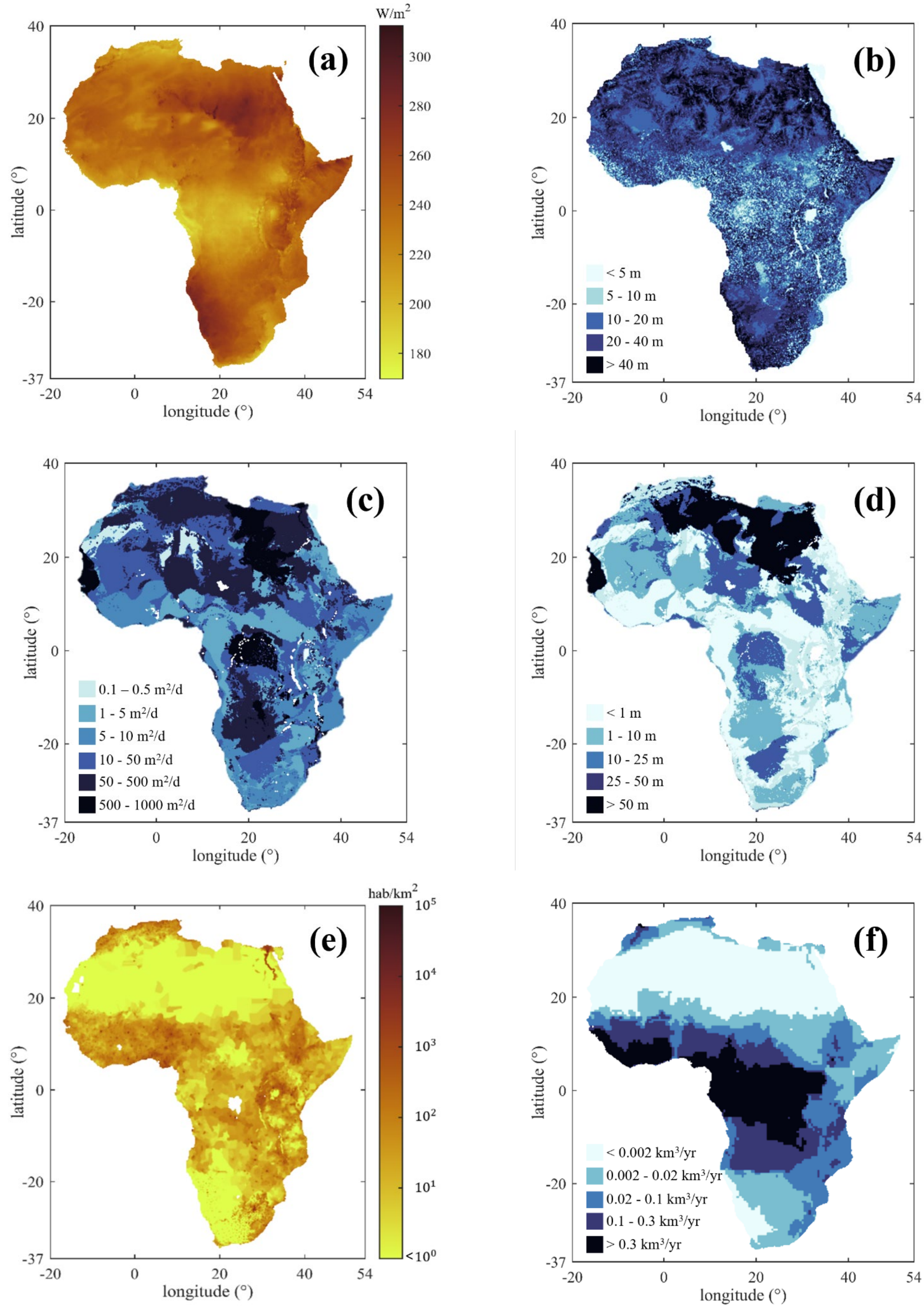
In this paper, we use the Analytic Hierarchy Process (AHP) to map the risk posed to GDEs in Sub-Saharan Africa by an uncontrolled expansion of access to groundwater through photovoltaic pumping. More specifically, we evaluate the risk of over-exploitation for GDEs using mapped data on groundwater, irradiance, population, and GDEs. Section 2 details the datasets used in our analysis. Section 3 outlines our methodology, followed by the presentation and discussion of results in Section 4. Section 5 covers the limitations of our study, and Section 6 explores the policy implications. Section 7 concludes the paper.

2. Data

The datasets used in this study are described in Table 1. These input datasets have different spatial resolutions. For the subsequent sections of the paper, we use the spatial resolution of the global horizontal irradiance (GHI) map, i.e., 0.2° (~22 km). We apply this resolution to all input datasets by nearest neighbour interpolation. The shape file on the type of GDEs is rasterized at this same resolution. Besides, we use irradiance data from 2020. In Figure 1, we plot the annual average of GHI for 2020, static water level, aquifer transmissivity, groundwater storage, population density, renewable groundwater resources and type of GDE across Sub-Saharan Africa.

Data	Description	Unit	Spatial resolution	Temporal resolution and coverage	Year of release	Provider	Type of data
Global Horizontal Irradiance (GHI)	Radiation received by a horizontal plane from all directions.	W/m^2	0.2° ~22 km	One temporal vector for each location. Data from 2005 to 2020 with a time step of 30 min (some datapoints are missing for years 2005 to 2012).	2021	European Commission, 2021	Raster file
Static water level	Depth of water in the borehole when there is no pumping.	m	0.0083° ~1 km	Dependence in time not provided.	2013	Fan et al., 2013	
Aquifer transmissivity	Rate at which groundwater flows horizontally through an aquifer	m^2/day	0.05° ~6 km		2012	British Geological Survey (Bonsor and MacDonald, 2011; Macdonald, 2012)	
Groundwater storage	Amount of water in the aquifer defined as a water depth	m					
Population density	Number of inhabitants per square kilometer	hab/km^2	0.04° ~5 km		2020	Center for International Earth Science Information Network, 2018	
Renewable groundwater resources	Volume of renewable groundwater that can be abstracted per year	km^3/yr	0.5° ~60 km		2022	World Bank	
Type of GDE	• Inland surface waters • Terrestrial springs • Coastal and marine ecosystems • Terrestrial vegetations	-	-				Shape File

Table 1 – Input datasets.


(a)
W/m2
300
280
260
240
220
200
180
(b)
< 5 m
5 - 10 m
10 - 20 m
20 - 40 m
> 40 m
(c)
0.1 – 0.5 m²/d
1 - 5 m²/d
5 - 10 m²/d
10 - 50 m²/d
50 - 500 m²/d
500 - 1000 m²/d
(d)
< 1 m
1 - 10 m
10 - 25 m
25 - 50 m
> 50 m
(e)
hab/km2
10^5
10^4
10^3
10^2
10^1
<10^0
(f)
< 0.002 km³/yr
0.002 - 0.02 km³/yr
0.02 - 0.1 km³/yr
0.1 - 0.3 km³/yr
> 0.3 km³/yr
latitude (°)
longitude (°)
40
20
0
-20
-37
-20
0
20
40
54

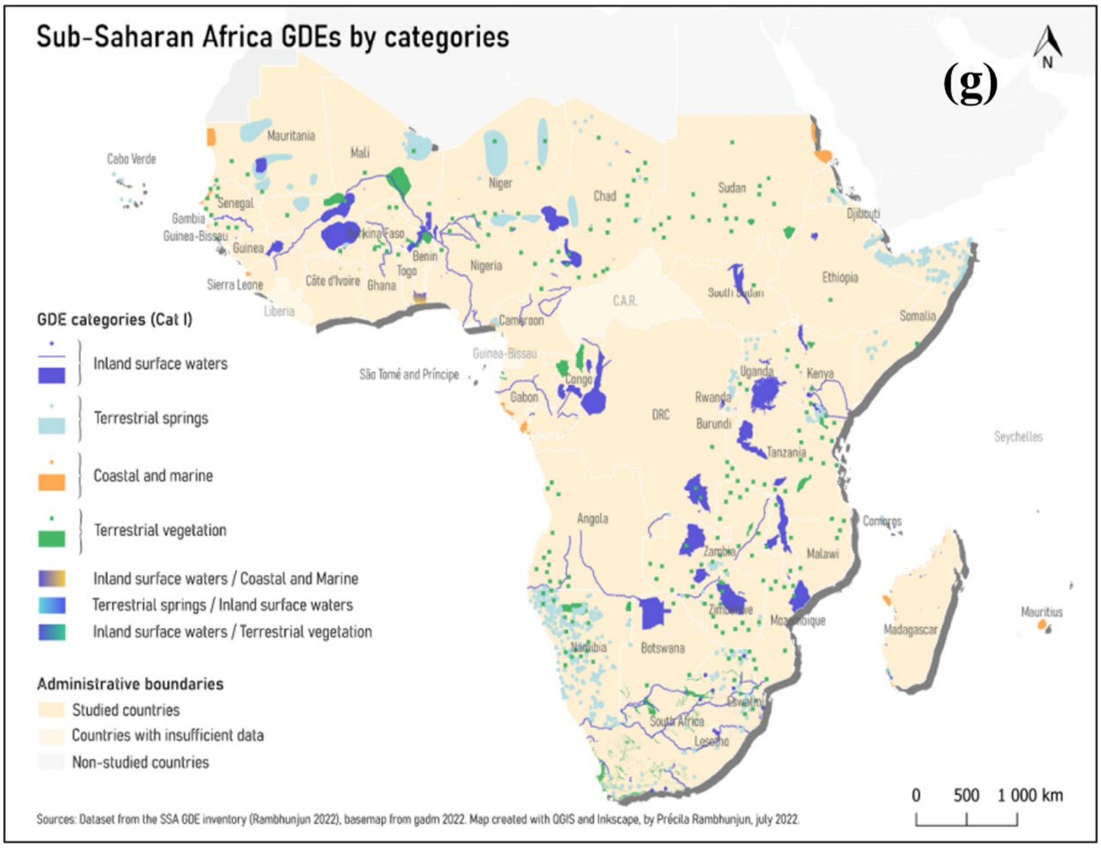


Figure 1 – Input data: the annual average of GHI for 2020 (a), static water level (b), aquifer transmissivity (c), groundwater storage (d), population density (e), renewable groundwater resources (f) and type of GDE across sub-Saharan Africa (g).

3. Methodology

To map the risk posed to GDEs by the uncontrolled access to groundwater through photovoltaic pumping, we use the Analytic Hierarchy Process (AHP). To apply the AHP, we first identify the datasets which have an influence on the identified risk. Then, we normalize these datasets to be able to compare them. Therefore, every dataset is normalized on a scale of 1 to 5 where 1 is the value that would lead to the lowest risk of overexploitation and 5 the value that would lead to the highest one. We then apply a linear regression between these two extremums for the other values. Thereafter, we classify these datasets based on their respective significance in influencing the risk of over-exploitation. Finally, we calculate the weights to be allocated to the datasets. This then allows to compute the risk of overexploitation as a weighted sum of all the datasets.

Identifying the datasets

The aim of this first step is to identify datasets which will have an important impact on the volume pumped by PVWPS which can then result in overexploitation.

1. *Annual average of GHI*: the greater the annual average of the global horizontal irradiance (GHI), the higher the energy generated by the photovoltaic modules, resulting in an increased pumped volume (Meunier et al., 2019) and consequently, a heightened risk of over-exploitation. Therefore, the smallest GHI value is allocated a 1 (leads to the lowest risk of overexploitation) and the largest value a 5 (highest risk).
2. *Renewable groundwater resources*: the less abundant the renewable groundwater resources, the riskier for the aquifer to be overexploited. Therefore, the highest renewable groundwater resources value is allocated a 1 and the lowest value a 5.
3. *Groundwater storage*: the lower the storage, the riskier for the aquifer to run dry. Therefore, the highest groundwater storage value is allocated a 1 and the lowest value a 5.
4. *Population density*: the higher the population density, the higher the water demand (Huang et al., 2018). Thus, in dense areas, if groundwater pumping systems are installed, abstraction from these systems is likely to be high. Therefore, the lowest population density value is allocated a 1 and the highest value a 5.
5. *Static water level*: for a given power, the deeper the static water level, the lower the volume pumped by a water pumping system (Meunier et al., 2019). Thus, the higher the static water level, the lower the risk of overexploitation. Therefore, the highest static water level value is allocated a 1 and the lowest value a 5.

6. *Aquifer transmissivity*: for a given power, the greater the transmissivity, the higher the volume pumped by a water pumping system and thus the risk of overexploitation. Therefore, the lowest transmissivity value is allocated a 1 and the highest value a 5.

Classifying the datasets

The next step of the AHP is to classify the datasets based on their impact on the pumped volume (i.e. abstraction level) and thus on the risk of overexploitation. We choose to consider the annual average of GHI as the most important data as this study focuses on PVWPS and because GHI directly impacts the pumped volume (Meunier, 2019). Then, we consider the renewable groundwater resources as it provides information about the sustainably extractible resource. We consider that storage is coming next as it is the amount of groundwater that is still available in the event of over-abstraction of renewable resources. Then comes the population density as it significantly influences the water demand and thus has a potentially important impact on groundwater abstraction. Subsequently, we consider the static water level because it is directly linked to the resource accessibility. Finally, we consider the transmissivity, which is less directly linked to the pumped volume than the static water level. To assess the robustness of our choices, we compare the outcomes derived from these choices with the results obtained when assigning equal importance to each dataset (see Section 4).

Calculating the weights

Following the AHP approach from (Saaty, 1977) and the classification detailed in the previous paragraph, the chosen pair wise comparison matrix is presented in Table 2. The consistency ratio for this pair wise comparison matrix is 0.027, which is acceptable (Saaty, 1977). The weights for each dataset drawn from this pair wise comparison matrix are summarized in Table 3.

	Annual average of GHI	Renewable groundwater resources	Aquifer storage	Population density	Static water level	Aquifer transmissivity
Annual average of GHI	1	2	3	4	5	6
Renewable groundwater resources	0.5	1	2	3	4	5
Aquifer storage	0.33	0.5	1	2	3	4
Population density	0.25	0.33	0.5	1	2	3
Static water level	0.2	0.25	0.33	0.5	1	2
Aquifer transmissivity	0.16	0.2	0.25	0.33	0.5	1

Table 2 - Pair wise comparison matrix for the risk of overexploitation of groundwater resources.

Dataset	Weight
Annual average of GHI	38 %
Renewable groundwater resources	25 %
Aquifer storage	16 %
Population density	10 %
Static water level	6.5 %
Aquifer transmissivity	4.5 %

Table 3 – Weight matrix for each dataset.

4. Results

The results using the weights of Table 3 are shown in Figure 2(a) and in Table 4. In Table 4, we classified the risk of overexploitation into 4 levels (the lower the level, the less risky). Results indicate that the risk of overexploitation is between 2 and 3 for 6% of the GDEs while 92% of them have a risk between 3 and 4. We see in Figure 2(a) that the major risk of overexploitation occurs in GDEs of western South Africa, Namibia, Kenya, Niger, and Somalia while the minor risk occurs in the GDEs of the Republic of Congo, Gabon and southern Nigeria. This is due to the important difference in terms of annual average of GHI between these areas (see Figure 1(a)). Indeed, the annual average of GHI in western South Africa and Namibia is allocated a 4 while the one in the Republic of Congo and Gabon is allocated ~1.75. This is also attributed to the significant difference in terms of renewable groundwater resources. Indeed, renewable groundwater resources in western South Africa and Namibia are allocated ~5 while the ones in southern Nigeria are allocated a 1.

The results when the datasets are equally weighted are provided in Figure 2(b) and in Table 4. Both columns in Table 4 and the maps of Figure 2 exhibit overall similarities, but we observe some slight differences. On the one hand, it results to be less risky in Southern Africa, northern Somalia, western Sahel and Kenya when all datasets are equally weighted than when the weights from Table 3 are considered. This is due to the average of GHI and the renewable groundwater resources both losing weight when considering the datasets equally weighted and the fact that the average of GHI is high and the renewable groundwater resources are low in these regions (see Figure 1). It can also be attributed to the very low population density in western South Africa and Namibia (see Figure 1), which gains weight when considering the datasets equally weighted. On the other hand, it appears to be riskier in the Republic of Congo when all datasets are equally weighted. Indeed, the renewable groundwater resources which are high and the irradiance which is low (see Figure 1) in this region both lose weight when considering the datasets equally weighted. It can also be related to the low static water level which gains weight when considering the datasets equally weighted.

Risk of overexploitation	Weights of Table 3	Same weight
1-2 (less risky)	0 %	0 %
2-3	6 %	8 %
3-4	92 %	92 %
4-5 (riskier)	2 %	0 %

Table 4 – Percentage of GDEs at the different levels of risk of overexploitation.

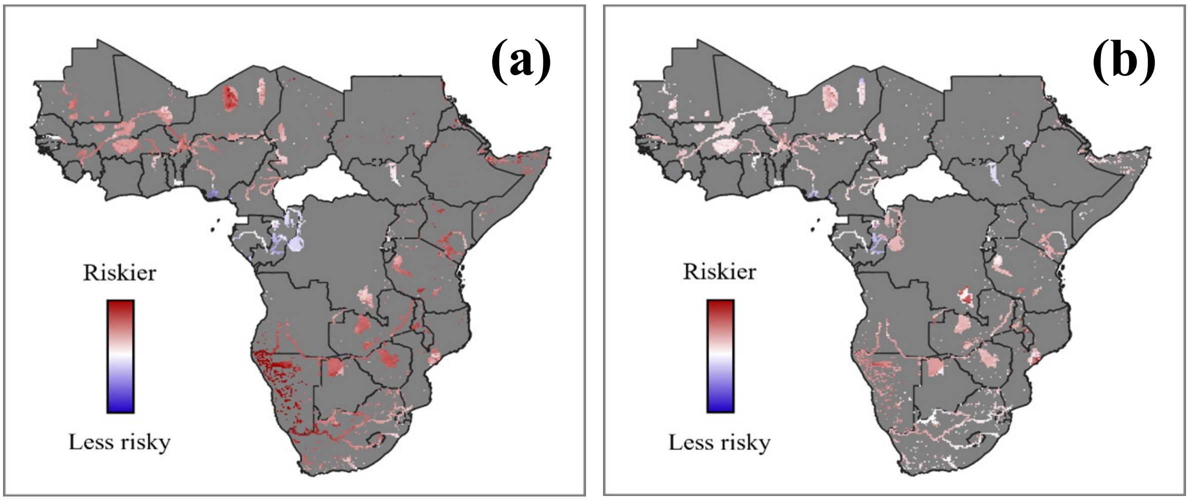


Figure 2 - Risk of overexploitation when considering the weights of Table 3 (a) and when considering the datasets equally weighted (b).

We compare the results of Figure 2 to the socio-economic situation of the different countries, in terms of need to develop groundwater. In Figure 3, we show, in shades of grey, gridded data at the 5x5 km-level on the number of people who rely on an unimproved water source in 2017 in Sub-Saharan Africa (Institute for Health Metrics and Evaluation, 2020), which is used as a proxy for groundwater development need. Indeed, groundwater pumping systems are of particular interest for improving domestic water access (Meunier, 2019; Ozano et al., 2022). We also superimpose the results of Figure 2 to these data. To analyse the results, we distinguish 4 situations:

1. *Higher groundwater development need and lower risk of GDE overexploitation*: this situation notably occurs in southern Nigeria and South Sudan where the risk of overexploitation for GDEs by the uncontrolled access to photovoltaic pumping is one of the lowest while the groundwater development need is high. Therefore, this situation could represent a priority in terms of PVWPS development.
2. *Higher groundwater development need and higher risk of GDE overexploitation*: this situation is observed for instance in Tanzania, Zimbabwe, and the western Sahel. Consequently, even though these regions are very interesting in terms of PVWPS development, they should be closely monitored to ensure the sustainable use of groundwater resources.

3. *Lower groundwater development need and lower risk of GDE overexploitation*: this situation occurs notably in Gabon and the Republic of Congo. Thus, even if the risk of overexploitation for GDEs is lower than in other regions, the development of PVWPS may not be worthwhile from a socio-economic point of view.
4. *Lower groundwater development need and higher risk of GDE overexploitation*: this situation occurs in western South Africa and Namibia. In this case, the development of new PVWPS should be wisely discussed by measuring the costs and the benefits.

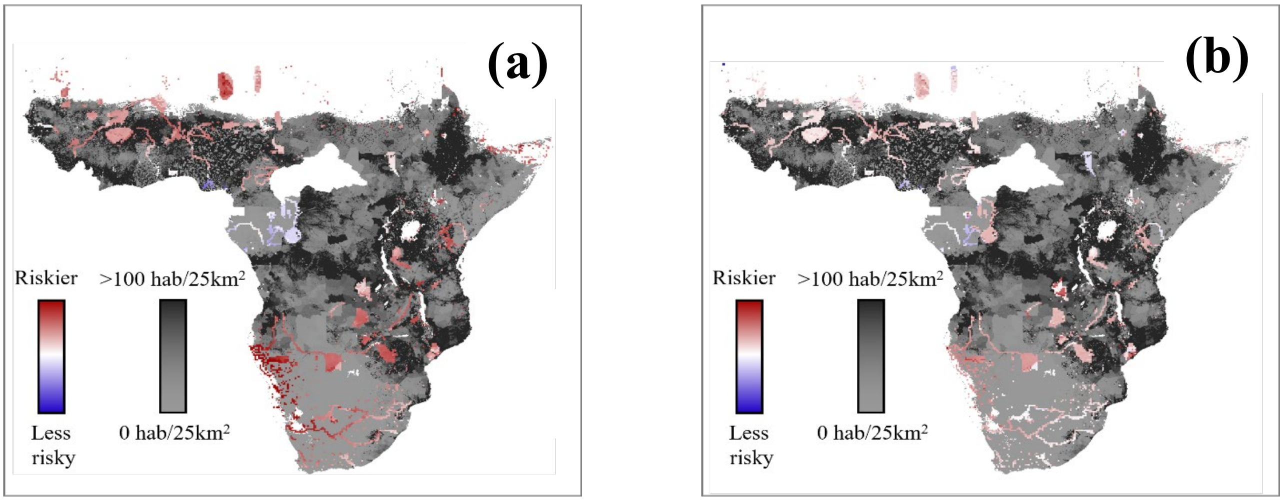


Figure 3 – Comparison between the number of people relying on an unimproved water source and the risk of GDEs overexploitation when using the weights of Table 3 (a) and when the datasets are equally weighted (b).
Note : data on the number of people relying on an unimproved water source are not available for northern sub-Saharan Africa.

In Figure 4, we overlay the results of Figure 2 to the aquifer typology in Sub-Saharan Africa, which provides information about groundwater economic accessibility (Rodella, Zaveri and Bertone, 2023). In Figure 4(a) and (c), we plot mapped results. In Figure 4(b) and (d), we present the distribution of the aquifer typologies depending on the level of risk of GDEs overexploitation. We observe on the results obtained using the weights of Table 3 that 49% of GDEs with a risk of overexploitation between 3 and 4 rely on shallow/local aquifers, which are highly economically accessible (Rodella, Zaveri and Bertone, 2023). Thus, a particular interest should be placed on shallow aquifers when it comes to groundwater resources sustainable management. It is notably the case in Southern and Eastern Africa. We also see that ~24% of these GDEs rely on major alluvial aquifers like in the north of Botswana and in Niger, which are also highly economically accessible aquifers (Rodella, Zaveri and Bertone, 2023). Complex aquifers are more difficult to analyse due to their heterogeneity. Nevertheless, 22% of the GDEs with a risk of overexploitation between 3 and 4 rely on them. Finally, we see that, some GDEs like the ones in eastern Somalia rely on karstic aquifers, which have low economic accessibility (Rodella, Zaveri and Bertone, 2023).

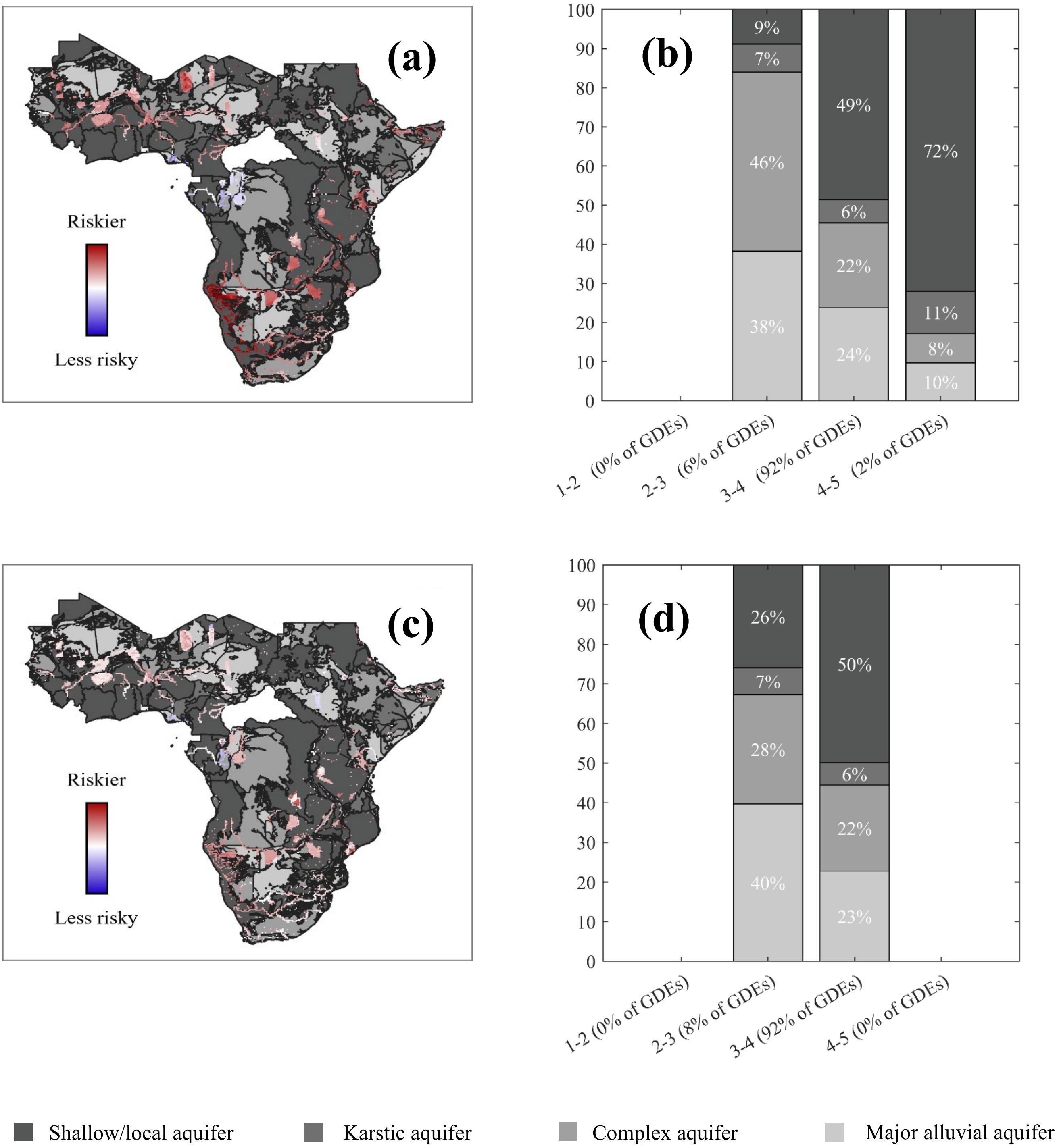


Figure 1 - Overlay of the aquifer typology (Rodella, Zaveri and Bertone, 2023) and the risk of GDEs overexploitation with the weights from Table 3 (a, b) and when the datasets are equally weighted (c, d).

5. Limitations

The first limitation of our study is related to very large-scale analyses (on a whole continent). Irradiance, population density and groundwater input data have been approximated and therefore mask the singularities of the local resources. That is notably why a detailed local investigation and monitoring of groundwater resources is crucial (Taylor and Alley, 2001; Vezin et al., 2020). The second limitation is associated to the AHP approach itself. Indeed, even though we justify our choices, the chosen weights can be questioned. We mitigated this limitation by also providing the results when the datasets are equally weighted, to investigate the impact of the weights on the results. We observed that, even when changing the weights, the results do not change significantly. Finally, this study focuses on the risk for GDEs of excessive volume extraction compared to available resources. In the future, other potential impacts of pumping on GDEs could be studied, such as the impact of significant drawdown during pumping.

6. Policy implications

Irrigation has shaped civilizations across history and continues to present much potential in regions such as Sub-Saharan Africa (SSA), where a small fraction of land is irrigated and even less by groundwater (Rodella, Zaveri and Bertone, 2023). Irrigation can significantly increase production, especially in arid and semi-arid regions (Kukal and Irmak, 2019, Fernández-Cirelli et al., 2009). In the case of SSA, shallow groundwater irrigation has the potential to be game-changing, protecting farmers from weather shocks and helping countries in the region tackle food insecurity (Gowing et al., 2016; Rodella, Zaveri and Bertone, 2023).

With stunting affecting one in four children in the SSA region, the question is not whether to expend groundwater irrigation, knowing that access to shallow groundwater can decrease the chances of childhood stunting by 20% for rural children in this region by protecting agricultural productivity (Rodella, Zaveri and Bertone, 2023), but how to do so sustainably, minimizing unintended consequences (Balasubramanya et al., 2024). Lessons from other regions, such as South Asia and the Middle East, can guide these efforts.

The results presented in our paper provide novel insights into some of those risks as they relate to groundwater-dependent ecosystems. They are threatening GDEs and present three main issues. First, as GDEs are poorly mapped or monitored, their total value and benefits need to be better understood and measured. Yet, with slight variation in groundwater level needed, there is little chance of restoration when they are gone due to their fragile nature, particularly in dryland areas (Rohde et al., 2017). Second, GDEs are important for the livelihoods of populations in rural areas that are typically more vulnerable. An unfettered provision of solar pumping could lead to a deterioration of GDEs on which pastoralists rely for their cattle while also expanding agricultural land to areas previously used for transhumance and grazing, heightening tensions between farmers and pastoralists (Rodella, Zaveri and Bertone, 2023). Third, beyond their importance for wildlife – including for migratory birds – GDEs play an essential role in carbon storage (Mendonça et al. 2017). Countries seeking to reduce their emissions by switching groundwater pumping to solar should consider the carbon impacts of compromising the role GDEs play as a carbon sink.

For those reasons, the results highlight the necessity for policy makers and development partners to collaborate upstream on large-scale solar energy deployment in regions with high irrigation potential, such as SSA, that will facilitate easier and cheaper access to much-needed solar pumping irrigation but require enforceable policy and regulation to protect against unintended consequences, such as the deterioration or destruction of GDEs. Our analysis also highlights the need for more data on GDEs, from their locations to the services they provide to people and the environment to monitor better their health and address situations of poor groundwater management that could threaten their existence. The proper monitoring of GDEs can thus be an efficient strategy to contribute early warning information on the mismanagement of groundwater resources and help prevent or remedy impacts.

7. Conclusion

We proposed an analytical hierarchy process to evaluate the risk posed to groundwater dependent ecosystems (GDEs) by an uncontrolled expansion of access to groundwater through photovoltaic pumping in Sub-Saharan Africa. More specifically, we evaluated the risk of overexploitation of groundwater resources, which could endanger GDEs, and we considered the following input data: global horizontal irradiance, renewable groundwater resources, groundwater storage, population density, static water level and aquifer transmissivity. We found that numerous GDEs in Southern and Eastern Africa have a higher risk of overexploitation, especially in South Africa and Namibia. On the opposite, we found that GDEs in the regions of Gabon, the Republic of Congo and southern Nigeria are less at risk. Additionally, by comparing our results with the number of people relying on an unimproved water source in 2017, we highlighted regions like southern Nigeria and South Sudan that could be prioritized for investments in new photovoltaic water pumping systems (PVWPS) because of the higher groundwater development need and the lower risk posed by photovoltaic pumping to GDEs. On the opposite, in other regions, like in Namibia and South Africa, where the groundwater development need is lower while the risk posed by PVWPS to GDEs is higher, investments should be wisely targeted, and a very close monitoring of groundwater resources will be required.

Despite the limitations (see Section 5), the results of this study are important in highlighting some of the unintended consequences that could result from a scaling up of photovoltaic pumping without the adequate safeguards in place to assess the potential impacts on GDEs. The findings can help policy makers and implementing ministries and agencies integrate in their development planning for the potential areas where the development of PVWPS could be prioritized and where it must be more carefully monitored to ensure a sustainable use of the groundwater resources and a reduced impact on GDEs.

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