

Addressing Sustainability and Equity Challenges in Managing the Environment and Natural Wealth in Sudan

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Abstract

Ensuring sustainability is about protecting the rights of future generations in natural wealth endowments, which include in addition to stocks of resource assets (minerals, land, water, forests, wildlife, etc.), a healthy environment and functional ecosystems. Prudent use of the proceeds from liquidation of natural assets and protection of environmental quality and ecosystems health, are therefore necessary for inter-generational equity. At the same time, consequences of depletion of natural assets and environmental degradation are not equally shared among different regions and social groups, with the least fortunate and more vulnerable bearing the largest burden. Such intra-generational inequities, in turn threaten sustainability. This illustrates how equity and sustainability are interlinked in the dynamics of natural and human systems' interactions. This paper is an attempt to contribute to an improved understanding of how human and natural systems interact in shaping livelihoods and environmental conditions in Sudan. The paper analyzed the natural, institutional, and socioeconomic contexts and policy environments within which the transitional period administration in Sudan is to design its reform strategies and implement programs for prudent environmental management and equitable distribution of the benefits from exploiting the country's natural wealth. Our analysis focused on identifying major challenges to pursuing the goals of inclusive and sustainable development and propose intervention measures necessary to address them.

Keywords: natural wealth, environment, Sudan

JEL Classifications: Q1

ملخص

يتعلق ضمان الاستدامة بحماية حقوق الأجيال القادمة في ثروات الثروة الطبيعية، والتي تشمل بالإضافة إلى مخزون أصول الموارد (المعادن والأراضي والمياه والغابات والحياة البرية، وما إلى ذلك)، بيئة صحية وأنظمة إيكولوجية وظيفية. ولذلك، فإن الاستخدام الحكيم لعائدات تصفية الأصول الطبيعية وحماية جودة البيئة وصحة النظم البيئية، ضروريان لتحقيق العدالة بين الأجيال. في الوقت نفسه، لا يتم تقاسم عواقب استنفاد الأصول الطبيعية والتدهور البيئي بالتساوي بين مختلف المناطق والفئات الاجتماعية، حيث يتحمل الأقل حظًا والأكثر ضعفًا العبء الأكبر. وتهدد أوجه عدم المساواة هذه بين الأجيال الاستدامة بدورها. يوضح هذا كيف ترتبط الإنصاف والاستدامة في ديناميكيات تفاعلات الأنظمة الطبيعية والبشرية. هذه الورقة هي محاولة للمساهمة في تحسين فهم كيفية تفاعل النظم البشرية والطبيعية في تشكيل سبل العيش والظروف البيئية في السودان. حللت الورقة السياقات الطبيعية والمؤسسية والاجتماعية والاقتصادية وبيئات السياسات التي من خلالها تقوم إدارة الفترة الانتقالية في السودان بتصميم استراتيجياتها الإصلاحية وتنفيذ برامج للإدارة البيئية الحكيمة والتوزيع العادل للمنافع من استغلال الثروة الطبيعية للبلاد. ركز تحليلنا على تحديد التحديات الرئيسية لمتابعة أهداف التنمية الشاملة والمستدامة واقتراح تدابير التدخل اللازمة لمعالجتها.

1. Introduction

Over the past three decades the vast majority of Sudan's population, particularly the poor in remote regions and the bulging reserve of unemployed youth, have been denied a fair share in the governance and revenue from exploitation of the country's natural wealth, and in turn opportunities for a prosperous future. This was a major factor behind the spread of civil strife and the 2019 uprising of the Hirak forces of change that overthrew the former authoritarian regime. Reforming the way natural wealth has been exploited to the benefit of the few ruling elites and their patrons and kleptocratic executives is therefore necessary for establishing justice, lasting peace, and sustainable development in Sudan. Addressing sustainability challenges for instance, is central to meeting aspirations of the young generation to a prosperous and healthy future. Equality is at the heart of protecting rights of vulnerable social groups, particularly women and children, endogenous communities, and all the disadvantaged. Instituting inclusive natural resources and environmental governance regimes is also necessary for reaching lasting peace and political stability. Given the intimate interconnections between the environment and all spheres of economic, social and political life, the scope of this paper overlaps with various dimensions of the other papers of the Hirak project.

Ensuring sustainability is about protecting the rights of future generations in natural wealth endowments, which include in addition to stocks of resource assets (minerals, land, water, forests, wildlife, etc.), a healthy environment and functional ecosystems. Prudent use of the proceeds from liquidation of natural assets and protection of environmental quality and ecosystems health, are therefore necessary for *inter-generational equity*. At the same time, consequences of depletion of natural assets and environmental degradation are not equally shared among different regions and social groups, with the least fortunate and more vulnerable bearing the largest burden. Such *intra-generational inequities*, in turn threaten sustainability. This illustrates how equity and sustainability are interlinked in the dynamics of natural and human systems' interactions.

This paper is an attempt to contribute to an improved understanding of how human and natural systems interact in shaping livelihoods and environmental conditions in Sudan. The paper analyzed the natural, institutional, and socioeconomic contexts and policy environments within which the transitional period administration in Sudan is to design its reform strategies and implement programs for prudent environmental management and equitable distribution of the benefits from exploiting the country's natural wealth. Our analysis focused on identifying major challenges to pursuing the goals of inclusive and sustainable development and propose intervention measures necessary to address them.

The next section covers macroeconomic aspects of sustainable development in Sudan. Section three deals with environmental quality protection challenges, while responding to threats of climate change are taken up in section 4. Aspects of sustainable management of key natural ecosystems are discussed in section 5. Section 6 discusses urban environmental management problems and environmental policy and governance issues are covered in section 7. Section 8 concludes with a summary of findings and recommendations.

2. Macroeconomic management for sustainability and inclusive development

In this section, we analyze the extent to which Sudan's macroeconomic management strategies and policy practices are coherent with the rules and principles of sustainability. A key question we investigate is how much of the resource rent is currently reinvested in environmental revival and rebuilding of natural assets and alternative forms of capital. Building on this assessment we then identify areas that call for urgent reforms and intervention measures to improve macroeconomic performance on environmental health goals.

Statistics on the macroeconomic structure of Sudan suggest that the country can be considered among the resource-abundant countries. The rich natural wealth with which the country is endowed is apparent in the shares of revenue from extraction of natural resources (proceeds from oil and minerals) in macroeconomic aggregates (e.g., gross domestic product, exports). Mining generated 15% of national income ranking second to agriculture, which contributed 28% of the country's gross domestic product (GDP) during the 2017 and 2018 years (CBS, 2018). As Table 1 and Figure 1 indicate, Sudan's export earnings come primarily from selling oil and minerals. Even after secession of South Sudan in 2011, when the share in the oil wealth abundance was lost, minerals continue to earn up to half of the country's foreign exchange. Whether proceeds (the resource rent) from liquidation of the country's natural wealth are sustainably managed is the question this section attempts to investigate.

Figure 1: Sudan exports 2000-2019 (us\$ million)-cbs (2018)

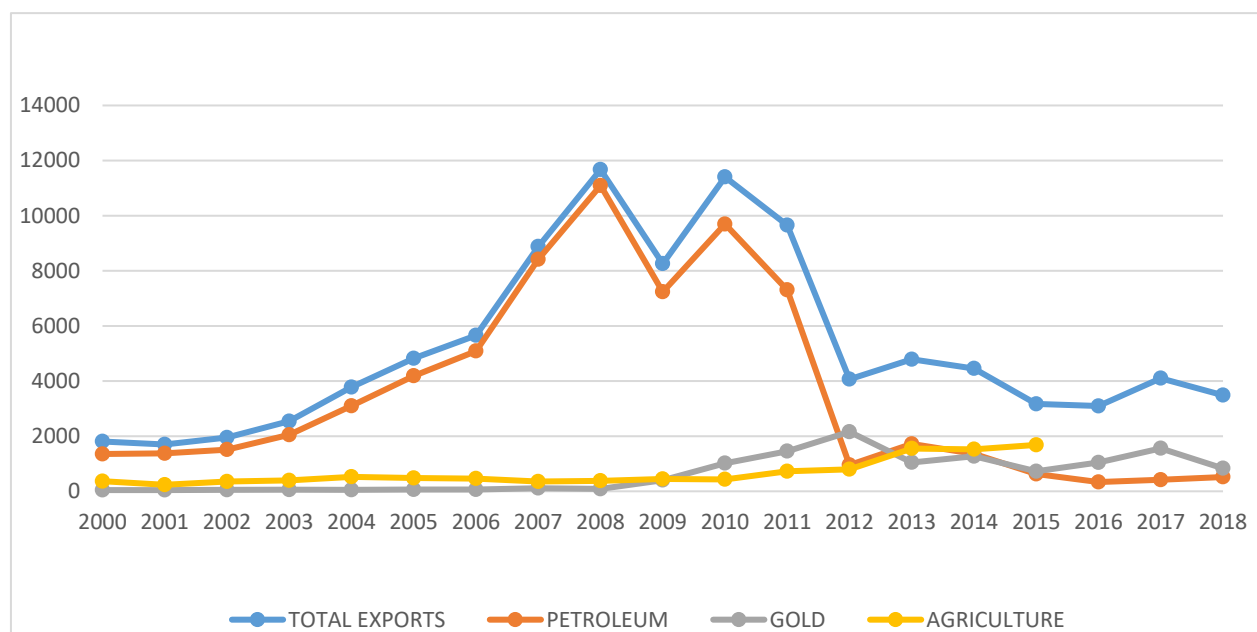


Table 1: Share of minerals in total exports of Sudan 2000-2019 (CBS, 2018)

Years	Petroleum	Gold	Minerals	Agricultural Exports
2000	75%	2%	77%	20%
2001	81%	3%	84%	14%
2002	78%	3%	80%	18%
2003	81%	2%	83%	15%
2004	82%	1%	83%	14%
2005	87%	1%	88%	10%
2006	90%	1%	91%	8%
2007	95%	1%	96%	4%
2008	95%	1%	96%	3%
2009	88%	5%	93%	5%
2010	85%	9%	94%	4%
2011	76%	15%	91%	7%
2012	23%	53%	77%	20%
2013	36%	22%	58%	32%
2014	30%	29%	59%	34%
2015	20%	23%	43%	53%
2016	11%	34%	45%	51%
2017	10%	38%	48%	46%
2018	15%	24%	39%	54%

While reliable information on the shares of royalties and taxes on extraction of natural resources (oil, gold, cement, timber, land, fishery, etc.) in government revenue is lacking, anecdotal indications suggest high dependence on income from liquidation of natural assets for financing budgetary outlays. The bulk of the government spending however, goes to finance current consumption, e.g., salaries, subsidies, purchase of goods, etc. (Table 2). Very little shares of government expenditure are allocated to building alternative forms of capital, such as human assets through investment in education, health, etc.

Table 2: Government of Sudan expenditures: 2016-2019 (MoF&EP, 2020)

	2016	2017	2018	2019
Total expenditure (SDP Billion)	68,146	81,253	155,796	220,758
Health	2%	3%	2%	5%
Education	3%	4%	4%	6%
Environment*	0,05%	0,09%	0,21%	0,47%
Subsidies (fuel, food, medicines)	13%	17%	41%	40%
Grants	22%	18%	15%	12%
Compensation of Employees	34%	37%	21%	27%
Purchase of Goods and services	13%	15%	10%	9%
Other	13%	6%	7%	1%

*Based on total government budget allocations to: Forest National Corporation (FNC), The Ministry of Environment, Higher Council for Environment and Natural Resources (HCENR), National Biosafety Council, and National Council to Combat Desertification (unpublished records of FNC and HCENR).

No information is available in the national income accounts on spending on environmental health and nature conservation. Numbers obtained from secondary sources indicate that the government budgetary allocations to natural resources and environment sectors are negligible (Table 2). In addition to the very low shares in public pending one should also consider the very high cost of

environmental degradation inflicted by the serious pollution externalities of current practices, particularly in the minerals and forest sectors, as will be further elaborated in subsequent sections. One must also note that subsidizing consumption of fossil fuels represents an indirect tax on environmental quality as that promotes socially non-optimal emissions and air pollution levels. In general, fuel and electricity subsidies are not only environmentally harmful, but are also regressive as typically the poor do not own cars or have access to electricity.

The government of the transitional period implemented major economic reforms, most important among them is removal of the high subsidy on fuels. This should correct distortions in the structure of economic incentives to be conducive to lower emissions from energy consumption. It is important however, that adequate shares of the significant budgetary savings resulting from these reforms be directed to improvement of environmental health and building alternative forms of capital to offset depletion of natural assets. Best for integrating environmental objectives in macroeconomic planning is to make fiscal allocations aligned with pursuance of the SDGs.

Genuine savings (GS) is one composite indicator of sustainability promoted by the World Bank (WB) for evaluating the prudence of macroeconomic management practice at country level. The GS measure operationalized the concepts of *Sustainable income (consumption) of Hicks* and the *Hartwick rule* that reflect weak sustainability paradigm principles. Based on the assumption that different forms of capital (produced, natural, human, and social) are substitutable, weak sustainability postulates that a country's total stock of capital (inclusive wealth) can be kept constant over time by offsetting depletion of natural wealth by equivalent investments in building stocks of alternative capital assets (industrial, infrastructure, education, health, science and technology, etc.). This will be necessary to compensate future generations for the income and employment opportunities lost due to liquidation of natural wealth and hence ensures *intergenerational equity*. Low GS imply that revenue from resource extraction is spent on current consumption rather than reinvested in alternative forms of capital, which erodes the basis for sustainability (ensuring the welfare of future generations) (Dasgupta, 2009; WB, 2011; Boos, 2015; Hamilton and Hepburn, 2017; Lange et al., 2018; Labat and Willebald, 2019).

The WB uses the Adjusted Net Savings (ANS) as one key indicator of sustainability (GS). ANS is calculated by subtracting depreciation of produced capital, depletion of natural capital, and the human health damage cost of air pollution from gross national savings, then adding investment in human capital (public expenditures on education). Depletion of natural capital accounts for changes in the value of subsoil assets (fossil fuels and minerals), agricultural land, forests, and terrestrial protected areas (marine-protected areas are currently not included). (Lange et al., 2018). Based on the ANS indicator Sudan was listed among the high dissaving resource-rich and conflict-ridden countries of sub-Saharan Africa, with an average rate of ANS of (-18%) over the 1990-2014 period (Carey et al., 2018). This clearly indicates that the country is on an unsustainable development path as it is excessively drawing down its wealth to finance current consumption at the expense of future development and welfare.

3. Protecting environmental quality

Assimilation of waste is another essential service of natural ecosystems of equal importance to the basic functions of nature as the source of energy and materials for economic activities. The capacity to assimilate waste and remove toxicity from our life is a quality attribute of nature dependent on the state of health and functional integrity of natural ecosystems. Environmental quality is therefore a constituent of natural wealth of significant importance to life on earth. This is why as explained in section 2 above, the cost of air pollution damages to human health is subtracted from gross savings to measure the true change in national wealth (i.e., air pollution reduces welfare, according to the ANS aggregate indicator of sustainability). The same applies to economic losses caused by all environmentally degrading anthropogenic processes. Several human production and consumption activities negatively impact, not only the atmosphere, but also the quality of soils, freshwater and marine resources. Therefore, sustainability indicators need to discount economic welfare by the value of such losses. Many environmental externalities threaten the welfare of the people of Sudan under the current economic order. This section identifies sources of key environmental hazards' risks to human and ecosystems' health, evaluating the current state of their management and reforms needed to ensure sustainability of economic growth. Our analysis focusses on the negative environmental impacts of exploration and production of oil and minerals, and use of chemicals in agriculture.

3.1 Pollution externalities of mining activities

It is clear from preceding analyses of macroeconomic management that the current way Sudan is liquidating its finite mineral wealth is not sustainable. In addition to depriving future generations from their just shares in the proceeds from exploiting mineral assets, we are also transferring environmental quality burdens to future generations. Practices currently followed, particularly in oil and gold mining, are major sources of such harms to the health of the country's ecosystems and its population.

3.1.1 Use of mercury in gold mining

The World Health Organization (WHO) lists mercury among the top ten chemicals that inflict serious damages on human health. Exposure to mercury is corrosive to the skin, eyes and gastrointestinal tract, and can cause major harms to the nervous, digestive, and immune systems, lungs and kidneys if ingested. One of the highest public health concerns is its potential danger to foetuses' brain development, and hence the risk of exposure to mercury of pregnant and childbearing age women². Exposure to mercury, even at low levels, is also linked to learning

² Mercury is a persistent pollutant that remains in the environment for long. Methyl mercury can easily reach the bloodstream, crossing through the normally protective blood-brain barrier to cause serious neurological and behavioral disorders, including

disabilities in children (WHO, 2017). Environmental quality damages of mercury extend to wildlife as it can bio-accumulate in food chain media (especially in fish and seafood) at levels harmful to human health and wildlife (WHO, 2017).

Results of a recent assessment of sources and uses of mercury in Sudan indicate that gold extraction is the main source, contributing 276,030.30 kg Hg per year, which represents more than 80% of all mercury input to society in the country. The highest contributions of gold mining were its share in mercury releases to water (96.5%), followed by releases to the atmosphere (88.1%), and to land (66.9%) (HCENR, 2021a). The reported amount is used in artisanal gold mining, which accounts for 85.8% of all mercury input in the mining sector. Basically, all mercury in artisanal mining is used in what is known as mining markets, where processing of collected soil takes place. Mercury is used by traditional miners to process gold soil in an estimated 44,296 mining wells (small mines dug by artisanal miners), utilizing about 5668 mills and 5398 washing bonds. It is estimated that about two million people are employed in these markets, which are found in 55 localities in 14 out of the 18 states of Sudan (only Gezira, White Nile, Sinnar and East Darfur states are free from artisanal gold mining activities) (HCENR, 2021a). These figures portray the wide geographic spread of mercury contamination risks of artisanal mining and consequent health hazards to which such large numbers of Sudanese people are exposed³.

There is no mercury waste management system in Sudan and all the mercury containing waste is discharged as part of the general waste stream. Only very few artisanal miners use retorts (distributed by the Ministry of Energy and Mining) to recycle mercury (HCENR, 2021a). The HCENR (2021a) study found that a large number of vulnerable members of the population, such as women, children, and old persons are employed in artisanal mining. Results from testing mercury levels in blood and urine samples collected from artisanal miners in Abu Hamad area of the Nile River State indicated very high levels of mercury contamination among miners compared to residents outside the highly contaminated sites (HCENR, 2021a). The said study also reported that mine workers do not use any protective measures and they handle gold extraction process with bare hands and without face or eye protection.

Sudan is party to almost all international and regional instruments and conventions relating to chemicals and hazardous wastes, including mercury and mercury compounds. Several institutional weaknesses and capacity constraints have limited effective implementation of these instruments at the national level. Sudan also became a signatory to The Minamata Convention on Mercury (MCM) on 24 September 2014 and obtained endorsement of the Council of Ministers in April 2021

tremors, insomnia, memory loss, neuromuscular effects, headaches and cognitive and motor dysfunction, as well as kidney failure (WHO, 2017).

³ There are 70 large-scale (organized, licensed) gold mining companies extracting gold from the tailings of artisanal gold mining ore (locally called Karta) spread over 12 states. These companies extract gold by methods other than mercury amalgamation, but their operations release the residual amount of mercury contained in these tailings, which is estimated to be about 8.6% of all mercury input (HCENR, 2021a).

for the ratification of the convention, which is now tabled for final approval by the joint sitting with the Supreme Council⁴. Effective implementation of the MCM however, requires adequate and appropriate national legislative frameworks and policy measures to secure the implementation of these ratified instruments.

In recognition of the important role of small-scale artisanal mining in poverty alleviation, employment, income and wealth creation, and rural development, a new global view is emerging about this sector. The new vision calls for policy reforms to move away from the traditional emphasis on technical interventions to support small-scale miners' entrepreneurial efficiency, to formalizing the sector on basis of its socioeconomic significance for the livelihoods of many millions around the world (WB, 2019). While the strategic choice to be made between reorganizing Sudan's informal mining activities into a formal small-scale artisanal industry or integration into large-scale mining units is beyond the scope of this paper, we draw the attention to the importance of considering the environmental and human health consequences of the chosen reforms. Nevertheless, it is mandatory that environmentally friendly alternatives to mercury be found for the benefit of the large number of people dependent for their livelihoods on artisanal mining.

Key recommendations of the HCENR (2021a) assessment include, in addition to completing the national procedures of ratification of the MCM, capacity strengthening, addressing gaps in legislation and data (especially disaggregation by gender and other social groups at high risk), promotion of inter-agency coordination, introducing environmentally sound system for management of mercury-containing waste; and provision of the needed technical and financial support for research in areas relevant to the implementation of the MCM articles.

Updating the many national and sectoral environmental regulations and policy measures of relevance to be consistent with the provisions of the MCM instrument is the task at hand with high priority, given the significance of the environmental quality risks and public health hazards associated with the use of mercury. Positive signs in this direction include the recent public outrage and pressures from civil society organizations and local community activism calling for urgent action to address mining mercury contamination problems. In response, some state level governments with mining activities, have begun to take measures to deal with adversities associated with the use of mercury in mining.

⁴ The Minamata Convention on Mercury is a global treaty to protect human health and the environment from the anthropogenic emissions and releases of mercury and mercury compounds (UNEP, 2013). The legally binding global instrument was formally adopted and opened for signature in October 2013 in Minamata and Kumamoto, Japan. 128 countries have signed the treaty and 127 have ratified it. Obligations under the Convention include among others, a ban on new mercury mines and the phase-out of existing ones, control measures on emissions to air and on releases to land and water, and the regulation of the informal sector of artisanal and small-scale gold mining. The Convention also addresses interim storage of mercury and its disposal once it becomes waste (UN Environment and Minamata Convention Secretariat, 2021)

3.1.2 Pollution from oil exploration and production

Oil production activities are major sources of water, land and atmospheric pollution. Construction and operations of associated infrastructures (refineries, storage facilities, pipelines, roads, etc.) also cause landscape damages and disturb ecosystems' functions and movements of wildlife and livestock. Impacts of these externalities on human health and other life (plant and animal species) can be significant. Environmental performance in the oil sector is governed by the rules of the special act: *Regulations for Protection of the Environment in the Petroleum Industry (Amendment 2005)* (Ministry of Energy and Mining, 2005). These bylaws require competent authorities to observe and monitor compliance with a number of procedures and measures necessary for protection of the land and water habitats being utilized and avoid environmental pollution. Investor companies are also required to insure against environmental damages and abide by international environmental agreements to which the Sudan is a party. Moreover, Section 43 of the Regulations requires any company undertaking petroleum operations, to establish an Environmental and Occupational Health Unit, with the aim to protect the employees and the environment surrounding and the establishment from the impact of occupational safety and health hazards.

Community and non-governmental organizations' (NGOs) sources however, report several incidences of pollution damages to water points, poisoning of livestock, wildlife and humans around oil production sites. An example of significance is the substantial amounts of highly polluted water (produced water)⁵ disposed of under weak, if any, measures of safe discharge or mitigation of harm. The said water, therefore is a source of high risk to human and ecosystems' health in surrounding areas. Good information on the extent and magnitudes of such impacts (particularly on women) is however, unavailable due to absence of credible formal monitoring systems as oil production sites and operations remain no go areas for the general public and official entities outside the oil industry. In particular, lack of transparency in meeting requirements for undertaking credible environmental and social impact assessment (ESIA) studies and processes may be the main reason behind the prevalence of such undesirable impacts (Hassan, 2020). Find more discussion of issues related to the administration of the ESIA requirements in the later section covering environmental policy and governance.

An important policy failure in protecting environmental quality against pollution hazards common to all extractive industries (mining of minerals and logging of forest resources) is the lack of clear strategies and policy measures for recovery and reinvestment of sufficient shares of the resource rent accruing to these firms in clean ups and restoration of damaged ecosystems.

3.2 Pollution from use of agricultural chemicals and persistent pollutants

⁵ It is estimated that about 600 thousand barrels of produced water are disposed of every single day in the Heglig processing facility alone (Moghraby, 2006; Fanack, 2019).

Use of chemical inputs continue to rise in Sudan, especially with increased agricultural intensification in the irrigated sector. Official statistics indicate that the country used about 5000 tons of pesticide in 2017, 60% of which was imported (Ministry of Agriculture and Forestry, 2018). Over use of chemicals in agriculture (fertilizers, pesticides) is a source of pollution to food and drinking water posing serious public health risks, the levels and extent of which are not well known. Most serious is the fact that, while the use of many of these chemicals containing persistent organic pollutants (POPs) have been banned, some continue to find their way into the country and are still used (HCENR/UNIDO, 2014). One good example of this is the continued importation of Endosulfan through 2016, according to records of the Pesticide Registration Office (HCENR/UNEP, 2020). Potential damages of POPs to human health are serious with very high environmental quality costs.

Information on POPs is regularly updated in the National Implementation Plan (NIP) as required under the Stockholm and Basel conventions on toxic and hazardous waste, ratified by the government of Sudan. The NIP report that uncontrolled domestic solid waste burning contribute more than 80% of total uncontrolled POP in the country (HCENR, 2007). Work on establishing a comprehensive national database on POPs is progressing at the HCENR under funding from the GEF.

Handling and storage of obsolete pesticides represent another major source of pollution risk and associated public health hazards that call for urgent action. A recent inventory by the HCENR found that there are 234 tonnes of obsolete pesticides stored at 341 sites in several states across the country. The same inventory survey reported piles of more than 9000 tons of soils and seed stocks and more than 500 empty containers contaminated with POPs still in storage in various parts of the country (Musa, 2014). Conditions in which the said toxic pollutants and contaminated items are stored are very poor in terms of safety and hence continue to pose a very serious risk to environmental quality and human health.

4. Responding to Climate change

The Fifth Assessment Report (FAR) of the Intergovernmental Panel on Climate Change (IPCC) confirms that global warming presents a real challenge to sustainable development, particularly in the already hot and dry regions of the world. Climate change is already negatively impacting ecosystems, human health and food security in these regions, making it more difficult to reach the goals of poverty eradication, reduction of inequality, and protection of life on earth⁶. Sub-Saharan Africa and southern Asia, where high levels of poverty persist are the most vulnerable to the predicted adversities of global warming. Climate adaptation strategies and actions explicitly

⁶ The FAR states that “*climate change and climate variability worsen existing poverty, exacerbate inequalities, and trigger both new vulnerabilities and some opportunities for individuals and communities*” (Olsson et al., 2014).

address *intra-generational* inequities by targeting the poor and most vulnerable (IPCC, 2014a). On the other hand, mitigation measures focus primarily on *inter-generational equity* (reducing future risks of CC to both, the rich and the poor in the future) (IPCC, 2014b). We present in this section the challenges facing Sudan and progress made and further efforts needed for coping with the impacts of climate change and variability.

4.1 Where and who is vulnerable to climate change risks in Sudan?

Recent records of rising temperatures, changing rainfall patterns, and increased frequency and intensity of extreme weather events such as droughts and flooding are evidence that Sudan is experiencing climate change. Climate scenario analyses conducted under the Initial National Communication – INC (HCENR, 2003) predicted that average temperatures will rise significantly to reach a range of 1.5° to 3.1° C higher during August and up to 2.1° C higher during January. Projections also suggest that by 2060 Sudan will experience sharp deviations in rainfall levels from the baseline scenario, with some models showing a decreasing trend. These manifestations of climate change constitute a serious threat to Sudan’s economy and ecosystems on which the country’s sustainable development and future prosperity depends. Sudan’s ecology indicates that the majority of its land is quite vulnerable to changes in temperature and precipitation.

A rise in average temperatures and drop in annual rainfall is bound to have serious adverse effects on the viability of current agricultural production systems and the efficacy of current water resource management strategies, while at the same time endangering public health. The country already suffers from recurrent droughts, over use of marginal lands, and dominance of biomass use for energy. The most vulnerable to climate change are farmers and pastoralists in the traditional rainfed sector of western, central, and eastern Sudan, and most vulnerable areas are the ones within the River Nile basin and low areas from extreme South to far North, as well as mountain areas along Red Sea (Table 3). For example, floods such as those experienced in 1988, 1998, and 2020 were one of the most damaging flooding events ever recorded (HCENR, 2019). Damages caused by the recent 2020 flood event, which was unprecedented in the long historical records (more 100 years) of the Ministry of Water Resources, by far exceeded any previous damage caused by floods in Sudan, affecting areas that have not been affected by floods in the past (UN-HABITAT, 2020).

Future drought threatens about 19 million hectares of rain-fed mechanized and traditional farms, as well as the livelihoods of many pastoral and nomadic groups (HCENR, 2013a). Pastoral and nomadic groups in the semi-arid areas of Sudan are also similarly affected. Like drought, floods inflict heavy damages to crops, infrastructure, ecosystems, and human lives. Non-climatic factors (poverty; resource mismanagement; excessive cultivation of fragile lands; poor soil fertility; civil conflicts; community displacement, and poor sanitation and health services) also contribute to increased vulnerability, especially in rural areas and local communities (Nimir and Elgizouli, 2008).

4.2 Sudan’s climate adaptation and mitigation policies and measures taken

Responding to the challenges of climate change is a national priority for Sudan. Several climate change-related policies, strategies, projects and programs to effectively cope with climate change challenges and embark onto a low-carbon climate resilient development path have been developed. Most important among those are: the Initial National Communication -INC (HCENR, 2003); Renewable Energy Master Plan - REMP (Ministry of Energy and Mining, 2005); Sudan National Action Programme to Combat Desertification (HCENR, 2006); National Adaptation Program of Action – NAPA (HCENR, 2007); National Clean Development Mechanism Strategy – NCDM (HCENR, 2011); Second National Communication – SNC (HCENR, 2013a); Technology Needs Assessment for Adaptation and Mitigation - TNA-A and TNA-M (HCENR, 2013b); Nationally Appropriate Mitigation Action – NAMA (HCENR, 2015a); National Biodiversity Strategy and Action Plan – NBSAP (HCENR, 2015b); Intended Nationally Determined Contribution – INDC (HCENR, 2015c); National Adaptation Plan – NAP (HCENR, 2016); Sudan First State of Environment and Outlook Report (HCENR/UNEP, 2020); and Mainstreaming of REDD+ in National Development Plans, Policies, Strategies, and Legislation for Sudan (HCENR, 2019), and the National REDD+ strategy (HCENR, 2021d).

Table 3: Extreme weather and climate events in Sudan

<i>Event</i>	<i>Occurrence</i>	<i>Vulnerable areas</i>	<i>Sectors</i>	<i>Impacts</i>
Drought	Frequent	North & Western Sudan (North Kordofan and Darfur), Kassala State and some parts of the rain-fed areas in central Sudan.	Agriculture, livestock, water and health.	Loss of crops and livestock (food shortage), decline in the hydroelectric power, displacement, wildfire
Floods	Frequent	Areas within the River Nile basin and low areas from extreme South to far North. Mountain areas along the Red Sea.	Agriculture, livestock, water and health.	Loss of life, crops, livestock; insects & plant diseases, epidemic/vector diseases, decline in hydro power; damage to infrastructure & settlement areas
Dust storms	Frequent	Central and northern parts of Sudan	Transport (aviation and land traffic)	Air and land traffic accidents and health.
Thunderstorms	Infrequent	Rain-fed areas throughout all Sudan	Aviation	Loss of lives and properties.
Heat waves	Rare	Northern, central parts of Sudan besides the Red Sea State.	Health, agriculture & livestock.	Loss of live, livestock and crops.
Wind-storms	Rare	Central and north central Sudan	Settlements and service infrastructure	Loss in lives, property; damage to infrastructure (electricity and telephone lines)

Source: HCENR (2013a)

The Government of Sudan also signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1993, Kyoto Protocol (KP) in 2005, and Paris Agreement (PA) in 2017. Sudan is an active member at UNFCCC negotiations and contribute to the Intergovernmental Panel on Climate Change (IPCC) meetings and publications. The Higher Council for Environment and Natural Resources (HCENR), being the country’s focal point for the UNFCCC and other international environmental conventions has implemented, with several national partners, many climate change management projects co-funded through significant contributions from various global and regional climate finance mechanisms and protocols. Activities and programs

implemented under the said projects aim at increasing income and improving livelihoods and resilience of communities in vulnerable regions and ecosystems (Elgizouli and Nimir, 2015; HCENR, 2019). Intervention measures identified as successful include

- Micro-fencing to reduce sand encroachment, rangelands reseeding, and village nurseries for rehabilitation of rangelands were the most important practices for increasing resilience
- Promotion of water harvesting to mitigate water stress from temporal and spatial variability of rainfall and the high risks on inter-seasonal dry spells
- Mitigation interventions including REDD+ programme, replacement of diesel water pumps with solar powered pumps, carbon sequestration through afforestation and reforestation
- Establishment of community managed horticultural farms to enhance adaptive capacities and households' incomes and food security
- Introducing drought and heat tolerant varieties of crops and vegetables seeds
- Vaccination of pastoralists herds of livestock against epidemics, as well as provision of supplementary feeding and better adapted animal species
- Shifting from total dependence on biomass energy to Butane gas units for domestic energy to reduce tree cutting for cooking and reducing sand dune movement. This practice also contributed to reducing the burden on women in firewood collection and cooking time

4.3 Constraints and recommended policy actions

Despite the determination and the commitment of the GoS to address climate change issues, there are still important challenges that need to be addressed to effectively steer the development of the country toward a low-carbon climate resilient trajectory. Emphasis on adaptation interventions with little attention to the huge potential Sudan has in climate mitigation opportunities, especially in transition to cleaner energy sources such as solar and wind is one deficiency to address. Lack of reliable climate data, which when available are neither up to date nor statistically robust, and usually relies on extrapolation or interpolation, and limited human and institutional capacity are other important challenges. Lack of mutually reinforcing actions across State and national levels of government, very low private sector investment in climate change adaptation and mitigation, and weak public-private sector partnerships are major constraints to effective institutional coordination.

It has been often noted that Sudan strategic planning is sectorial in nature, led by limited groups of politicians and a few professionals, never based on wide grassroots' consultations. Limited effort has been made to raise awareness of climate risks to food security. Moreover, government institutions are subject to frequent changes resulting in high turnover among key policy decision makers and this has resulted in limited mainstreaming of climate change management policies and measures into national development plans and strategies (Nimir and Elgizouli, 2008).

Several policy reform measures were recommended to address the above identified constraints, which include:

- Devoting bigger attention and resources to exploiting the huge decarbonization potentials, particularly in switching to renewables (solar and wind), and place this at the top of its strategic national development priorities
- Mobilization of stronger political support at the national and State level to mainstreaming climate change adaptation and mitigation into national and state development planning
- Undertaking concerted efforts to reform the enabling institutional, legislative, and policy environments to achieve effective coordination between stakeholders (government, NGOs, private sector) at federal and state levels
- Establishment of a national early warning system, including community-based communication mechanisms to facilitate speedy responses at local levels, and better coordination between producers and users of climate information
- Ensuring active participation and empowerment of communities, particularly women and the disadvantaged in all phases of climate adaptation planning and implementation. This emphasizes the need for improving data generation to provide disaggregated statistics that pay attention to roles and impacts on women and other vulnerable social groups
- Capacity Building of all stakeholders.
- Document and promote indigenous knowledge adaptation practices and encourage exchange of experience between the States
- Strengthen the role of extension and awareness raising on adaption and mitigation and promotion of best practices
- Innovate microcredit and climate risk insurance instruments for small farmers and pastoralists.
- Increase investments in scientific research on climate change adaptation and mitigation
- Incentivize private sector investments in climate change adaptation and mitigation practices through inclusive value chain and market-based approaches
- Forge and strengthen public-private partnership and viable business approaches to enhance climate change adaptation and mitigation strategies.

5. Threats to sustainable management of key natural resource sectors

Major risks threatening the functional integrity of terrestrial and marine ecosystems in Sudan are examined in this section. The efficacy of current strategies and policy practices followed to manage such key natural resource sectors as forests, rangelands, wildlife, wetlands, freshwater, and marine resources are evaluated. Environmental risks and natural resource management challenges for two key sectors are addressed, namely: managing the risks of desertification and land degradation, and conservation of biodiversity in terrestrial and marine ecosystems. Recommendations are provided on policy reforms needed to ensure sustenance and equitable sharing of the flow of the essential services of the said ecosystems.

5.1 Managing the risks of desertification and land degradation in Sudan

Bordered and enmeshed in the Great Sahara Desert, and simultaneously, being dominated by hyper-arid, arid, semi-arid and dry sub-humid ecosystems, Sudan must have experienced desertification and land degradation (DALD) processes for decades. About 64% of the 1.88 million km² total land area of the country is classified as desert and semi desert. The remaining 36% is split between Low and High Rainfall Woodland Savannah, together with Special Areas of Montane Vegetation and Flood Region. As such Sudan is a dry, Low-cover Forest's country exhibiting typical Sahelian zone with its characteristics of low level of rainfall, scarcity of water, and short agricultural season (3-4 month) (IFAD, 2006; Hassan and Tag, 2017; IDDRISSI, 2017).

Historic and contemporary DALD processes that prevailed in Sudan have been extensively studied particularly over the post 1960s period. DALD continues to cause reduction of agricultural, forests, range, and livestock production, and environmental deterioration with adverse consequences for the quality of life. Desertification rates in Sudan have accelerated over the last six decades, leading to marginalization and loss of arable land. The main factors contributing to DALD include drought, population growth, agricultural expansion, deforestation, rapid urbanization, weak economic and social institutions, lack of participatory environmental governance, which led to erosion of local political power and reduced capacity of the local people and ecosystems to cope with the resource degradation problem as one imminent threat to sustainable development in Sudan (FAO, 2018; MoA&F, 2018b; Osman and Sharaf, 2018).

According to the FAO (2015), area under forest dropped from more than 40% in the pre 1950 era to 10.7% of all lands in Sudan by 2017. The estimated 17 million ha of forests are managed under federal, state, institutional (e.g. agricultural / sugar schemes), community, and private ownership regimes. According to the 1986 forest policy, all forests, except the privately owned, fall under the custodianship of the Forest National Corporation (FNC) (Osman and Sharif, 2018).

In spite of the many major policy reforms and institutional intervention measures introduced⁷, DALD continues to loom as one imminent threat to sustainable development in Sudan (Hassan and Taj, 2017; Osman and Sharaf, 2018). Among the most contemporary pressing challenges that need to be addressed to increase resilience to the threats of DALD are:

- Continued dependence on extensive land-based agricultural expansion strategies and the consequent pressures on forested and woody ecosystems
- Encroachment on woodlands from other economic activities, especially recent massive expansions in artisanal mining
- Weak enforcement of existing forest management regulations and bylaws to control illegal logging for timber and charcoal production by traders, the military, etc.
- Forest resources governance regimes that are not conducive to sustainable exploitation and benefit sharing arrangements between local community, state and national level stakeholders

⁷ The most prominent actions taken by the Government of Sudan to address the risks of DALD together with evaluation of their efficacy are highlighted in Sudan National Drought Plan (MoA&F, 2018b).

- Continued high reliance on biomass sources for energy (wood fuel) leading to high levels of deforestation. This is severely exacerbated by the massive influx of refugees from neighbouring countries due to recurrence of regional conflicts, particularly on the eastern, southern, and the western borders in and around key forest and protected areas
- Global warming and its consequent adverse impacts on forest ecosystems
- Low environmental awareness
- A recent ranking of the relative importance of drivers of deforestation and forest/range degradation indicates that agricultural expansion is the major cause of DALD (Hassan and Tag, 2017).

The true value of forests ecosystem services (FES) lost due to DALD is substantially underestimated as a result of focusing only on the use value of a subset of these services (primarily timber). This does not account for the significant direct and indirect benefits of the many other intangible regulating (carbon sequestration, flood regulation, pollination, aesthetic, etc.) and supporting (biological diversity, etc.) services of the forest ecosystem. The consequence of such undervaluation is over harvesting and unsustainable utilization of forest resources.

5.2 Conservation of biological diversity in terrestrial and marine ecosystems

Sudan is endowed with great diversity of plant and animal species in a wide range of ecosystems and environmental regimes. Biodiversity provides the basis for livelihood and sustainable social and economic development; and safeguards ecological safety and food security. Protection and sustainable utilization of this richness face serious threats from natural and anthropogenic pressures. Excessive deforestation, human settlements, overgrazing, poaching and illicit trade in wildlife products (e.g., skin, ivory, meat), uncontrolled fires, poor planning and ill-advised expansions of agricultural, industrial, and mining activities, continue to be the primary drivers of terrestrial biodiversity loss in Sudan (UNEP-HCENR, 2020). In search for grazing pasture, pastoralists trespass their cattle herds into PAs, increasing the pressure on water and grazing resources needed to support wildlife population and inadvertently ushering in diseases common to domestic livestock and wildlife. For lack of alternative sources of livelihoods, local communities who live in and around PAs tend to over-extract accessible resources for energy and timber, wild foods and game meat, excessive grazing and land clearing for crop cultivation.

Marine ecosystems face similar threats from coastal infrastructure development and navigation, pollution from oil spills and sediments, unregulated and unsustainable fishing, mangroves' depletion, and coral bleaching driven by climate change impacts. Biodiversity of inland freshwaters also suffers from over fishing and use of illegal methods, as well as invasion by alien *spp.* (Abdelnour, 2008; HCENR, 2021b).

Sudan is party to the Convention on Biological Diversity (CBD), which calls upon all parties to develop and update a national strategy and action plan (NSAP) for conservation and sustainable use of biological diversity. Accordingly, Sudan developed its first biodiversity NSAP in 2002, and

continues to regularly update and prepare, in a consultative process, the framework for taking actions by the different stakeholders for achieving the three objectives of the CBD, namely conservation of biodiversity, sustainable use of its components, and fair and equitable sharing of benefits arising from their use, and to fulfil the global Biodiversity Vision, of living in harmony with nature.

A system of protected areas (PAs) has been introduced since 1936 by the government of Sudan to conserve its natural habitats and the biodiversity they harbor. After the secession of South Sudan in 2012 Sudan remained with a national network of 13 PAs that covers desert, semi-desert, savannah, marine and coastal, arid region mountains, and riverine ecosystems in only 7 of the 18 states in the country (HCENR, 2021b). Land reserved as PAs in Sudan is under 6% of total land (Table 4), which is less than the Aichi Target of 10%.

In spite of all conservation efforts, the country’s PAs remain poorly managed and experience steady decline in wildlife habitats and populations. A recent survey by Elkhidir and Ali (2018) estimated that about 87% of the wildlife species in Radom, the second largest national park in the country, were lost over the 40 years between 1976 and 2016, mainly due to poaching and human settlements. Reports in media and other sources point to alarming encroachments by extensive artisanal mining and accelerated illegal logging and poaching, as well as commercial cultivation of narcotics in the Radom Park over past few years. Similar trends are observed in other protected areas, such as Dinder, the largest in Sudan (HCENR, 2021b; UNEP-HCENR, 2020).

Table 4: Protected areas in Sudan by type and size

Analysis of Area under Protection	Area	Unit	Percentage of total area
Sudan Total area	1,886,068.00	km2	
Total Protected Areas	112,112.00	km2	5.94%
Terrestrial Protected Areas	109,079.00	km2	5.78%
Marine Protected Areas	3,033.00	km2	0.16%
National Parks	89,019.00	km2	4.72%
Game Reserves and Game Sanctuaries	8,415.00	km2	0.45%

Source: HCENR (2021)

In general, Sudan lacks proper, together with ineffective implementation of PAs management plans. This calls for urgent need to institute the currently under-review PAs management strategy and wildlife policy. Improving the management and conservation of these areas have a huge potential to significantly contribute to sustainable rural economic development and livelihoods. While the time is now opportune for introducing such reforms after the recent peace agreements signed in Juba (RoS, 2020a), major challenges remain in resolving lingering disputes over land rights and equitable sharing of the proceeds from exploitation of local resources (e.g., minerals, oil, timber, water). Successful establishment of democratic and inclusive governance regimes in conflict regions is therefore a prerequisite for conservation of biodiversity and peaceful transition to sustainable management of ecosystems and rural livelihoods in Sudan (Hassan, 2020; UNEP-HCENR, 2020; Anon, 2021).

6. Urban environmental management challenges

Urban centers in Sudan face major challenges to achieving the “*sustainable cities and communities*”, which is target 11 of the UN SDGs. High rates of population growth and rapid urbanization experienced over the past three decades in most regions of the country are responsible for these challenges. Massive influx of population into urban centers places serious pressures on natural ecosystems and transport, housing, energy, clean water and sanitation and many other supply infrastructures for basic services (health, education, security, etc.) (Vardoulakis *et al.*, 2016; Güneralp *et al.*, 2017). This section of the paper focuses on implications of rapid unplanned urbanization for environmental health and sustainable management of urban ecosystems (e.g., planning functional clean and green cities).

6.1 Management of pollution sources

Severe pollution problems threaten urban environmental health in Sudan. The nature and levels of pollution problems, and in turn policy measures required for the control and mitigation of their consequences vary by source and type, as will be explained in the following subsections.

6.1.1 Municipal waste

a. Municipal solid waste

All cities in Sudan suffer from poor solid waste management (SWM) systems leading to serious pollution and human health hazards. Low collection rates (about 30%), negligible recycling (less than 10%), high open burning or dumping on the open or in storm water drains (about 50%), and lack of proper (sanitary) dumping sites’ facilities are common features of SWM (CEA, 2014; HCEURP, 2016; Hamdalla, 2017; Hassan, 2020; HCENR/UNEP, 2020). The existing network of SWM services also excludes large segments of the urban population, especially in crowded low-income suburbs and informal settlements where the urban poor reside (CEA, 2014; HCEURP, 2016). The environmental and human health risks of these inadequate and inefficient SWM services are more serious in management of medical and industrial waste as explained below.

Environmentally unfriendly behavior of the general public, major capacity and institutional weaknesses, negligible investments and low priority in allocation of public funds, poor environmental policy and governance regimes, especially with respect to engagement of local communities and the private sector, are key areas that need urgent attention. Recent research identified a number of intervention options with high potential for improved SWM in the Khartoum

State (CEA, 2014; HCEURP, 2016; Hassan, 2020)⁸, key recommendations of which are summarized below.

- Use pre-generation waste prevention measures (taxes, incentives and regulation instruments, e.g., banning use of plastic bags)
- Introduce segregation of waste at source, particularly at education campuses, office & industrial premises, hospitals, supermarkets, and high-income suburbs
- Integrate informal waste separators (Barkata) in organized formal recycling systems
- Raise public awareness to promote engagement and participation of local communities
- Modernize and raise the efficiency of existing plastic, paper and carton recycling
- Exploit the potential in recycling the currently unutilized large share of organic waste and refuse from crop and livestock agriculture, as well as other types of solid waste (e. g. construction demolitions, electronic waste, used tires and batteries, etc.)
- Introduce necessary reforms to address current institutional weaknesses in agencies mandated to manage solid waste, such as cleaning corporations, municipal authorities, rural councils, and local committees and facilitate effective coordination among them.
- Enforce regulations to prevent discharging waste in illegal sites and open public spaces
- Regulate discharge of construction and demolition debris
- Exploit the high waste to energy potential for health and climate mitigation benefits
- Create opportunities for employment of the youth and women in various phases of the waste value chain employing innovative business models (e.g., cooperatives and other SMEs) supported by provision of skills development and concessional credit

b. Hazardous waste

The poor state of management of hazardous medical waste continues to pose major health risks to residents of all cities in Sudan. Toxic constituents of medical waste are rarely disposed of separately and much of it ends up in general landfills, exposing particularly landfill scavengers (Barkata) to serious health hazards. The vast majority of hospitals lack onsite waste incineration capacities (Ahmed et al., 2014; CEA, 2014; Hassan et al., 2018). The COVID-19 pandemic has aggravated the health risks of medical waste calling for urgent attention to enforcement of regulations and policies for the safe discharge of medical waste, particularly collection, segregation and treatment of toxic and infectious waste.

⁸ Khartoum is one of the seven megacities (over 10 million people) of Africa (Cairo, Kinshasa, Lagos, Accra, Johannesburg–Pretoria, , and Nairobi) (Güneralp *et al.*, 2017).

Hazardous waste from urban-based industrial processes (tanneries; textiles, chemicals, and steel industries; etc.) and services (restaurants, slaughterhouses/abattoirs, etc.) is routinely discharged directly (without treatment) into river channels and municipal wastewater networks (HCENR, 2007; CEA 2014; HCENR/UNEP, 2020). The weak legislative and institutional arrangements that prevail in managing hazardous waste call for urgent reforms.

c. Liquid waste (sewage)

In addition to hazardous waste discharges from municipals and industrial activities, lack of hygienic sewage disposal networks is a major source of pollution of soil and water ecosystems that pose high risks to environmental quality and human health. Only 0.8% of the population of Sudan have access to a sewerage network service, which covers only 2.8% of the GKC population (MoH, 2016). In almost all urban areas in Sudan faecal material is typically disposed of through on-site pit latrines or septic tank. Evidence exists that seepage from these faecal storage systems is a major source of contamination of groundwater sources (NBCBN, 2010; MoH, 2016, Banaga, 2016). Also, these faecal storage systems are regularly emptied by suction tankers, which deliver to wastewater plants or illegally discharge contents on to some remote open land sites. Sewage delivered to wastewater treatment plants receive partial treatment then discharged into open drains and often directly into river courses (HCENR, 2020). Serious microbial contamination and adverse environmental and human health impacts of the said urban sewage disposal systems have been documented, especially in the GKC (Abdel-Magid et al., 2014; MoH, 2016; Abdelmoneim et al., 2017; HCENR, 2020).

Clearly current sewage waste treatment and disposal in urban Sudan lacks sound pollutants' monitoring and control regulations and proper institutional mechanisms. Measures to reform existing systems and correct for their deficiencies have been proposed in the Sudan National Sanitation and Hygiene Strategic Framework (SNSHSF), which spanned rural and urban situations across the whole country (MoH, 2016). Other useful recommendations for rehabilitation of existing sewerage networks are provided by Banaga (2016), including decentralization and recycling of treated effluents. Recommendations of recent reports (NAC, 2019; HCENR, 2020) on the Khartoum State Sanitary Corporation (KSSC) performance emphasize completion of a master plan and enforcement of compliance with sanitation bylaws through regular monitoring and inspection and competent lab testing facilities.

To realize the substantial gains from investment in sanitation (more than double the costs), Sudan needs to make every effort to realize its pledge in the Khartoum Declaration (2009), to allocate 0.05% of its GDP for sanitation and hygiene (MoH, 2016).

6.1.2 Atmospheric pollution

Sudan's Greenhouse gasses (GHGs) inventory indicates that the energy sector is the second largest source of atmospheric pollution, contributing about 11% of all GHGs emissions in 2015 (HCENR,

2021c). As the bulk of Sudan's population (38% in 2020) and industrial and services sectors' activities concentrate in cities, urban centers are the major consumer of all sources of energy (fossil fuels, electricity, biomass). Consequently, atmospheric pollution in cities is very high. Clearly investing in increasing the share of non-biomass renewable energy sources, particularly from exploiting the high potential of the country's rich solar and wind energy resources should be central to Sudan's climate mitigation and sustainable development strategies.

Road transport contributed the biggest share (41%) of all energy emissions in 2015 (HCENR, 2021c), and hence it is a major source of air pollution in urban Sudan. Switching from road to river modes of public transport in the Greater Khartoum City (GKC) presents an opportunity for significant potential environmental and socioeconomic co-benefits. One major advantage among many others of such a switch to river transport is the fact that the GKC is endowed with a natural infrastructure of the three rivers' system (the Blue, White, and River Nile) within close proximity to the banks of which the vast majority of residential, industrial, and business centres are established, i.e., no need for a railway or roads' infrastructures to build. In addition to the potential significant gains in reduced emissions from burning fossil fuels, the river transport system brings several social and economic co-benefits, including lucrative tourism opportunities.

Current SWM practices represent another major source of urban air pollution contributing 1.4% of all GHGs emissions in 2015 (HCENR, 2021c). This estimate accounts for emissions from open dumping, burning, and incineration stages of the waste supply chain. Recent studies suggest that about half of solid waste is burned by roadside and open dumps in Khartoum and other cities (Hassan, 2020; HCENR, 2020). Reduction of emissions from this source is directly linked to achieving sustainable SWM discussed above.

6.2 Resilience to weather extremes and natural disasters

Although vulnerabilities of Sudan to natural disasters and the hazards of climate change have been addressed in earlier sections, we give special attention in this section to the high flooding risks to which residents of riparian urban centres, particularly in the GKC are exposed. Flash and river flooding inflict serious damages to urban infrastructures (houses, roads, schools, etc.), cause major disruptions to mobility, and severely impacts the health status and livelihoods of millions in urban and peri-urban settlements. Records indicate that the frequency and intensity of flood events have risen over the recent past as devastations caused by the 2018 and 2020 floods demonstrate (GOS, 2013 and 2014; GoS, 2021).

Rapid urbanization coupled with poor and often absent urban planning are to blame for aggravating the consequences of flooding for urban life. A typical feature of expansion of megacities in Africa is the proliferation of unplanned informal settlements and unregulated slums. Such peripheral residential zones represent the refuge for the influx of millions of migrants and internally displaced people-IDPs (Güneralp *et al.*, 2017). The vast majority of these in-migrants are accommodated in locations prone to flooding. Instead of relocating these residents out of flood plains with smart

sustainable city planning, most are in fact given formal status and change over time from temporary informal settlements to crowded unorganized formal segments of cities with very poor if any provisions of basic services (e.g. clean water and sanitation, transport, security, education and medical facilities, etc.). Naturally such neighbourhoods are where the disadvantaged and the poorest of urbanites concentrate. A number of the big cities in the country, especially the GKC are typical examples of this pattern of poor urban settlement planning (Pantiliano et al, 2011; UN-HABITAT, 2020; GoS, 2021).

The National Civil Defence Authority is mandated with the role of addressing the problem of lack of coordination between various national and international agencies in planning and actions to manage flooding. The focus of Sudan's efforts however, remains on short-term reactive coping response measures, primarily improving the technical and institutional capacities to forecast and prepare for flooding events. While some sound long-term strategic interventions such as construction of physical infrastructures to dam flood waters upstream to reduce floods and provide water in the dry season have been proposed (UN-HABITAT, 2020; Elhaj and Eljack, 2016), relocation of the millions who bear the brunt of flood damages out of current flood prone areas continue to receive little attention and low priority in allocation and investment of public funds. An integrated watershed management approach is required to manage urban floods in Sudan (Elhaj and Eljack, 2016; UN-HABITAT, 2020; GoS, 2021).

6.3 Provision of green public spaces in urban centers

Greening cities through tree planting, sufficient public spaces and urban parks for cultural, recreational, and physical fitness (walking, cycling, etc.) activities, have become an integral element of sustainable urban living quality and ecosystems' health (Vardoulakis et al. 2016). Apart from few exceptions, most urban centres in Sudan call for significant efforts in this regard, particularly where the urban poor reside. Experiences in various parts of the world (including some of our own home-grown examples) highlight the key role of local community organizations and NGOs, particularly youth and women-led, in supporting successful smart city planning and introduction and maintenance of green urban infrastructures (Vardoulakis et al. 2016).

Development of recreational spaces and allowing the public access to the generous natural spread of river banks all around the GKC is one potential improvement on the road of making the capital city Khartoum an environment friendly city. Similar opportunities are plenty in many other towns and cities, particularly along the banks of the several rivers and streams running throughout the country.

7. Environmental governance challenges to the democratic transition regimes in Sudan

The way rights of access to and use of natural resources are governed is central to the success of Sudan's efforts to achieve sustainable and inclusive development and establish lasting peace.

Reforming existing environmental governance regimes is therefore necessary for equitable sharing of the fruits of exploiting natural wealth among current and future generations. It will be difficult however, to provide comprehensive coverage of the full scope of environmental and natural resource governance issues in this paper. Accordingly, our discussions in this section focus on key governance challenges we consider to be at the top of the transitional period priority agenda.

Resolving disputes over land rights, particularly for the millions displaced from their homelands as a result of armed conflicts in their regions, is among the biggest governance challenges facing the peace process in Sudan. Given the fact that the said conflicts were fueled primarily by struggles over the control of resources, reaching agreements on cessation of hostilities and political power-sharing arrangements alone will not be sufficient for sustenance of peace. While wealth-sharing and establishment of land commissions, among other provisions, have been included in the Juba Agreement for Peace in Sudan (RoS, 2020a), big difficulties remain to be ironed out in working through the implementation details of such complex governance arrangements, especially for land (UNEP, 2012; Hassan, 2020; UNEP/HCCNR, 2020; RoS, 2020a). Of special importance is the need for a critical review of land tenure laws, development strategies, and investment policies that incentivize expansions in large-scale agriculture and mining. Evidence has been mounting that the said land lease concessions are posing serious threats to the livelihoods of communities dependent on the functional integrity of competing land uses such as rangeland and forest ecosystems (Umbadda, 2014; Calkins and Ille, 2014; Sulieman, 2015; Elhadary and Abdelatti, 2016; El Amin, 2016).

One of the main deficiencies of the new Law of Decentralized Governance of the year 2020 (RoS, 2020c) is the focus on regulating the sharing of direct benefits from exploitation of natural wealth, such as revenues from extraction of oil, minerals, timber, land, and water. This does not consider the value of the many indirect and intangible benefits lost due to excessive and sub-optimal exploitation of these resources. Increasing the supply of these direct benefits comes at the expense of reducing provisions of indirect ecosystems services critical for sustenance of life on earth, such as nutrient cycling, climate and disease regulation, pollination, genetic diversity, protection against flooding, soil erosion and natural hazards (MEA, 2003). For example, while the agreements and legislations referred to guarantee fair sharing of the revenue from oil and gold extraction, they pay little if any attention to protecting environmental and human health against pollution damages caused by the activities of such extractive industries. Even in cases where the social responsibility principle is observed by some of the extractive industries' firms, most of the funds availed are misappropriated by the local government or community leadership elites. As a result, little of the appropriated resource rents end up reinvested in environmental rehabilitation and all damages done to the environment continue to threaten human health and other life in affected areas.

Another key attribute of the services of natural ecosystems is the fact that in addition to the immediate benefits they supply at the local level (e.g., timber, food, flood protection, etc.), they also provide significant public goods' benefits that have long-term regional and global reaches (e.g., climate, water flow, and disease regulation; biodiversity conservation; nutrient cycling; etc.).

Current legislation (e.g., The Law of Decentralized Governance of the year 2020, Mineral Resources and Mining Development Law of the year 2015) however, does not fully recognize the rights of stakeholders beyond local territories (e.g., outside a given state administrative boundaries) and time horizons (future generations) to such transregional flows of the services of these ecosystems. Whether land, forest, and protected areas, should be considered national or state resources, to be governed by federal or state level regulations, are good examples of sources of potential institutional policy failures to be addressed.

Disregarding or under-valuation of the said indirect and long-term (delayed) environmental costs and benefits is responsible for the irrational individual and social choices causing the serious environmental degradation problems currently experienced in several parts of the country. As indicated in preceding sections of this paper, excessive and illegal logging and hunting, ill-planned horizontal expansion of cultivation agriculture and other land uses, including un-regulated mining, coupled with weak enforcement of environmental regulations are behind the desertification and land degradation; erosion of forest and grazing resources; loss of biodiversity; water, air, and land pollution problems of Sudan. The environmental and social impact assessment (ESIA) requirements stipulated in Sudan's Environment Protection Law of 2001 Amendments of the year 2020 (RoS, 2020d), represent an important instrument for addressing the above enumerated environmental management challenges. Unfortunately, several institutional weaknesses, lack of coordination among concerned arms of the executive systems at the federal and state levels, among other constraints result in major failures in enforcement of and compliance with the ESIA procedures. An unfortunate serious legislative omission to be urgently corrected is not including satisfaction of ESIA standards and protocols among the basic requirements for licensing economic investment activities in the newly approved investment encouragement law of 2021 (RoS, 2021).

8. Conclusions and implications for policy reform

This paper identified the major challenges to pursuing the goals of inclusive and sustainable development and proposed intervention measures necessary to address them at macro and resource sectors' levels. Our analysis indicate that Sudan is excessively drawing down its natural wealth at an average genuine savings rate of -18%, to finance current consumption at the expense of future development and welfare. By wasting the revenue from liquidation of its exhaustible natural assets on current consumption with negligible investments in environmental conservation and building alternative forms of capital (e.g., manufactured and human), the country is clearly on an unsustainable development path. In addition to depriving future generations from their just shares in the proceeds from exploiting mineral assets, current practices, particularly in oil and gold mining, are sources of serious harms to the health of the country's ecosystems and its population. The widespread careless use of mercury in artisanal mining tops the list of current environmental pollution threats in Sudan. An important policy failure in protecting environmental quality against pollution hazards common to all extractive industries (mining of minerals and logging of forest resources) is the lack of clear strategies and policy measures for recovery and reinvestment of

sufficient shares of the resource rent accruing to these firms in clean ups and restoration of damaged ecosystems.

One key recommendation of the study is completing the national procedures of ratification of the Minamata Convention on Mercury, and updating the many national and sectoral environmental regulations and policy measures of relevance to be consistent with the provisions of the convention. It is necessary however, that environmentally friendly alternatives to mercury be found for the benefit of the large number of people dependent for their livelihoods on artisanal mining. Handling and storage of obsolete pesticides represent another major source of pollution risk and associated public health hazards that call for urgent action.

Severe pollution problems also threaten urban environmental health in Sudan. All cities in Sudan suffer from poor solid waste management (SWM) systems leading to serious pollution and human health hazards. Toxic constituents of medical waste are rarely disposed of separately and much of it ends up in general landfills, exposing particularly landfill scavengers (Barkata) to serious health hazards. The vast majority of hospitals lack onsite waste incineration capacities. Hazardous waste from urban-based industrial processes and services is routinely discharged directly (without treatment) into river channels and municipal wastewater networks. In addition to hazardous discharges from municipals and industrial activities, lack of hygienic sewage disposal networks is a major source of pollution of soil and water ecosystems that pose high risks to environmental quality and human health. Only 0.8% of the population of Sudan have access to a sewerage network service, which covers only 2.8% of the GKC population.

Efforts in raising awareness levels to change the environmentally unfriendly behavior of the general public and address the institutional weaknesses in agencies mandated to manage urban waste (cleaning corporations, municipal authorities, etc.) to facilitate effective coordination among them are urgently needed to minimize/eliminate the adversities of urban pollution. Significant opportunities exist for private and public sectors' investments in waste segregation and recycling to exploit the high waste to energy potential. This should also create gainful employment opportunities and enhance the potential roles of youth and women-led establishments in sustainable urban environmental management, particularly in various phases of the waste value chain. To realize the substantial gains from investment in sanitation (more than double the costs), Sudan needs to make every effort to realize its pledge in the Khartoum Declaration (2009), to allocate 0.05% of its GDP for sanitation and hygiene (MoH, 2016). Exploiting the plenty opportunities for development of recreational spaces and allowing the public access to the generous natural open spaces and spread of river banks in the GKC and many other towns are needed for promoting sustainable urban living quality and ecosystems' health across the country.

Sudan is highly vulnerable to the predicted adversities of global warming. The country already suffers from recurrent droughts threatening the livelihoods of millions in the semi-arid areas. Like drought, floods inflict heavy damages to crops, infrastructure, ecosystems, and human lives. A number of the big cities in the country, especially the GKC are typical examples of poor urban settlement planning characterized by proliferation of unplanned informal settlements and unregulated slums. Such peripheral residential areas are usually in locations prone to flooding and

are where the poorest of urbanites concentrate. Instead of relocating the millions who bear the brunt of flood damages out of current flood prone areas, Sudan's efforts in managing climate disaster risks remain focused on short-term reactive coping response measures. An integrated watershed management approach is required to manage urban floods in Sudan.

The fact that about 64% of the land in Sudan is classified as desert and semi desert (i.e., dry and low forest cover) is a major factor behind the country's high vulnerability to climate change. The country however, continues to experience accelerated rates of desertification as a result of adverse human actions. Excessive deforestation, human settlements, overgrazing, poor planning and ill-advised expansions of mechanised agriculture are the main contributors to deforestation and environmental degradation with serious negative impacts on livelihoods. The said interventions coupled with drought episodes, poaching and illicit trade in wildlife products, uncontrolled fires, environmentally insensitive expansions of mining activities into protected areas, are the primary drivers of terrestrial biodiversity loss in Sudan. Marine ecosystems face similar threats from coastal infrastructure development and navigation, pollution from oil spills and sediments, unregulated and unsustainable fishing, mangroves' depletion, and coral bleaching driven by climate change impacts. Biodiversity of inland freshwaters also suffers from over fishing and use of illegal methods, as well as invasion by alien spp. Improving the management and conservation of protected areas have a huge potential to significantly contribute to sustainable rural economic development and livelihoods. This calls for urgent need to institute the currently under-review PAs management strategy and wildlife policy.

Sudan's GHGs inventory indicates that the energy sector is the second largest source of atmospheric pollution, contributing about 11% of all GHGs emissions in 2015. Road transport contributed the biggest share (41%) of all energy emissions in 2015. Switching from road to river modes of public transport in the GKC presents an opportunity for significant potential environmental and socioeconomic co-benefits (reduced fossil fuels' emissions, a natural infrastructure-no need for a railway or roads' infrastructures, lucrative tourism opportunities). Removal of the high subsidy on fuels should correct distortions in the structure of economic incentives to be conducive to lower emissions from energy consumption. It is important however, that adequate shares of the significant budgetary savings resulting from these reforms be directed to improvement of environmental health and building alternative forms of capital to offset depletion of natural assets. Best for integrating environmental objectives in macroeconomic planning is to make fiscal allocations aligned with pursuance of the SDGs.

Despite the determination and the commitment of the GoS to address climate change issues, there are still important challenges that need to be addressed to effectively steer the development of the country toward a low-carbon climate resilient trajectory. Most important is mainstreaming climate change adaptation and mitigation into national and state development planning and support higher investments in climate science and its applications. Sudan also needs to introduce appropriate economic policy incentives to promote exploitation of its huge decarbonization potentials, particularly in switching to renewables (solar and wind), and make this a strategic development

priority. Innovative microcredit and climate risk insurance instruments are necessary for increasing the climate resilience of small farmers and pastoralists.

Reforming existing environmental governance regimes is necessary for equitable sharing of the fruits of exploiting natural wealth among current and future generations. One of the biggest governance challenges facing the peace process in Sudan is resolving disputes over land rights, particularly for the millions displaced from their homelands as a result of armed conflicts in their regions. Current investment policies that incentivize expansions in large-scale agriculture and mining through land lease concessions that disadvantage local communities need to be critical reviewed. Similarly, the new Law of Decentralized Governance which limits the focus to sharing of only direct benefits from extraction of natural resources (oil, minerals, timber, land, and water) requires revision. Increasing the supply of these direct benefits comes at the expense of reducing provisions of indirect ecosystems services critical for sustenance of life on earth, and does not compensate for pollution damages caused by such extractive industries.

Current environmental legislation also does not fully recognize transregional and intergenerational flows of the services of critical ecosystems such forests. Whether land, forest, and protected areas, should be considered national or state resources, to be governed by federal or state level regulations, are good examples of sources of potential institutional policy failures to be addressed. Environmental and social impact assessment requirements represent an important instrument for addressing most of the above enumerated environmental management challenges. Unfortunately, several institutional weaknesses, lack of coordination among concerned arms of the executive systems at the federal and state levels, among other constraints result in major failures in enforcement of and compliance with the ESIA procedures. An unfortunate serious legislative omission to be urgently corrected is not including satisfaction of ESIA standards and protocols among the basic requirements for licensing economic investment activities in the newly approved investment encouragement law of 2021.

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