OPEN ACCESS

African Journal of Environmental Science and Technology

September 2022
ISSN 1996-0786
DOI: 10.5897/AJEST
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

About AJEST

African Journal of Environmental Science and Technology (AJEST) provides rapid publication (monthly) of articles in all areas of the subject such as Biocidal activity of selected plant powders, evaluation of biomass gasifier, green energy, Food technology etc. The Journal welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. Papers will be published shortly after acceptance. All articles are peer-reviewed

Indexing

The African Journal of Environmental Science and Technology is indexed in:
CAB Abstracts, CABI's Global Health Database, Chemical Abstracts (CAS Source Index), China National Knowledge Infrastructure (CNKI), Dimensions Database, Google Scholar, Matrix of Information for The Analysis of Journals (MIAR), Microsoft Academic

AJEST has an h5-index of 14 on Google Scholar Metrics

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Environmental Science and Technology is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Article License

Self-Archiving Policy

The African Journal of Environmental Science and Technology is a RoMEO green journal. This permits authors to archive any version of their article they find most suitable, including the published version on their institutional repository and any other suitable website.

Please see http://www.sherpa.ac.uk/romeo/search.php?issn=1684-5315

Digital Archiving Policy

The African Journal of Environmental Science and Technology is committed to the long-term preservation of its content. All articles published by the journal are preserved by Portico. In addition, the journal encourages authors to archive the published version of their articles on their institutional repositories and as well as other appropriate websites.

https://www.portico.org/publishers/ajournals/

Metadata Harvesting

The African Journal of Environmental Science and Technology encourages metadata harvesting of all its content. The journal fully supports and implement the OAI version 2.0, which comes in a standard XML format. See Harvesting Parameter

Memberships and Standards

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

Academic Journals is a member of the International Digital Publishing Forum (IDPF). The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajest@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJEST

Submit manuscript online http://ms.academicjournals.org

Academic Journals
73023 Victoria Island, Lagos, Nigeria
ICEA Building, 17th Floor,
Kenyatta Avenue, Nairobi, Kenya.

Table of Content

Vol. 16(9), pp. 320-334, September 2022
DOI: 10.5897/AJEST2020.2924
Article Number: 60B2AA169641
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Contaminated land management policy transfer: Drivers and barriers within the Nigerian context

Kabari Sam[1,2]

[1]Faculty of Science and Health, School of Environment, Geography & Geosciences, University of Portsmouth, PO1 3QL, UK.
[2]Department of Marine Environment and Pollution Control, Faculty of Marine Environmental Management, Nigeria. Maritime University, Okerenkoko, Delta State, Nigeria.

Received 22 September, 2020; Accepted 7 January, 2021

Barriers to successful transfer of contaminated land management policy from one country to another include socio-cultural, economic and environmental differences. While weak contaminated land management regimes desire effective legislation and make efforts to transfer policies from established regimes, contextual differences or characteristics between the two countries involved is a key challenge. These differing characteristics include social values, economic strength, governance structure, and technical know-how. An investigation was conducted through workshop and interviews to determine core social values that are impacted due to contaminated land by oil spills in the Niger Delta region of Nigeria. Workshop was undertaken for participants involving community groups (N=35), while interviews involved contaminated land management regulator (N=8), experts in contaminated land management in the Niger Delta (N=6), and operators in the oil exploration industry (N=7). Water quality, soil quality for agriculture, farming and fishing, and health/wellbeing indicated core social values that influence contaminated land management decisions while stakeholders expressed long-term concern about economic losses, clean-up, environmental degradation and public engagement. It is proposed that policymakers should consider unique conditions and country-specific characteristics in the event of policy adaptation for contaminated land management. An alternative approach to improving contaminated land management is recommended that will account for core social values and accommodate varying perceptions of stakeholders.

Key words: Socio-economic values, stakeholder participation, livelihood, drinking water, oil spills, stakeholders' perception.

INTRODUCTION

Large scale oil spills has led to an epidemic of contaminated sites in the Niger Delta region of Nigeria (UNEP, 2011; Kadafa, 2012; Umukoro, 2012). These sites have had an impact on the health and livelihoods of the local population, as well as an impact on the broader socio-economic and environmental values of the region

E-mail: Kabari.sam@port.ac.uk.

(Orubu et al., 2004; Chinweze et al., 2012). The Nigerian Government's response to the management of these sites has been delayed. As a result, over 2000 contaminated sites resulting from oil spills were reported in 2008 (Oyefusi, 2007) with many more oil spills occurring after, yearly (UNEP, 2011), for example, the Bodo oil spills in 2008 and 2009. In addition, legislation in place to manage contaminated site has been fragmented (Ajayi and Ikporukpo, 2005; Sam et al., 2015). In 2011, the United Nations Environment Programme (UNEP) conducted an environmental assessment of a section of the region and reported that Nigeria is in urgent need of improved contaminated land policy in order to address large scale contamination in the Niger Delta region (UNEP, 2011). However, the true state of contaminated sites in Nigeria is unknown as the UNEP report and other relevant literatures could not ascertain the current state and quantity of sites contaminated by oil spills in the region.

The current legislation to manage contaminated sites in Nigeria has been reported to be undeveloped, poorly enforced, and ineffective at meeting stakeholder expectations (Ajayi and Ikporukpo, 2005; UNEP 2011; Sam et al., 2015; Sam et al., 2022).

Countries such as the United Kingdom (UK) and United States of America (USA) have long-established contaminated land management policies (Forton et al., 2012; Sam et al., 2017a). These policies had evolved to address both legacy and new contaminations, incorporate stakeholder expectation and included the principles of sustainability in contaminated land management (Nathanail et al., 2013; Hou et al., 2014; Prpich et al., 2019). The UK contaminated land management regime has continually improved its regulation to reflect current science and stakeholders' values through several stakeholder engagements prior to reviewing the contaminated land Statutory Guidance (DEFRA, 2012; Sam et al., 2017c). This process ensures stakeholders' values are considered in improving contaminated land management policy.

For countries that lack a robust contaminated land management policy, many might seek to adopt policies from established countries, e.g. UK and USA. Many different factors might motivate a country to adopt or emulate the policies of another. This includes a lack of policy on a programme, ineffectiveness of the existing policy (Page, 2000), lack of technical know-how in implementing a policy (Dolowitz and Marsh, 1996), lack of resources or simply a desire to improve available policy (Page, 2000), and a desire for innovation. Cameroon and China have emulated institutional frameworks from the UK in efforts to improve their contaminated land management regimes (Luo et al., 2009; Forton et al., 2012). This process of emulating or copying established contaminated land management from an established regime is described as policy transfer (Dolowitz and Marsh, 1996; Rose, 2002).

Policy transfer is thus described as the process whereby policies perceived to be effective in a particular country or setting are emulated or adapted for adoption in another country or setting (Dolowitz and Marsh, 1996; Stone, 2001). Policy transfer has been used in different settings, in politics to improve political administration (Martinez, 2005), finance to improve monetary policy (Bulmer and Padgett, 2005), and in contaminated land management to improve effectiveness of contaminated land management decision-making (Luo et al., 2009).

Policy transfer is not always successful; this is largely due to differing characteristics between the two countries involved (Dolowitz and Marsh, 1996). This condition include difference in environmental factors (e.g. soil types and chemical properties) (Luo et al., 2009), administrative and governance framework (e.g. procedures, expertise and experience) (Dolowitz and Marsh, 1996), institutional policy (e.g. policy goals) and socio-cultural factors (e.g. understanding values and expectations) (Page, 2000), and economics (e.g. funding) (Benson, 2009; Evans, 2009). Luo et al. (2009) identified two key challenges with policy transfer in contaminated land management, namely, environmental variability and impracticable integration into existing policy. Difference in environmental media and specific conditions that characterize a country in policy transfer is likely to affect effective policy transfer. In addition, governance structures, historical development and socio-cultural factors could affect policy transfer in contaminated land management.

Countries seeking to improve extant policies through policy transfer need to consider the context in which the policy is to be implemented. To achieve this, pertinent questions to provide answers to include; (1) Does the policy meet stakeholder values and concerns? (2) Is there economic and personnel resources for implementation? (3) How does the policy fit into the governance structure and existing regulations? Answers to these questions will seek to resolve challenges that affect the effectiveness of transferred policy.

In this paper, a key factor that impacts on the effectiveness of policy transfer is explored, namely; social values and perception (Sam et al., 2017b). The study investigated how social values differ between contaminated land management stakeholders and how this could lead to ineffectiveness of transferred policy. It also discussed an alternative approach to improving policy that will account for the unique socio-economic and environmental conditions within Nigeria.

METHODS

General overview

In this study relevant stakeholders were engaged through workshops and interviews to gather data on values and perceptions on the impacts of ineffective contaminated land management in the Niger Delta region.

Figure 1. Sample postcard used during interview. The postcards were used to communicate with semi-literate stakeholders that could not understand English.
Source: Author

Planning and preparation

Literature search to identify stakeholder values in the Niger Delta region were conducted. The literature search on Google, Google scholar and Science direct used key phrases including "values impacted by oil spills in Nigeria" and "concerns from contaminated land in the Niger Delta". This resulted in numerous values, however, in order to effectively manage stakeholder response and directly focus on the key issues in the Niger Delta only 13 of these values was selected. The 13 values considered include drinking water, soil quality, communal crisis, and health/wellbeing (Figure 1). These factors were validated through emails and voice calls with contaminated land management stakeholders in the Niger Delta.

The postcards (Figure 1) were used to communicate with semi-literate stakeholders that could not fully understand English language, for example the postcard on soil quality was used to communicate availability of fertile soil for agriculture. Other postcards that were used communicated health/wellbeing, drinking water, farming, and fishing, resource conservation, cultural places, loss of biodiversity, communal crisis, family, and household, legacy for future generation, financial issues, collaboration/co-existence and reputation.

Workshop

A workshop was conducted to identify stakeholder values that are impacted by oil spills in the Niger Delta region of Nigeria, in December 2016. Stakeholder values refer to the necessities (e.g. quality drinking water) that stakeholders hold in high esteem which are impacted by oil spill in their environment. These values and perceptions define the setting of the Niger Delta region and reflect stakeholder's expectations in contaminated land management. Thus, these values and perceptions play a considerable role in the adoption of policy or decision making for policy improvement.

Different stakeholder groups and selected participants who were able and willing to participate in the workshop and interviews were identified. The study targeted stakeholders with knowledge of contaminated land management in Nigeria. From the pool of stakeholders, participants were selected across oil impacted communities that have experienced oil spills (that is, Nsisioken, Ogale, and Kwawa), experts that participated in the UNEP environmental assessment of Ogoniland, operators in the oil industry in Nigeria, and the contaminated land regulator in Nigeria (Department of Petroleum Resources) (Table 1). However, only community groups were able to attend the workshop while other stakeholders were engaged through interviews.

The workshop was held at the community town hall Ogale comprising of thirty-five (35) participants from the four local government councils of Ogoniland, in the Niger Delta region, using the procedure described in Figure 2. At the beginning of the workshop, the aim and significance of the workshop was explained in an introductory remark, followed by consent and assurances of confidentiality of participants' data. After this, participants were put in seven groups of five persons each, to aid knowledge sharing and networking. Data collection was facilitated by the use of postcards that had images that represented by different valuables impacted by oil spills in the environment.

Participants were asked to prioritize identified postcards in order of importance, with the first indicating the most important and the last the least important valuable impacted by oil spills. Group members discussed their priorities and rationale with other members of the group. During this 30-minute deliberation by the groups, participants within each group had to agree on a single prioritized list of valuables most affected by oil spills. A representative spoke on behalf of each group to share their prioritized list with all workshop participants. Lastly, participants were asked what they would do to help the people if they were in authority. Responses from the groups were captured electronically using a voice recorder and then transcribed for analysis.

Table 1. Stakeholder values described using postcards.

Value	Element	Description
Socio-cultural	Communal crisis	Communal crisis refers to crisis that exists between communities, oil companies and government
	Cultural places	Cultural places include places of worship and cemeteries
	Family and household	Children, parents and relatives
Environmental	Drinking water quality	The water used to provide drinking water to communities
	Loss of biodiversity	Loss of variety of flora and fauna in the local environment
	Resource conservation	How you use, allocate and protect your natural resources such as fishes and mangrove habitats
	Soil quality for agriculture	Maintenance of soil quality to enable agriculture for nutritional and economic value
Economic	Food and local supply chain: farming and fishing	Sources of local food supply such as farming and fishing, and nutrition
	Legacy for future generation	Natural resources you wish to transfer to your grandchildren are in decline
	Human health/wellbeing	Health and wellbeing (sickness and diseases)
	Financial issues/income security	Financial health, the ability to sustain an income
	Reputation	The reputation of your community or institution
	Collaboration/ co-existence	Collaboration and cooperation among operators, regulators, community members and government

Source: Author

Interviews

Twenty-one interviews were conducted between July and December 2016. Each interview lasted between 80 and 90 min. The interviews were to identify stakeholder values and perceptions that are impacted by oil spills in the Niger Delta region of Nigeria. Interview participants comprised of experts on contaminated land management in the Niger Delta, regulator and oil industry operators that were not able to attend the workshop. The tool developed to drive the engagement process is presented in Table 2.

Data analysis

Qualitative data from the workshop and interviews were obtained in the form of audio recordings. The data were transcribed into MS Word and stored on a personal computer. The transcribed data from the workshops and interviews were analyzed using the content analysis methodology (Sandelowski, 1995; Krippendorff, 2012). This methodology allows the reiterative reading of the qualitative data in order to understand the meaning and possible topical issues addressed in the data. These topical issues form units which were later used to form clusters and then typical themes discussed (Table 3). Consistency was validated by a second researcher using the coding rules and reiterative coding (Carey et al., 1996). The data was manipulated using descriptive statistics in MS Excel and presented in graphs.

RESULTS AND DISCUSSION

Stakeholder overview

The demographic distribution of stakeholders chosen for this study was broadly consistent with the demographics of the Niger Delta region (e.g. more males 54% than females 46%) (NDDC, 2014), with the majority of the participants (64%) between the ages of 40-59 years. This age group is the most literate age group in the region (78%) (NDDC, 2014; Table 4) .

Participants from all stakeholder groups stated that they had been affected directly, or indirectly, by oil spills. In many instances, interview attendees had upwards of 10 years' experience dealing with oil spill contamination, while many workshop participants had been living with/on contaminated land since their birth. One workshop participant explained thus *"Since I was born I have been living here, I am almost 60 years in age. What experience about oil spill sites do you still want me to have? I have experienced it all my life".*

Stakeholders' priorities

To identify stakeholder priorities that influence contaminated land management decisions within the Niger Delta region of Nigeria, participants were asked to identify factors that they valued most which are impacted as a result of land contamination by oil spills. Identifying these priorities would ensure an understanding of the contextual socio-economic and environmental factors that require immediate attention in the region. It would also identify factors for consideration in policy improvement.

Of the 13 Stakeholder values outlined, seven of them were prominent during prioritization (Figure 3). In Figure 3, the tip of the heptagon represents the seven core priorities, valued by stakeholders. The percentage of each stakeholder group that valued each priority is represented in the heptagon. Drinking water quality, soil quality, food and local supply chain (farming and fishing) –as well as health and wellbeing were identified as the most valued factors affected by oil spills and thus could

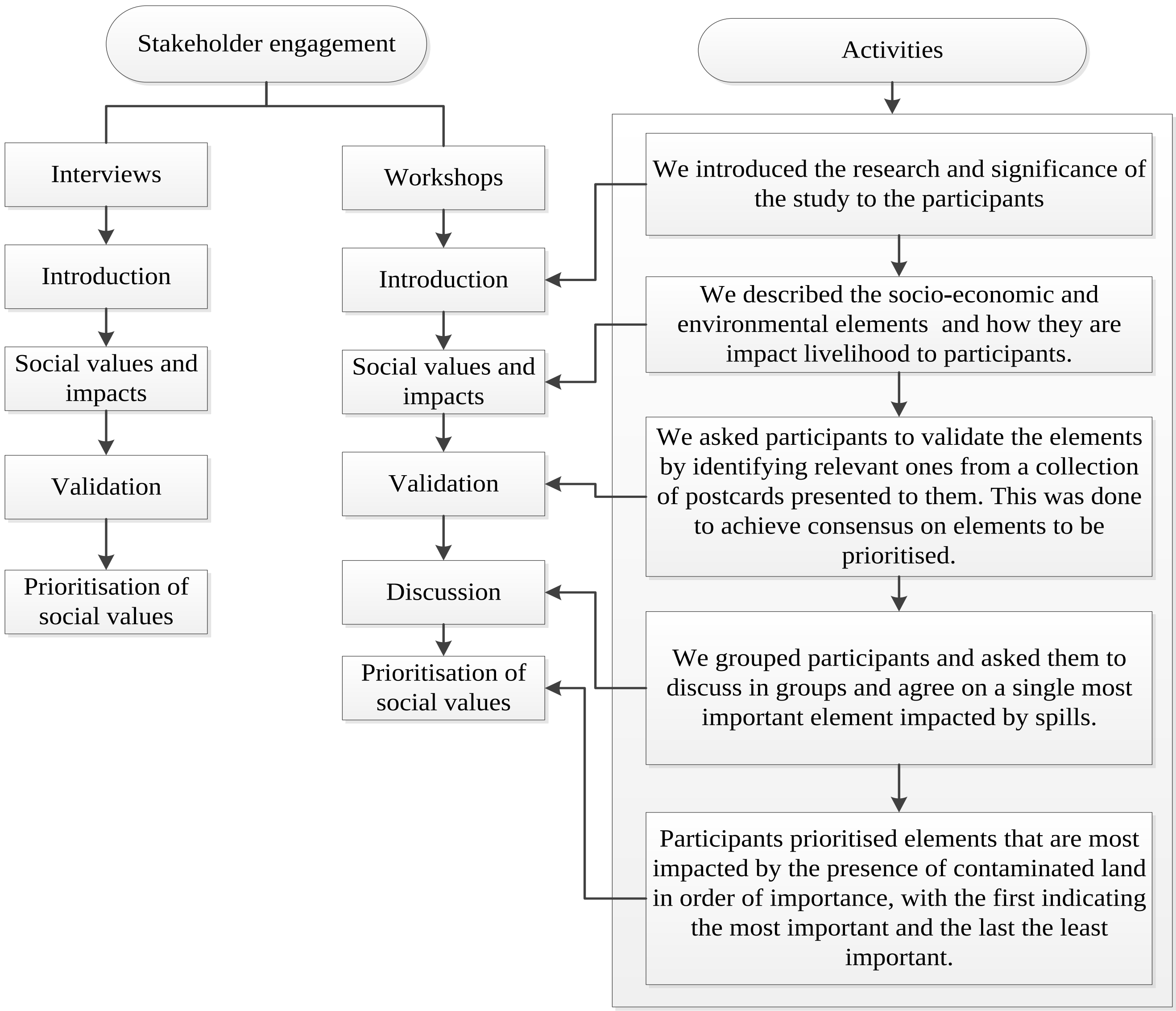

Figure 2. Procedure adopted during engagement with stakeholders for data collection.
Source: Author

influence contaminated land management decisions in the Niger Delta, while factors including cultural places, family and household, legacy for future generation, financial issues, collaboration/co-existence and reputation were not prioritized.

Regulators value drinking water the most (25%) followed by soil quality (21%), human health/wellbeing (21%) with food and local supply chain (17%). The least valued factors include loss of biodiversity (8%), resources conservation (4%), and collaboration/co-existence (4%).

Operators value drinking water the most (29%), soil quality for agriculture (24%), food and local supply chain (24%), and human health/wellbeing (15%). The least valued priority for the operators were communal crisis (2%).

The public value drinking water quality the most (30%), followed by soil quality for agriculture (24%), food and local supply chain (21%), and human health/wellbeing. The least factors prioritized by the public include communal crisis (2%) and resource conservation (3%). Experts value drinking water quality the most (28%). This is followed by soil quality (22%), food and local supply chain (22%) and human health/wellbeing (11%). The lease priorities include loss of biodiversity (6%) and communal crisis (6%).

To confirm or refute the hypothesis, an analysis of variance (ANOVA) (Tables 5 and 6) was conducted using a significance *level* = 0.05, for the four shared values among stakeholders.

The *P-value (0.8)* (Table 6) is > the significance level of

Table 2. Questionnaire used to drive the engagement process.

	Question	Assessment scale	Rationale
1	Have you personal experience dealing or living contaminated land?	1=not at all; 5=considerable	To determine whether participants has contaminated land experience in order to be able to answer the questions.
2	Any other comments you wish to add on your experience?	Open ended	To explore stakeholder experiences
3	Confirm that images contained on postcards reflected stakeholder values.	Open ended	To validate stakeholder values and reach a consensus
4	Prioritise a set of postcards, choosing the first as most important and the last as least important	Line postcards up from worst to first	To determine stakeholders' priorities of values that are impacted by the presence of contaminated land
5	How might you assist other stakeholders to help with the clean-up of contaminated land if you had the chance" and "How can the Government help the people in the affected region?	Open ended	To reveal subjective beliefs held by the participants and to explore other social values that were not represented by the postcards that could be affected by contaminated land
6	How would you rate your knowledge about contaminated land management?	1=not at all; 5=considerable	To determine participants' knowledge of the contaminated land management regime in Nigeria
7	Are you satisfied with the Nigerian approach to land contamination management?	1=not at all; 5=considerable	To measure participants satisfaction with Nigeria's current approach to contaminated land
8	Please explain why you are satisfied or no	Open ended	To explore the reasons for participant's response,
9	How familiar are you with foreign contaminated land regulation?"	1=not at all; 5=considerable	To assess if stakeholders had heard of other regimes so they could learn from them
10	Do you believe policy transfer from a foreign country or institution will work in Nigeria?	1=not at all; 5=considerable	To assess participants' willingness to accept policy transfer
11	Do you foresee any barriers preventing policy transfer?	Opened ended	To understand fears to policy transfer assuming a better policy was identified abroad

Source: Author

0.05, and hence we do not reject the hypothesis. This implies that there are shared contextual values that influence contaminated land decision making within the Niger Delta region. Thus, it can be explicitly stated that the shared values be considered in improving contaminated land management policy.

The priorities identified by the stakeholders confirm that drinking water continues to be an issue in the Niger Delta region (UNEP, 2011), and that the livelihood of the local population (that is, farming and fishing) which is depended on soil quality and rivers continue to be impacted (Watts, 2004; Aaron, 2005; Omotola, 2006; UNEP, 2011). In addition, several reports highlighted concerns about loss of biodiversity as a result of oil spill in rural areas (Leopold et al., 2008; Park and Park, 2010; Linden and Palsson, 2013) which has resulted in the decline of species of seabirds and benthic organisms, extinction of medicinal plants and degraded mangroves forest and wetlands in the region (Onyena and Sam, 2020; Eriegha and Sam, 2020). Loss of biodiversity was among the least valued factors among stakeholders. This implies limited knowledge on the role of biodiversity loses in delivering of ecosystem goods and services in local communities (Onyena and Sam, 2020; Zabbey, 2004).

Many studies in the Niger Delta region have linked communal crisis to pollution caused by oil spills (Oviasuyi and Uwadiae, 2010; Umukoro, 2012; Aaron and Patrick, 2013). These studies suggest that the struggle for limited available clean land for agricultural purposes has often resulted in communal crisis in the region (Salau, 1993; Orubu et al., 2004; Steiner, 2010), however, communal crisis was the least on communities priorities. This could be attributed to competing values on the list provided in this study.

Overall, stakeholders share similar values. Despite slight differences in the identified priorities, drinking water quality, soil quality, food and local supply chain (farming and fishing) and health/wellbeing were prioritized by all stakeholder groups, and thus form the core priorities that should influence contaminated land management decisions in the region. These values reflect the socio-economic and environmental challenges related to changes in land use occasioned by oil exploration, and a long term neglect of contaminated land within the region (UNEP, 2011; Ite et al., 2013; Linden and Palsson, 2013).

From a regulatory perspective, the shared values should motivate the development of stringent regulations for effective management of new oil spills and legacy sites. Extant regulations outlining intervention and target values should be site specific and precautionary to disincentivize activities that pollute the environment. An understanding that drinking water is a core priority should reflect in the design and implementation of precautionary measures to prevent pollution of drinking water sources and farmlands. Despite shared values, a community member commented thus:

"Our water is polluted all the time by oil spills and this has made us suffer different sicknesses. Water is a serious issue in our community because of oil spills. We are

Table 3. Coding system for responses during interview.

Main category	Codes	Sub codes	Code definition	Example of quotes for this code	Frequency of code
Environmental issues	Clean-up	Timely response restoration	Statements that connote the need for clean-up, land restoration and urgency of clean-up	*"If I were the President I would ensure proper sanitation, we need some clean-up to wash the soil and ensure the soil is clean; if that is not immediately possible, Government can provide alternative source of water"*	81
	Environmental degradation	Pollution environmental damage	Statements on pollution, impacts of oil spill, bunkering, sabotage activities and insecurity	*More than 95% of spillages in Ogoniland since 2012 is as a result of illegal bunkering and sabotage. The trend has caused untold devastation on the aquatic and agricultural sectors in Ogoniland*	25
Social/economic issues	Economic loses and welfare	Livelihood Economic loses welfare	Statements that suggest economic loses (livelihood) as a result of oil spill and express concerns about water, soil, health and safety	*"..their main source of occupation is farming and fishing and some cultural crafts like canoe making and so, they derive their livelihood from the environment, so if the environment is impacted, the quality of their socio-economic and cultural life will also be directly impacted"*	106
	Participation and collaboration	Stakeholder engagement participation	Statements that suggest the impact of stakeholder participation/collaboration in the decision making process.	*"Very importantly the three stakeholders in the spill of crude oil; which are the oil companies themselves the multinationals, the regulators and the communities where this oil is situated or where the pipelines transverse"*	45
	Unethical practices	Trust and transparency	Statements that concern corruption, trust and transparency between contaminated land management stakeholders	*"According to several authors in literature, the spills that have been reported so far, is just about probably half of what actually goes out into the environment in terms of spill. So it is never, it is never a proper mechanism"*	32
	Regulation performance	Monitoring and implementation	Statements that concern regulatory performance, monitoring and implementation, as regards contaminated land decisions	*"Nigeria's policies are ok, it is implementation that is a concern"*	59
Policy transfer	Political and cultural issues	Constraints	Statements that suggest resistance to transfer policy due to socio-cultural, political and economic issues	"*..yes I foresee a barrier because there is no political will, that is the major barrier. If there is a political will in favour of the people …a desire by the politicians to do the right thing for the people"*	40

Source: Author

farmers and fishermen, oil spills destroy our soil and make it unfertile"

Within advanced contaminated land management regimes such as the UK, risk management policies are informed by stakeholder values (DEFRA, 2012; Nathanail et al., 2013). It is

Table 4. Demographic breakdown of the stakeholders.

Variable	Number of stakeholders	Percentage of total
Sex		
Male	30	54
Female	26	46
Age		
18-25	3	5
26-39	10	18
40-59	36	64
60 and above	6	11
Missing	1	2

Source: Author

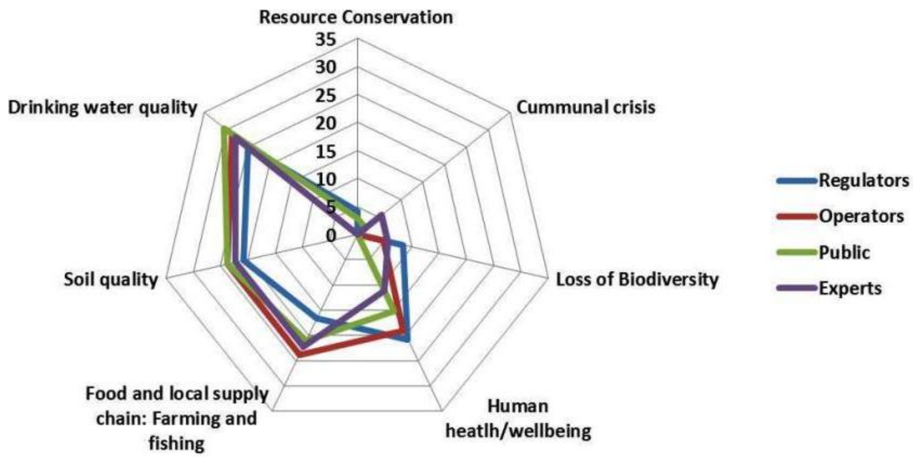

Figure 3. Prioritised values by stakeholders.
Source: Author

Table 5. Summary of mean and variance.

Group	Count	Sum	Average	Variance
Regulators	4	83.33333	20.83333	11.57407
Operators	4	95.2381	23.80952	15.11716
Public	4	90.47619	22.61905	40.13605
Experts	4	83.33333	20.83333	48.86831

The mean of the core priorities.
Source: Author

common practice in the UK to undertake several consultations with stakeholders prior to the development of policies (EA, 2009; DEFRA, 2012).

During such consultations all stakeholder perspectives are considered and integrated in decision-making and consequently in the policy development, thus allowing for exchange of ideas and creating awareness of a new policy. For example, prior to publishing the 2012 Statutory Guidance on contaminated land, public consultation with stakeholders were held (DEFRA, 2012). Similar approach is adopted in Cameroon to ensure stakeholder participation in efforts to address land contamination issues (Forton et al., 2012).

To improve contaminated land management policy within the Niger Delta region, approaches identified in the UK and Cameroon could benefit the country. For

Table 6. Analysis of variance.

Source of variation	SS	Df	MS	F	P-value	F crit
Between Groups	25.5102	3	8.503401	0.293992	0.829012	3.490295
Within Groups	347.0868	12	28.9239			
Total	372.597	15				

Source: Author

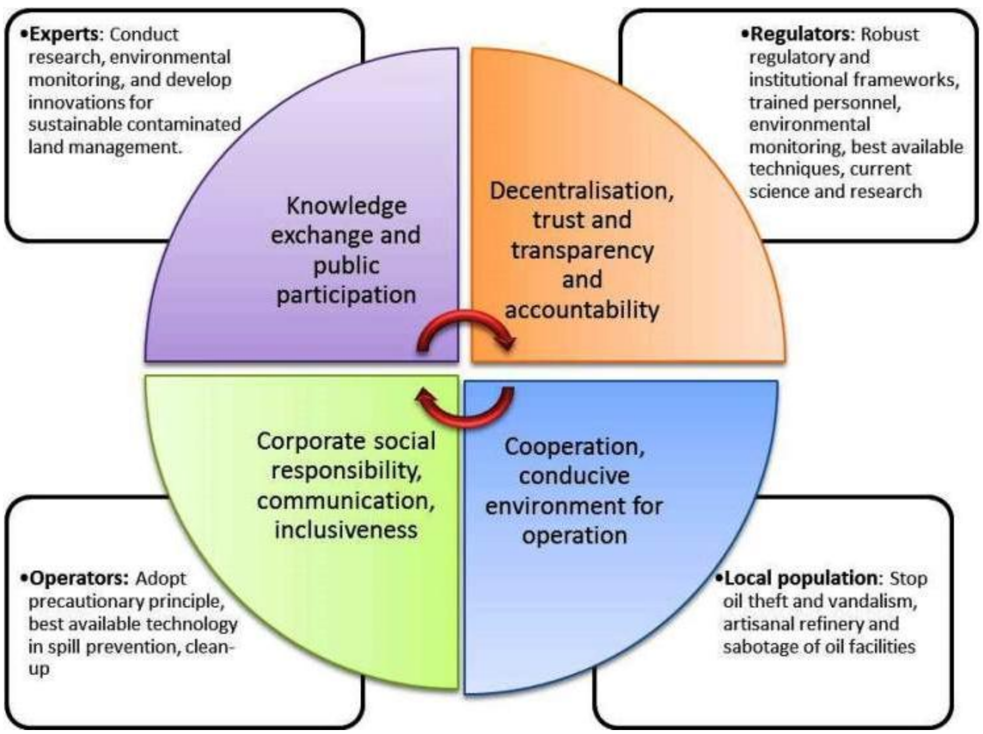

Figure 4. Stakeholder responsibilities in dealing with contaminated land.
Source: Author

example, knowledge gaps and lack of awareness on values that promote sustainability could be remedied through consistent consultations within stakeholders. This will provide opportunity for stakeholder inclusiveness and ensure that similar values shared among stakeholders reflect decisions made and consequently policies for contaminated land management in the region.

The operators, local population, regulators and experts represent the stakeholders that are impacted by oil-related land contamination and thus have collective responsibility in ensuring existing contaminations are dealt with while new ones are prevented. The research, therefore, proposed a regime where all stakeholders will contribute meaningfully to addressing land contamination issues in the Niger Delta (Figure 4).

Within the purview of the regulators, robust legal and institutional frameworks should be provided to address existing contaminations and prevent new ones. Such frameworks should adopt an integrated approach to dealing with contaminants in air, water, and soil compartments (Zabbey et al., 2017). The regulatory agency should comprise of trained personnel while adequate resources are provided for research and the functioning of the agency to eliminate regulatory unethical practices.

The local population contributes a significant 28% to oil-related land contaminated through oil theft and sabotage (Nwilo and Badejo, 2006). This is the highest sole contributing factor to contaminated land in the Niger Delta. Thus, local communities can prevent new contamination by ending oil theft, sabotage and cooperating with other stakeholders in addressing the threats of contaminated land.

Operators should adopt more rigorous procedures to improve prevention efforts by ensuring reduced engineering failures and human errors, while being more

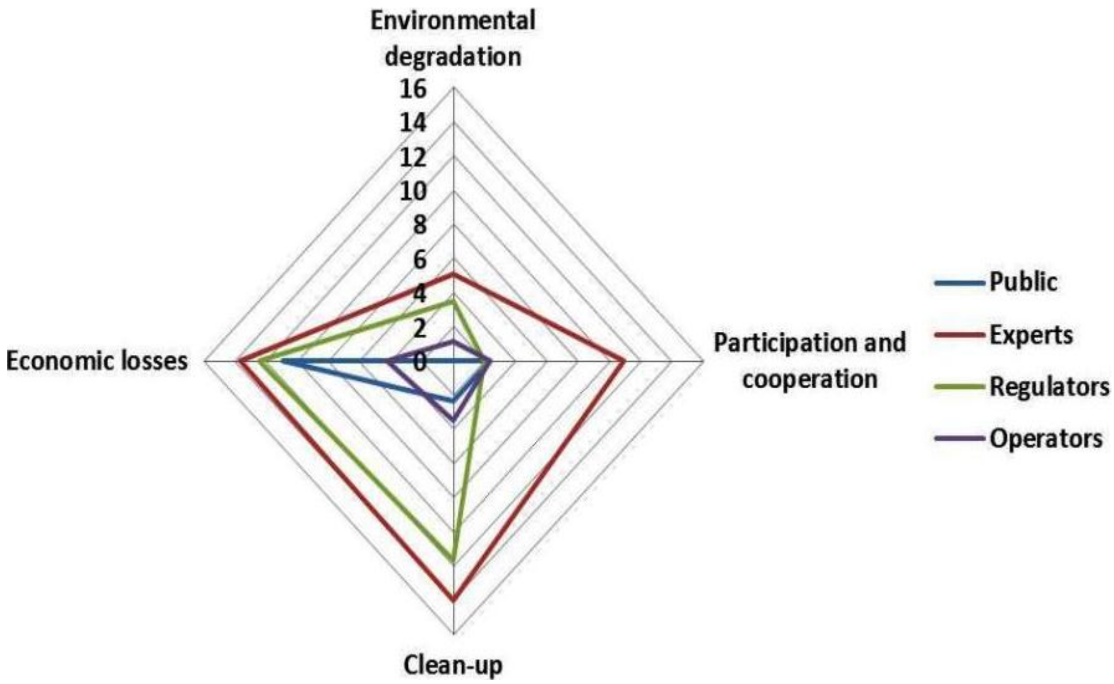

Figure 5. Stakeholders' long-term concerns.
Source: Author

transparent and accountable to other stakeholders. In addition, adopting best practice in the exploration process will reduce the impacts on the environment and the society. Experts should be funded to conduct more research into sustainable methodologies for dealing with contaminated sites. They should undergo specific professional trainings in order to develop skills for dealing with contaminated land.

Nigeria requires an improved policy for achieving stakeholder expectations, prevent new contamination and address legacy contaminated sites. This will reduce the long-term impacts suffered by all stakeholders. To achieve this, while all stakeholders will take responsibility for preventing land contamination, a more inclusive approach aimed at involving all stakeholders in decisions that lead to policymaking is required, as demonstrated in the UK contaminated land regime. This will lead to a policy framework with an acceptable balance between sustainable development, regulatory needs, and scientific robustness to restore livelihood, and soil functionalities.

Long-term socio-economic and environmental concerns of stakeholders

Stakeholders expressed long term concern regarding contaminated land impacts in the region. Four main concerns including economic losses, participation and cooperation, environmental degradation, and clean-up were identified by stakeholders (Figure 5).

The results indicated that stakeholders' (40%) long term concerns bother on economic losses, clean-up (32%), while participation and cooperation and environmental degradation are 18 and 10%, respectively.

Economic losses associated with contaminated land include monetary losses incurred as a result of oil spilled into the environment. This affected the national government in the form of shortage of crude, and also impacts on communities as their livelihood structures are impacted by spilled oil (Eweje, 2006; UNEP, 2011). When clean-up efforts fail, communities are further impacted as they are out of jobs (that is, fishing and farming). Polluted rivers occasioned by oil spills have led to a decline in fish breeding areas, thus affecting catches during fishing ventures. In early 2015, the Shell Corporation paid £55m pay-out to fisher folks and farmers for environmental damages caused by the 2008 and 2009 spills in the region (The Guardian, 2015). The local populations were compensated six years after the oil spill incident; within this period and beyond, the impacted areas will be economically unproductive for the people, until the area is effectively remediated. Similarly, entrepreneurs and farmers who own fish farms in or close to the creeks or spill sites are consequently out of business due to oil spills (Salau, 1993; Watts, 2004). A respondent commented thus:

"…our main source of occupation is farming and fishing and some cultural crafts like canoe making and so, they derive their livelihood from the environment, so if the

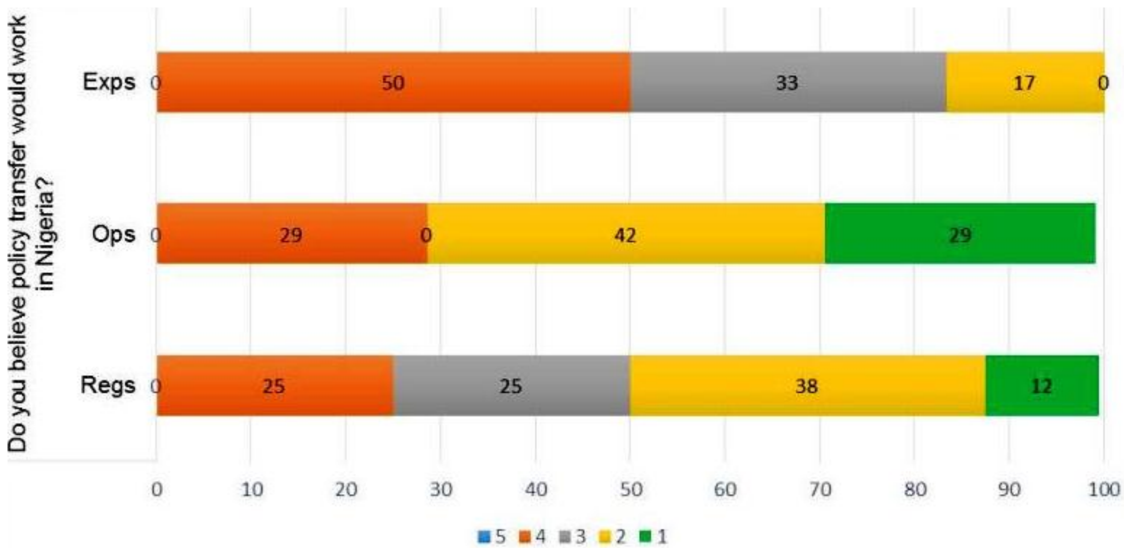

Figure 6. Perceptions on policy transfer (learned lessons) (Reg - regulators, Ops – operators, Exps - experts). Source: Author

environment is impacted, the quality of their socio-economic and cultural life will also be directly impacted"

The results also indicated that stakeholders are concerned about exclusion from the environmental remediation decision-making process. Concerns were expressed about their views not being sought and reflected in policies for effective environmental remediation. Omeje (2006) and Dada (2009) reported that community exclusion in the decision-making process is a potential cause of conflict, and a lack of buy-in and project ownership by local communities, the ongoing clean-up of Ogoniland is a classic example (de Zeeuw et al., 2018). As a result, stakeholder participation and inclusion in remediation projects are limited (de Zeeuw, 2018), and thus different stakeholders' perspectives are often not integrated in the final decisions and policies adopted for contaminated land management.
A respondent commented thus:

"Without collaboration from these three primary stakeholders –regulators, operators and the communities, there are no way we can forge ahead on discussions of the clean-up. There are lots of issues, lots of personal interest in the clean-up"

These long-term concerns are critical to a contaminated land management regime that ensures inclusiveness towards achieving environmental sustainability.

Perception of policy transfer

To attempt policy transfer from effective contaminated land regimes to Nigeria, it is necessary to understand stakeholders' knowledge of international contaminated land regimes for the purpose of effective implementation. To achieve this, respondents were asked to identify foreign contaminated land management regimes they were familiar with and elements of such regimes that would benefit Nigeria if eventually transferred. Questions on policy transfer were limited to experts, regulators and operators. On the effectiveness of foreign contaminated land management lessons in Nigeria, experts (50%), regulators (25%), and operators (29%) believed policy transfer will improve the current regime in Nigeria (Figure 6). Generally, these perceptions could be attributed mainly to the limited knowledge of foreign contaminated land management regimes.

Experts were most optimistic that learned lessons from foreign regimes could improve the Nigerian situation. A stakeholder admitted thus:

"Well, a stark jacket transfer of policy should be discouraged. But workable policy around the world that have been tested and found working can be adapted within the context of the socio-cultural setting of Nigeria"

This suggests that a form of adaptation considering contextual socio-cultural factors would be required in making learned lessons effective in Nigeria. This view is consistent with those of Meyer et al., (1995) and Burayidi (2000). They reported that transferring learned lessons across nations require an understanding of cultural differences as this could affect implementation. However, for any transferred policy to be effective stakeholders need to demonstrate sufficient knowledge in the workability of the regime (Dolowitz and Marsh, 1996;

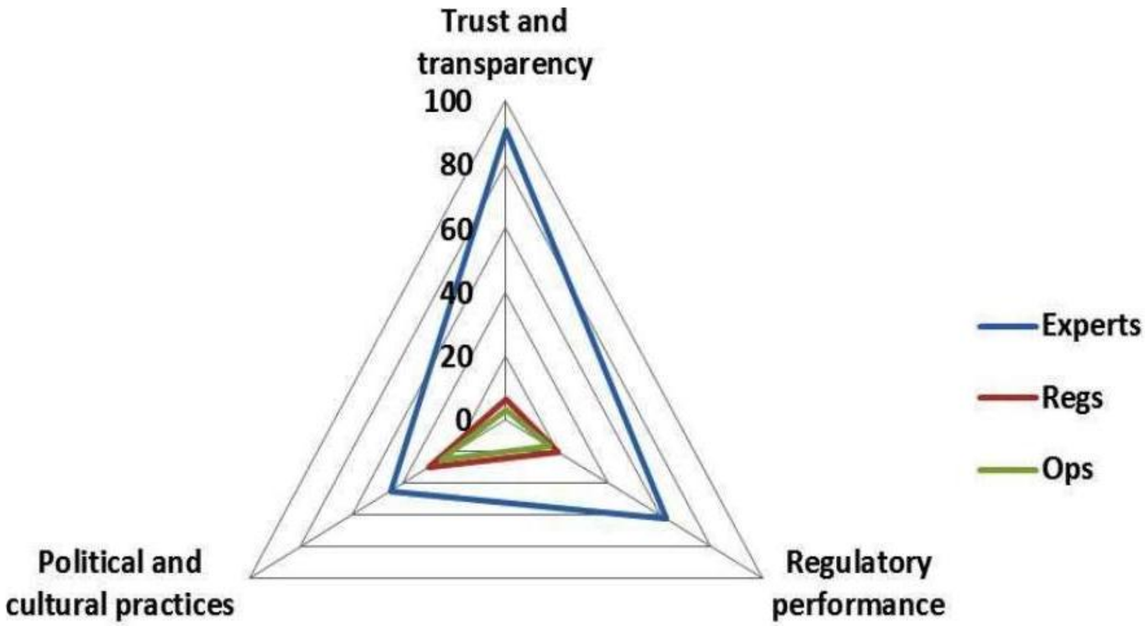

Figure 7. Identified barriers to policy transfer.
Source: Author

Rose, 2002), which is lacking in this context.

Regulators slightly believed policy transfer would improve the current regime in Nigeria and hinged their perception on contextual issues:

"Policy transfer may not work in Nigeria because foreign countries have a system that works which Nigeria does not have. Again, selfish interest, corruption, and politics in Nigeria may not allow it work"

This perception could be attributed to the limited knowledge of contaminated land regulation in foreign regimes and the contaminated land regulatory environment in Nigeria. Operators were also doubtful on the effectiveness of learned lessons within Nigeria. An operator said:

"Nigeria's policies are ok; it is implementation that is a concern"

This implies operators are keen on improved implementation rather than a holistic improvement of the current regulation. Respondents identified political will, corruption, and poor implementation approach as constrains of the current regime which would also affect an improved policy, if not addressed. This is consistent with a study conducted by Peace (2013). The study stated that barriers including corruption and unethical issues characterize the contaminated land regime in Nigeria. Thus, addressing these, in addition to providing adequate training in current contaminated land management practice is recommended for stakeholders in Nigeria, lessons learned from foreign regimes could serve as guidance for developing a regime that meets both core priorities and long-term concerns within Nigeria.

Barriers to policy transfer

Stakeholders identified political and cultural practices, regulatory performance, and trust and transparency as barriers that can impede the transfer of learned lessons in Nigeria. Experts identified trust and transparency as a top barrier, followed by regulatory performance, and political and cultural practices (Figure 7). Regulators and operators shared the same view. Both stakeholder groups identified political and cultural practices as the top barrier to the effectiveness of any policy transferred from a foreign regime.

The results suggest that lack of trust and transparency which has introduced corruption and unprofessional practices in the current contaminated land regime is a major barrier. A respondent commented thus:

"Not just copying, but how do you allow these things to work? Nigeria has good policies, but how often do we allow them to work; it is corruption…Of course, I foresee a barrier, it is corruption. In corruption you have injustice; in fact, anything that is bad is corruption"

This view is consistent with those of Idemudia and Ite (2006), Omeje (2005) and Edoho (2008). The regulators have an unethical relationship with the operators, thus where environmental regulations are violated, operators face no serious penalty, as in most cases operators will prefer to bride their way out (Idemudia and Ite, 2006; Edoho, 2008). A classic example is the Halliburton case where Halliburton admitted paying 2.4 billion USD to Nigerian government officials in return for tax breaks during operators (Idemudia and Ite, 2006). While this undermines the credibility of the regulator, reduce trust and confidence of the public, it mostly results in environmental deterioration as operators engage the faster means to resolving violations. Omeje (2005) stated that the desire and pervasiveness of corrupt enrichment inform this unethical practice. However, to the regulators and operators, political and cultural practices are perceived as the core barriers. The difference in culture and political practice between the originator and the benefiting regimes could hinder implementation. This is due to the role social context and perception play in policy making and implementation (Lupton, 1999, 2006).

Three strategies are recommended for addressing identified barriers. A disclosure policy, adequate funding/effective regulatory structure and education-based policies. Disclosure policies address the lack of trust and transparency between stakeholders with competing interest (Mitchell, 2011). Disclosure policies will grant stakeholders considerable access into activities of regulators and operators in the sector. A classic example is the ongoing Ogoni clean-up supervised by the Hydrocarbon Pollution Remediation Project (HYPREP). Stakeholders are reportedly concerned about the secrecy of key performance indicators (KPI) used by HYPREP to monitor the remediation process in Ogoniland. This has affected independent monitoring by interested civil society organizations. Targeted stakeholders (e.g. operators and regulators) need to disclose appropriate information about their activities, make it available and accessible to other stakeholders (Florini, 2010; Mitchell, 2011). Such policies will increase the openness of the process and ensure all stakeholders participate in the decision-making process. More importantly, disclosure policy could be used as a tool to eliminate doubts, environmental harmful behaviours and allow for inclusive participation in decision making.

Expertise and funding

To address barriers associated with weak regulatory performance, training of regulators, adequate funding and a coordinated regulatory structure is imperative. The existing structure seems weak and has resulted to ineffective enforcement and thus stakeholders are concerned that implemented learned lessons would suffer similar challenges. For example, the National Oil Spills Detection and Response Agency (NOSDRA) have a mandate to detect and respond to spills, but lack the necessary funding for undertaking its functions. As a result, the number of oil spills requiring remediation activities continues to increase. An effective regulatory structure where regulators are well trained and funded and regulatory agencies understand their roles and responsibilities will be instrumental to the effectiveness of an improved regime. Therefore, efforts towards improving the system should be comprehensive including, training, and development of policies for private enterprise involvement in managing contaminated land.

Education-based policies

Education based policies should be the antidote to harmful environmental perceptions and behaviours (Mitchell, 2011). This can be achieved through self-conscious communication, seminars, and advocacy campaigns in which information made available should be targeted towards changing community behaviours and value systems. This could be implemented through different approaches depending on the targeted audience. Inclusion of environmental education in school curriculum can be used to target school age children in local communities where change in behaviour would be incremental. Religious organizations, social gatherings, and door to door awareness campaigns can be used to reach the generality of stakeholders. Continuous education would result in a change in behaviour and reduce cultural issues that could impede the effectiveness of an improved regime.

Conclusions

Importing contaminated land management policies without consideration of socio-economic and environmental issues in context could be counterproductive. Thus, contaminated land management stakeholders within the Nigerian Niger Delta identified impacts on drinking water quality, soil quality, food and local supply chain (farming and fishing) and human health/wellbeing as core priorities that should motivate and be considered during contaminated land management policy improvement. In addition, economic losses, participation and cooperation, clean-up and environmental degradation are long-term concerns affecting contaminated land management decision-making. The current contaminated land management regime has been unable to meet these expectations and thus drive the need for an improved policy. In efforts to improve the current contaminated land management policy, stakeholders outlined contextual issues to be addressed, while recommending disclosure policy, provision of adequate resources and education-based strategies for addressing barriers to policy transfer. Contaminated land policy improvement processes should be informed by science, expert knowledge, and public values, and stakeholder participation for a sustainable contaminated land management regime in Nigeria.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

Aaron KK (2005). Perspective: big oil, rural poverty, and environmental degradation in the Niger Delta region of Nigeria. Journal of Agricultural Safety and Health 11(2):127-134.

Aaron KK, Patrick JM (2013). Corporate social responsibility patterns and conflicts in Nigeria's oil-rich region. International Area Studies Review 16:341-356.

Ajayi DD, Ikporukpo CO (2005). An analysis of Nigeria's environmental vision 2010. Journal of Environmental Policy and Planning 7(4):341-365.

Benson D (2009). Review Article: Constraints on Policy Transfer, Review article: constraints on policy transfer. CSERGE working paper EDM, East Anglia, UK.

Bulmer S, Padgett S (2005). Policy transfer in the European Union: an institutionalist perspective. British Journal of Political Science 35(1):103-126.

Burayidi MA (2000). Urban planning in a multicultural society. Greenwood Publishing Group.

Carey JW, Morgan M, Oxtoby MJ (1996). Intercoder Agreement in Analysis of Responses to Open-Ended Interview Questions: Examples from Tuberculosis Research. Field methods 8:1-5.

Chinweze C, Abiola-Oloke G, Jideani C (2012). Oil and Gas Resources Management and Environmental Challenges in Nigeria. Journal of Environmental Science and Engineering 1:535-542.

Dada C (2009). Towards a successful packaged water regulation in Nigeria. Scientific Research and Essay 4(9):921-928.

DEFRA (2012). Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance. HM Government, London.

Dolowitz D, Marsh D (1996). Who Learns What from Whom: a Review of the Policy Transfer Literature. Political Studies 44:343-357.

EA (2009). Dealing with Contaminated Land in England and Wales: A review of progress from 2000-2007 with Part 2A of the Environmental Protection Act. Environment Agency, Bristol, UK.

Edoho FM (2008). Oil transnational corporations: corporate social responsibility and environmental sustainability. Corporate Social Responsibility and Environmental Management 15(4):210-222.

Eriegha OJ, Sam K (2020). Characterization of Crude Oil Impacts and Loss of Livelihood in the Niger Delta, Nigeria: A Fisheries Perspective. International Journal of Interdisciplinary Research 1:255-273.

Evans M (2009). Policy transfer in critical perspective. Policy Studies 30(4):243-268.

Eweje G (2006). Environmental costs and responsibilities resulting from oil exploitation in developing countries: the case of the Niger Delta of Nigeria. Journal of Business Ethics 69(1):27-56.

Florini A (2010). The national context for transparency-based global environmental governance. Global Environmental Politics 10(3):120-131.

Forton OT, Manga VE, Tening AS, Asaah AV (2012). Land contamination risk management in Cameroon: A critical review of the existing policy framework. Land Use Policy 29(4):750-760.

Hou D, Al-Tabbaa A, Guthrie P (2014). The adoption of sustainable remediation behaviour in the US and UK: A cross country comparison and determinant analysis. Science of The Total Environment. 490:905-913.

Idemudia U, Ite UE (2006). Corporate-community relations in Nigeria's oil industry: Challenges and imperatives. Corporate Social Responsibility and Environmental Management 13(4):194-206.

Ite AE, Ibok UJ, Ite MU, Petters SW (2013). Petroleum Exploration and Production: Past and Present Environmental Issues in the Nigeria's Niger Delta. American Journal of Environmental Protection 1:78-90.

Kadafa AA (2012). Oil exploration and spillage in the Niger Delta of Nigeria. Civil and Environmental Research 2(3):38-51.

Krippendorff K (2012). Content analysis: An introduction to its methodology. Sagepublishers, London.

Leopold EN, Jung MC, Auguste O, Ngatcha N, Georges E, Lape M (2008). Metals pollution in freshly deposited sediments from river Mingoa, main tributary to the Municipal lake of Yaounde, Cameroon. Geosciences Journal 12:337-347.

Linden O, Palsson J (2013). Oil contamination in ogoniland, Niger delta. Ambio 42(6):685-701.

Luo Q, Catney P, Lerner D (2009). Risk-based management of contaminated land in the UK: Lessons for China? Journal of Environmental Management 90(2):1123-1134.

Lupton D (1999). Risk and sociocultural theory: New Directions and Perspectives, Risk and sociocultural theory-New directions and perspectives. Cambridge University Press, Edinburgh, UK.

Lupton D (2006). Sociology and risk, in: Lupton, D (Ed.), Beyond the Risk Society. McGraw-Hill International, Berkshire UK, pp. 11-13.

Martinez C (2005). Policy Transfer in the EU: A Model for MENA Countries?, in: UNDESA Ad Hoc Expert Group Meeting on Approaches and Methodologies for the Assessment and Transfer of Best Practices in Governance and Public Administration. Tunis, Tunisia.www. Unpan. Org/Innovmed/Meetins/Tunisiedoc1.Html

Meyer PB, Williams RH, Yount KR (1995). Contaminated land: reclamation, redevelopment and reuse in the United States and the European Union. Edward Elgar Publishing Ltd.

Mitchell RB (2011). Transparency for governance: The mechanisms and effectiveness of disclosure-based and education-based transparency policies. Spec. Sect. - Earth Syst. Gov. Account. Legitimacy 70:1882-1890.

Nathanail CP, Bardos RP, Gillett A, McCaffrey C, Ogden R, Scott D, Nathanail J (2013). International Processes for Identification and Remediation of Contaminated Land. Land Quality Management Ltd, Nottingham, UK.

Niger Delta Development Commission (NDDC)(2014). Niger Delta Development Master Plan 2006. Retrieved March, 3, 2020. Available at https://www.nddc.gov.ng/masterplan.aspx.

Nwilo PC, Badejo OT (2006). Impacts and management of oil spill pollution along the Nigerian coastal areas. Administering Marine Spaces: International Issues 119.

Omeje K (2005). Oil conflict in Nigeria: Contending issues and perspectives of the local Niger Delta people. New Political Economy 10(3): 321-334.

Omeje KC (2006). High stakes and stakeholders: Oil conflict and security in Nigeria. Ashgate Publishing.

Omotola SJ (2006). The next Gulf? Oil politics, environmental apocalypse and rising tension in the Niger Delta.

The African Centre for the Constructive Resolution of Disputes 1:1.

Onyena AP, Sam K (2020). A review of the threat of oil exploitation to mangrove ecosystem: Insights from Niger Delta, Nigeria. Global Ecology and Conservation 22:e00961.

Orubu C, Odusola A., Ehwarieme W (2004). The Nigerian oil industry: environmental diseconomies, management strategies and the need for community involvement. Journal of Human Ecology 16(3):203-214.

Oviasuyi PO, Uwadiae J (2010). The Dilemma of Niger Delta Region as Oil Producing states of Nigeria. Journal of Peace, Conflict and Development 16:110.

Oyefusi A (2007). Oil-dependence and Civil conflict in Nigeria. CSAE (University of Oxford), Oxford, UK.

Page EC (2000). Future governance and the literature on policy transfer and lesson drawing. ESRC Future governance Program. Work. Policy Transfer 28:1-15.

Park IS, Park JW (2010). A novel total petroleum hydrocarbon fractionation strategy for human health risk assessment for petroleum hydrocarbon-contaminated site management. Journal of Hazardous Materials 179(1-3):1128-1135.

Peace O (2013). The State and Development Interventions in the Niger Delta Region of Nigeria 3:255-263.

Rose R (2002). Ten steps in learning lessons from abroad. European University Institute, Glasgow, UK.

Salau AT (1993). Environmental Crisis and development in Nigeria. An Inaugural Lecture Series pp. 24-26.

Sam K, Prpich G, Coulon F (2015). Environmental and Societal Management of contaminated land in Nigeria: the need for policy and guidance changes, In: 4th International Contaminated Site

Remediation Conference: Program and Proceedings. Melbourne, Australia pp. 427-428.
Sam K, Coulon F, Prpich G (2016). Working towards an integrated land contamination framework for Nigeria. Science of the Total Environment 571:916-925.
Sam K., Coulon F, Prpich G (2017a). Management of petroleum hydrocarbon contaminated sites in Nigeria: Current challenges and future direction. Land Use Policy 64:133-144.
Sam K., Coulon F, Prpich G (2017b). Use of stakeholder engagement to support policy transfer : A case of contaminated land management in Nigeria. Environmental Development 24:1-13.
Sam K, Coulon F, Prpich G (2017c). Use of stakeholder engagement to support policy transfer : A case of contaminated land management in Nigeria. Environmental Development 24:50-62.
Sam K, Zabbey N, Onyena AP (2022). Implementing contaminated land remediation in Nigeria: Insights from the Ogoni remediation project. Land Use Policy 115:106051.
Sandelowski M (1995). Qualitative analysis: What it is and how to begin. Research in Nursing and Health 18:371-375.
Steiner R (2010). Double standard: Shell practices in Nigeria compared with international standards to prevent and control pipeline oil spills and the Deepwater Horizon oil spill. Friends of the Earth Netherlands, Amsterdam, Netherlands.
Stone D (2001). Learning lessons, policy transfer and the international diffusion of policy ideas. University of Warwick. Centre for the Study of Globalisation and Regionalisation, Coventry, United Kingdom.
The Guardian (2015). Oil spill - Shell announces £55m pay-out for Nigeria oil spills [WWW Document]. URL http://www.theguardian.com/environment/2015/jan/07/shell-announces-55m-payout-for-nigeria-oil-spills
Umukoro N (2012). Governance and environmental inequality in Nigeria: Implications for conflict management strategies in the Niger Delta. International Journal of Environmental Studies 69:913-920.
UNEP (2011). Environmental Assessment of Ogoniland. UNEP, Switzerland. https://www.unenvironment.org/explore-topics/disasters-conflicts/where-we-work/nigeria/environmental-assessment-ogoniland-report
Watts M (2004). Resource curse? Governmentality, oil and power in the Niger Delta, Nigeria. Geopolitics 9:50-80.
Zabbey N (2004). Impacts of extractive industries on the biodiversity of the Niger Delta region, Nigeria, in: Conference Proceedings: National Workshop on Coastal and Marine Biodiversity Management, Pyramid Hotel, Calabar, Nigeria pp. 7-9.
Zabbey N, Sam K, Onyebuchi AT (2017). Remediation of contaminated lands in the Niger Delta, Nigeria: Prospects and challenges. Science of the Total Environment 586:952-965.

Vol. 16(9), pp. 335-354, September 2022
DOI: 10.5897/AJEST2022.3112
Article Number: 7821A2969719
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Impact of dust accumulation and deposits on polycrystalline solar panel: Case of Senegal

Abdoulaye Bouya Diop[1], Babacar Niang[1], Malick Wade[1], Aboubakary Diakhaby[1], Amadou Thierno Gaye[2] and Bouya Diop[1]*

[1]LSAOMED, Applied Science and Technology Training and Research Unit, Gaston University, BP 234, Saint-Louis 32000, Senegal.
[2]LPAOSF, Polytechnic School, Cheikh Anta Diop University, BP 5085, Dakar 10700, Senegal.

Received 4 April, 2022; Accepted 16 August, 2022

This study focuses on the Sahel, one of the areas with the highest concentration of desert dust, with source areas having fine particle emissions in Chad, Niger, Mauritania, etc. It also includes areas of subsidence of air masses that promote the deposition of dust, such as Senegal. It turns out that the countries of Sahel are among the poorest in the world. They have a relatively low electrification rate. However, this area is also characterized by its good solar potential which makes it an ideal place for the installation of photovoltaic solar collectors. Senegal has launched the challenge to solve this problem of electrification by turning to renewable energies. But being a drop zone, the sensors on the ground will be impacted. This study defines the impact of the thickness of the dust deposit layer on a polycrystalline photovoltaic sensor. By looking at the behaviour of irradiation and aerosol deposition in Senegal with the ERA5 and Giovanni data, the intra-annual profile of deposition and irradiation in Senegal was established. By applying the results obtained on the climatology of these parameters to a monocrystalline solar photovoltaic collector, it was contrasted that the evolution of the power, as well as the yield of the collector was strongly impacted by the accumulation of the deposit after 5 years. The power delivered by the collector went from 59.779 W during the month of the 1st year of accumulation to 4.28 W during the last month of the 5th year of accumulation. The resulting yield is also affected. More detailed illustrations are given in this work.

Key words: Dust, accumulation, photovoltaic, polycrystalline, efficiency, Senegal.

INTRODUCTION

Photovoltaic solar energy comes from the conversion of sunlight into electricity within semiconductor materials such as silicon covered with a thin metallic layer (Saint-Gregoire, 2009). These photosensitive materials have the property of releasing their electrons under the influence of external energy. This is the photovoltaic effect (Quilliet et al., 1960; Wilson and Woods, 1973). The energy is provided by photons (components of light) which strike the electrons and release them, inducing an electric current (Mouratoglou and Pierre-Guy 2009). This direct current is calculated in watt-peak (Wp) and can be transformed into alternating current using an inverter. The

*Corresponding author. E-mail: bouyadiop@gmail.com. Tel: +221-777946213.

Figure 1. Simplified diagram of the device for simulating dust deposition on a photovoltaic collector.
Source: Author

energy produced is available as direct electricity or stored in batteries (decentralised electrical energy) or as electricity fed into the grid. It is said to be renewable because its source (the sun) is considered inexhaustible on a human time scale (Dahmoun, 2021).

Countries in the Sahelian zone are continuously affected by the presence of dust in the atmosphere. As Senegal is located in an air mass subsidence zone, aerosols in our atmosphere tend to fall and form accumulations of deposits. Accumulations impact ground-based devices such as solar photovoltaic collectors. This study simulates the deposition of aerosol on a photovoltaic collector over 5 years, applying the results obtained from the climatology of irradiation and dry dust deposition.

This application was done by taking the first grid. This grid is for Senegal, a country that is beginning to turn to renewable energies, namely photovoltaic energy. The behaviour of these collectors in the presence of deposit accumulation is shown in this work.

MATERIALS AND METHODS

The aim of this study is to simulate the deposition of dust on a solar photovoltaic panel. In the present case the panel used is polycrystalline panel. The accumulation of deposits took place over 5 years.

We placed ourselves in the first grid, more precisely in Senegal. With the climatology of irradiation and dust deposition made previously using the ERA5 and Giovanni data, we were able to simulate the impact of prolonged dust deposition on PV panels with the appropriate equipment. The dust thickness at which the panel production reaches a critical threshold was determined. Figure 1 shows a simplified diagram of the set-up.

A RE550B solar simulator was installed and used as a light source to illuminate a 100 W polycrystalline solar panel. The panel is connected to a long-life battery which in turn is connected to a control console.

The panel is also connected to the control console, which allows to read the current and voltage characteristics of the panel, as well as other parameters such as the temperature of the panel and the irradiation received by the panel.

The light intensity received by the panel is calibrated by adjusting the distance between the panel and the solar simulator and by adjusting the number of lamps lit. After connecting the battery to the PV panel, it is connected to the control console to supply it with power. The console is supplied with power by the battery, which protects it from current fluctuations, voltage drops and power cuts. Once the installation is complete and the dust deposit in G1 in grams per square meter per month is known, the procedure of accumulating dust deposits on the sensor begin.

In order to know the thickness of the deposits on the collector, the density of the collected dust was first determined.

In this study 127.7 g occupies a volume of 100 ml, which gives 127.7×10-4 g/m^3. The present panel is about 1 m^2 in area considering the uniform deposition over the entire panel surface. The thickness of the deposit is obtained by taking the infinitesimal height of the cube formed by the deposit whose base area is the surface of the panel.

$P_{dust} = 127.7 \times 10^{-4}\ g/m^3$

$$\text{Cubic volume} = \text{Base area} \times \text{Height} = S_b \times H_{\text{épaisseur}} \quad (1)$$

The density is given by: $\rho_{dust} = \frac{m}{v}$ (2)

Knowing Equation 1:

$$\rho = \frac{m}{S \times H} \quad (3)$$

Knowing the density of the dust collected, as well as the base area of the deposit, for a mass of dust deposited on the panel the deposit thickness is given by Equation 4.

$$\text{Deposit thickness} = \frac{\text{deposit mass}}{\text{Deposit area} \times \rho\ \text{dust}} \quad (4)$$

All the manipulations in this part were done as follows.

A solar simulator type RE551B consists of a frame of 12 lamps,

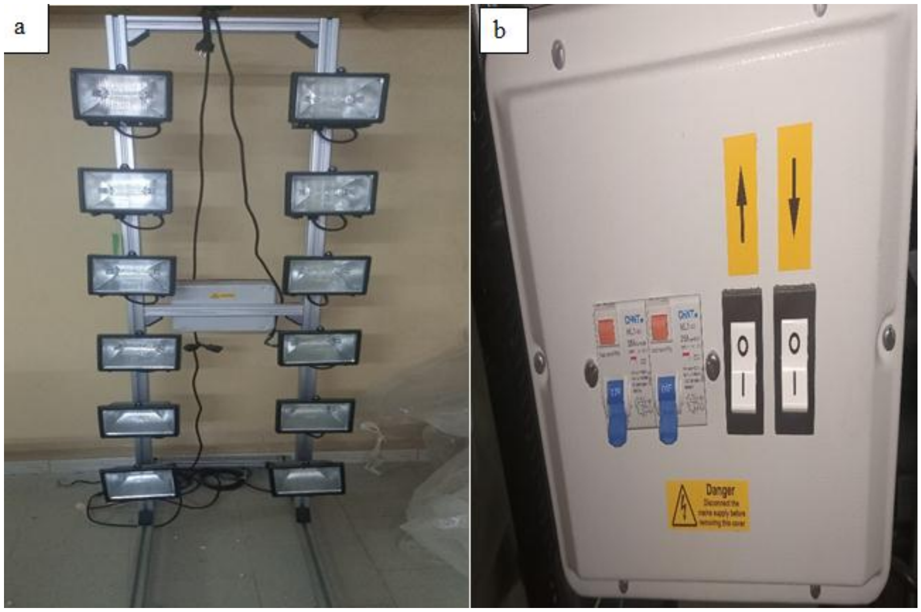

Figure 2. Test bench for a solar simulator type RE551B. (a) Left front view of the two 12-lamp blocks, (b) right rear view with the safety device consisting of switches and circuit breaker.
Source: Author

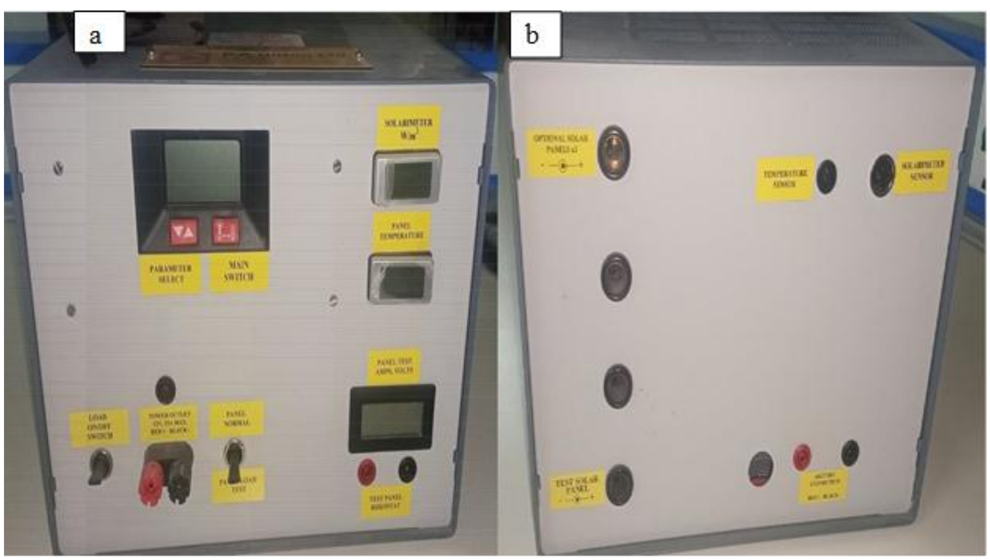

Figure 3. Control console allowing. (a) The top image is a front view of the console allowing the visualisation of the values associated with the different sensors. (b)The bottom image is a view from the back of the console.
Source: Author

each of which can deliver 500 W. The solar simulator is accompanied by a safety device containing two switches and two circuit breakers. The simulator consists of two blocks of 6 lamps and each block is controlled by a switch and a circuit breaker (Figure 2).

There is also a control console which allows the front panel to read the voltage and current delivered by a panel, the power of the solar flux and the temperature of the panel. On the rear panel are all the ports for connecting the various sensors to the console (Figure 3).

A rheostat is also used, which is nothing more than a manually

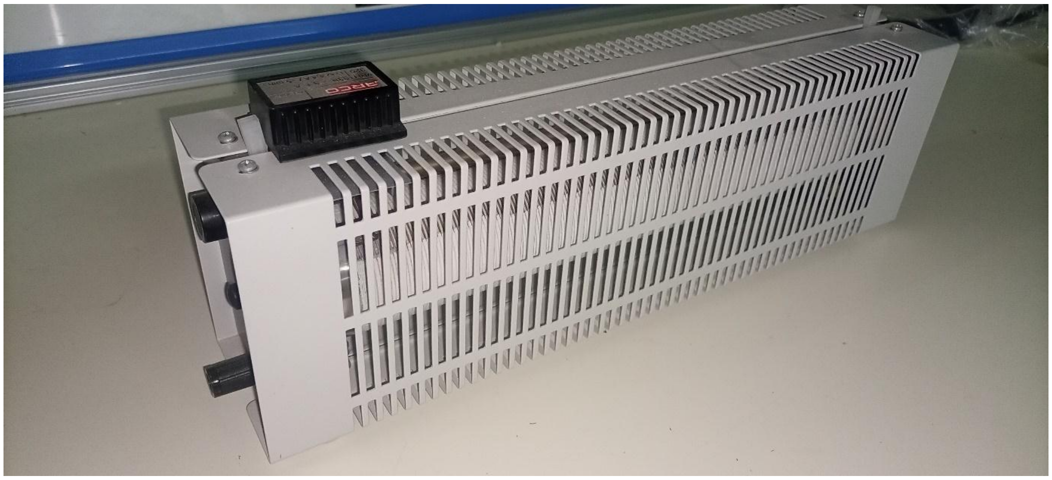

Figure 4. Perspective view of a rheostat.
Source: Author

Figure 5. AGM Series 3 battery used in our study.
Source: Author

variable resistor. In the present study, it is connected to our solar collector and then to the control console (Figure 4).

There is need for a battery that will be connected to both the PV solar collector and the console in order to have storage and also protect the console from being switched on or off too suddenly when it is directly connected to the panel (Figure 5).

There is need for a polycrystalline panel of one square meter on a tiltable bench, with a power of 100 W, an open circuit voltage of 21.84 V, a short circuit current of 6.11 A, a maximum power voltage of 17.99 V and a maximum power current of 5.57 A (Figure 6).

Finally, there is a precision balance, a low-profile beaker with a graduated scale for weighing the dust collected (Figure 7).

In this work, UV index aerosols (AUVI) and dust depositions were used. The data were derived from MODIS sensor on the Terra and Aqua satellites. The AUVI data were initially derived from the Total Ozone Mapping Spectrometer (TOMS) version 8 daily global gridded data product (EP) containing total column ozone, UV aerosol index, Lambertian effective surface reflectivity (Rayleigh corrected) and local noontime UV-B irradiances. The data were considered in a global grid of size 180° × 288° with a lat-long resolution of 1.00 × 1.25 degrees. The AUVI were also obtained from the OMI science team. The OMTO3d product is produced by meshing and averaging only good quality orbital data over the total ozone level 2 (OMTO3, based on the improved TOMS version-8 algorithm) on grids of resolutions 1°×1°.

These data are pre-processed by Acker in 2014 on the https://giovanni.gsfc.nasa.gov/giovanni/).The irradiation is directly extracted from the ERA5 platform. ERA5 is the fifth generation of ECMWF reanalysis for global climate and weather for the last 4 to 7 decades. Currently, data are available from 1979 onwards. ERA5 re-places the ERA-Interim reanalysis. The data were re-gridded to a regular lat-lon grid of 0.25° for the reanalysis and 0.5° for the

Figure 6. 100 W polycrystalline photovoltaic solar panel: (a) bottom view, (b) top view.
Source: Author

Figure 7. Top view of the precision balance on which the low-profile graduated beaker containing dust is placed.
Source: Author

Table 1. Summary of maximum irradiance in W/m2 in each grid.

Grid	January	February	March	April	May	Jun	July	August	September	October	November	December	Average
Grid 1	479.55	525.46	574.07	613.43	611.11	618.06	615.74	590.28	562.50	525.46	481.48	467.59	569.13
Grid 2	491.49	527.78	574.07	604.17	594.91	620.37	615.74	590.28	576.39	534.72	500.00	479.17	571.09
Grid 3	510.26	553.24	594.91	620.37	601.85	625.00	615.74	590.28	581.02	557.87	525.46	497.69	573.09
Grid 4	511.22	543.98	601.85	641.20	648.15	645.83	622.69	590.28	592.59	555.56	520.83	497.69	573.14
Grid 5	517.98	555.56	523.15	657.41	655.09	645.83	625.00	590.28	590.28	550.93	532.41	497.69	571.18
Grid 6	508.93	548.61	587.96	625.00	571.76	622.69	599.54	590.28	562.50	532.41	509.26	490.74	568.75
Grid 7	534.84	527.78	576.39	613.43	625.00	613.43	599.54	590.28	567.13	555.56	604.17	488.43	571.89
Average	**507.75**	**540.34**	**576.06**	**625.00**	**615.41**	**627.31**	**613.43**	**590.28**	**576.06**	**544.64**	**524.80**	**488.43**	

Source: Author

uncertainty estimation. There are four main subsets: hourly and monthly products, both on pressure levels (upper air fields) and single levels (atmospheric, ocean wave and land surface quantities).

RESULTS AND DISCUSSION

Table 1 and Figure 8 summarize the variation of maximum solar radiation observed over 30-year monthly averages from 1980 to 2010. The results are close to Soulouknga et al. (2017). For each of the seven grids of the 10-20 bands, the highest values are observed in April, June and July. The observations found were in line with Bilal et al. (2007).

Table 2 and Figure 9 give the average dust deposition on each of the seven grids of the 10-20 bands; the results are close to Orange et al. (1990). It can be seen that in January and February the maximum deposition is located on the first grid (G1), with a monthly average per square meter per month exceeding 2.5 g. Grids G3 and G4 have a deposition of 2.28 g during these first months (Soleilhavoup, 2011). G2 and G6 have 1.52 g of deposition. G5 and G7 have the lowest deposits in January and February (0.76 g).

For the month of March, G3 and G4 keep the same deposit values. However, G1, G2 and G6 have a deposit of 1.9 g. The deposit values in G5 and G7 remain the same as in January and February.

In April the deposit in G1 rises slightly as well as in G3 with a value of 2.9 grams. G2 and G4 keep the same values as G2 in March. The deposits for G5 and G6 remain the same as in January and February, while the deposit in G7 drops to 0.38 g.

May and June have quite similar profiles with a slightly higher deposition in G1 for May; but, it was higher in G5, G6, and G7 for June.

In July the deposition values in G1 do not change compared to the previous month and the deposition in G3 increases to the same value as in G1. The deposits in G2, G3, G5 and G7 also remain the same as in June. In G6, there is a slight decrease.

In August the deposition in the first four grids decreases, but in G5 and G6, we have the same variations as in June with a deposition of 1.4 g/m^2/month; while the deposition in G7 remains almost the same.

In September the lowest deposition values are noted for G1, G2, G3, and G4, with 1.4 g. In G5 and G7, the same deposits are noted. In G6, we have the same values as in the first three grids. In October, November and December, we note that the deposit in G1 remains the same as in September, but in G2, G3 and G4 it rises again to the same values as in January, that is, 1.5 and 2.28 g, respectively.

It is interesting to note the downward trend of dust deposit in G1 between January and December.

During and after the passage of Ultraviolet Index Aerosols (AUVI), deposits are noted in the 10-20 bands. Countries like Senegal, the two Guineas, part of Mali, Burkina Faso, Niger, Chad and Nigeria are covered by the deposit depending on the month. A maximum deposition in grids 3 and 4 is noted in November and December. This concerns Niger and part of Chad, because these two grids are source zones. According to the process of uplift, transport and deposition of fine particles, aerosols and the sandblasting process are favoured by harmattan circulation. A large part

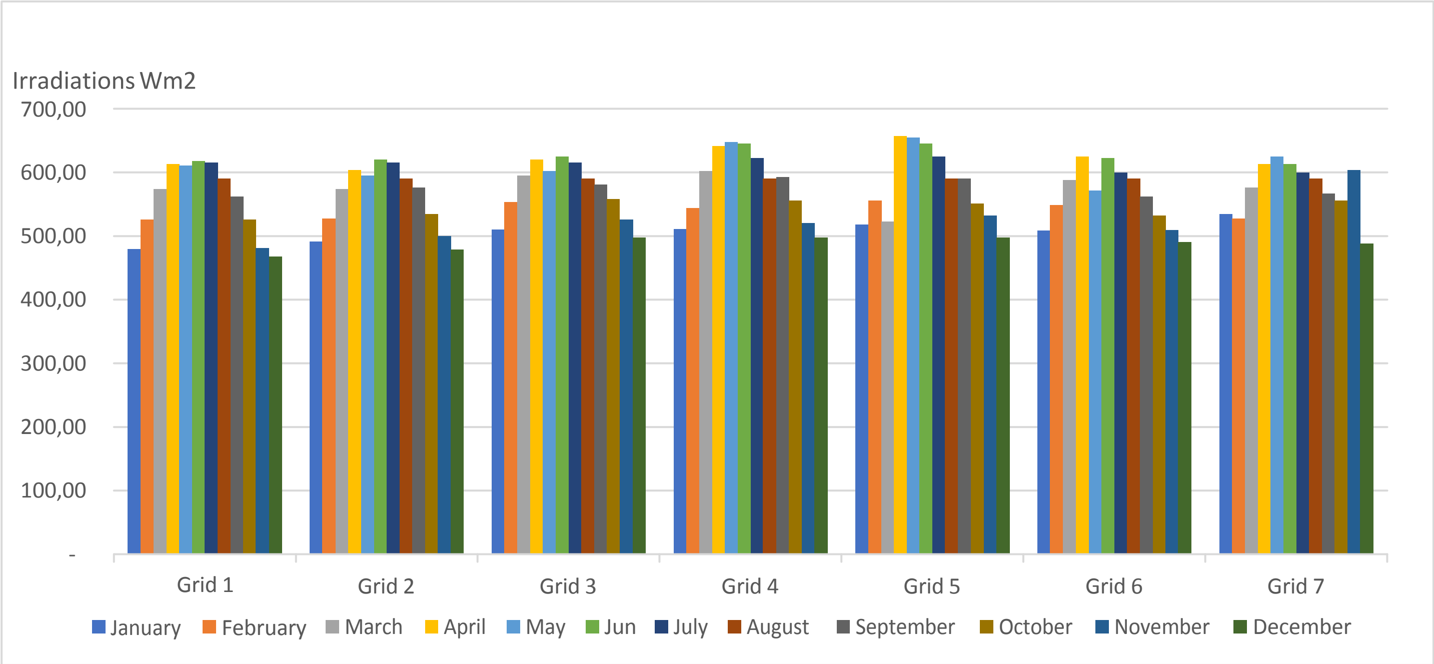

Figure 8. Variation of maximum solar irradiance in W/m2 in the 10-20 band: monthly average in each grid of the band monthly average from 1980-2010.
Source: Author

Table 2. Summary of maximum dust deposition in g/m^2/month in each grid of the 10-20 band.

Grid	January	February	March	April	May	June	July	August	September	October	November	December
Grid1	2.66	2.66	1.90	2.28	2.28	1.90	1.90	1.52	1.14	1.14	1.14	1.14
Grid2	1.52	1.52	1.90	1.90	1.52	1.52	1.52	1.33	1.14	1.14	1.52	1.52
Grid3	2.28	2.28	2.28	2.28	1.52	1.52	1.52	1.33	1.14	1.52	2.28	2.28
Grid4	2.28	2.28	2.28	1.90	1.52	1.52	1.90	1,52	1.14	1.52	2.28	2.28
Grid5	0.76	0.76	0.76	0.76	0.95	1.14	1.14	1.14	0.76	0.76	0.76	0.76
Grid	1.52	1.52	1.90	1.52	0.95	1.14	0.95	1.14	1.14	0.76	1.52	1.52
Grid7	0.76	0.76	0.76	0.38	0.57	0.76	0.76	0.76	0.76	0.38	0.38	0.38

Source: Author

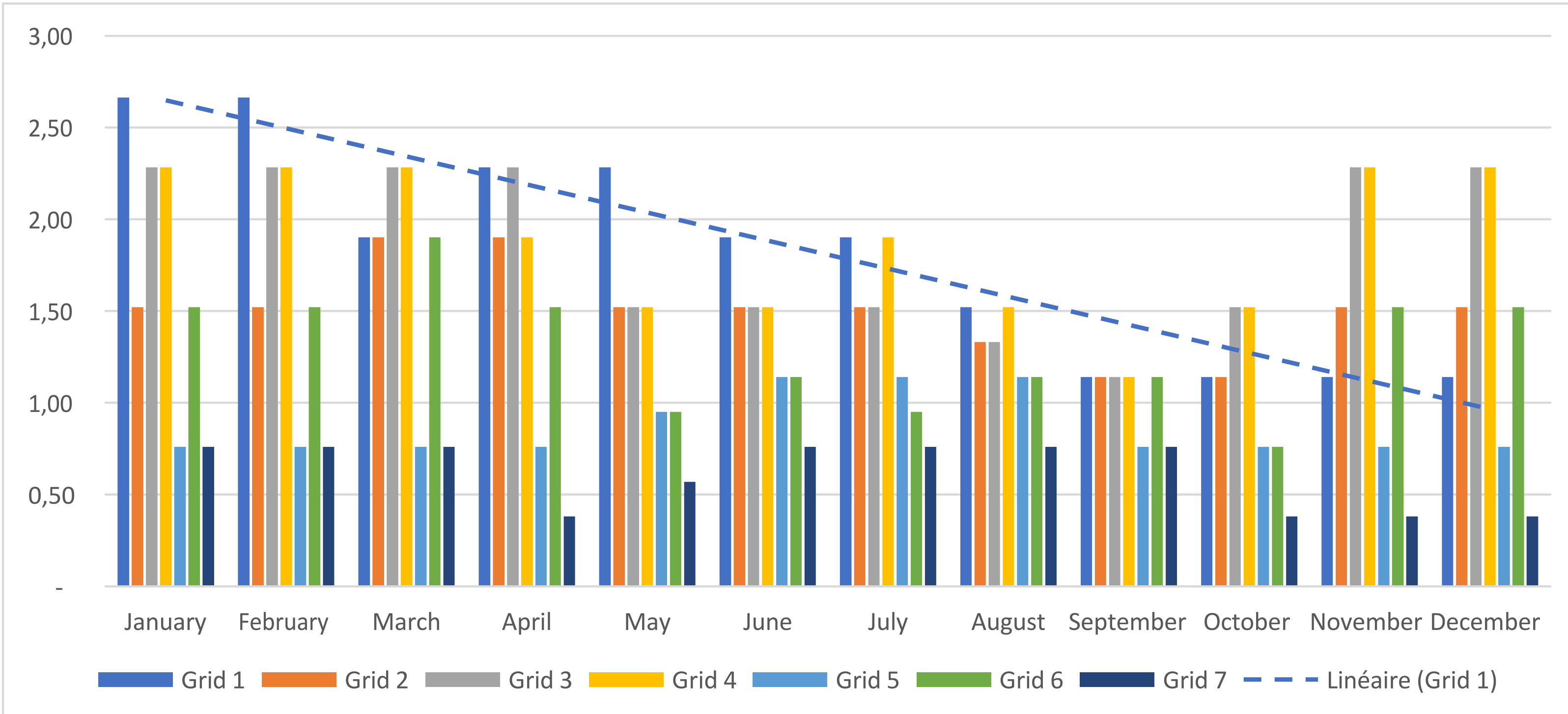

Figure 9. Climatic variability of maximum dust deposition in the 10-20 band from 1980 to 2010: monthly average in each grid of the band.
Source: Author

of the particles fall first on and around this same uplift zone, hence we have maximum deposits in Niger and Chad area. In January and February, the maximum deposits are located in grids 1 and 2. These two grids mainly cover Senegal and part of Mali. There are correlations between the deposition observed in the Chad-Niger region and the deposition in the Senegalo-Malian region. After the uplift of aerosols in grids 3 and 4, particles smaller than or equal to 20 µm are transported over thousands of kilometres in the lower and middle layers of the atmosphere; they end up arriving in grids 1 and 2. A shift of 'about 1 month and a half is observed. A significant deposit is observed in January, February, June and August in the Tchat-Niger region as well as Senegal-Malian zone in March, April, May, July and September.

Regarding the evolution of PV production in the absence of collector deposition, Table 3 gives a summary of the evolution of the current, voltage and power characteristics of a solar PV panel as a function of the average monthly irradiation in G1, which includes Senegal. In this table, it is considered that there is no deposition and therefore no accumulation; the powers obtained are optimal.

The evolution of the PV production for a year of deposit accumulation on the collector is shown in Table 4. The evolution of the PV production during the 2nd year of deposit accumulation on the collector is shown in Table 5. The evolution of the PV production during the 3rd year of deposition on

Table 3. Summary of power generated in a deposit year in grid 1 with no deposit.

Month	**January**	**February**	**March**	**April**	**May**	**Jun**	**July**	**August**	**September**	**October**	**November**	**December**
Deposit	0	0	0	0	0	0	0	0	0	0	0	0
Irra-medium (W/m^2)	479.55	525.46	574.07	613.43	611.11	618	615	590.74	562.5	425.46	481.48	467.59
Current I (A)	2.93	2.94	3.2	3.4	3.06	3.17	3.15	3.17	3.14	3.12	3.11	3.01
Voltage V (V)	20.4	19.9	18.7	18.7	18.5	18.4	18.4	18.3	18.1	18.1	18.1	18
Accum 0 (g/m^2)	0	0	0	0	0	0	0	0	0	0	0	0
Power (w)	59.772	58.506	59.84	63.58	56.61	58.328	57.96	58.011	56.834	56.472	56.291	54.18

Source: Author

Table 4. Summary of power output in Watt in relation to the 1st year of accumulation Maximum dust deposit in g/m^2 in the grid 1.

Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Deposit	2.66	2.66	1.9	2.28	2.28	1.9	1.9	1.52	1.14	1.14	1.14	1.14
Irra-Medium(W/m^2)	570	570	570	570	570	570	570	570	570	570	570	570
Current I (A)	3.11	2.9	2.83	2.6	2.3	2.23	2.14	2.12	2.13	2.11	2.09	2.1
Voltage V (V)	18.3	18.1	17.9	17.9	17.8	17.8	17.7	17.7	17.7	17.7	17.6	17.6
Accum 1 (g/m^2)	2.66	5.32	7.22	9.5	11.78	13.68	15.58	17.1	18.24	19.38	20.52	21.66
Power (w)	56.913	52.49	50.657	46.54	40.94	39.694	37.878	37.524	37.701	37.347	36.784	36.96

Source: Author

Table 5. Summary of the power in Watt produced in relation to the 2nd year of accumulation Maximum dust deposit in g/m2 in the grid 1.

Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Deposit	2.66	2.66	1.9	2.28	2.28	1.9	1.9	1.52	1.14	1.14	1.14	1.14
Irra-Medium (W/m^2)	570	570	570	570	570	570	570	570	570	570	570	570
Current I (A)	2.03	1.77	1.75	1.67	1.4	1.4	1.4	1.4	1.4	1.37	1.37	1.2
Voltage V (V)	17.6	17.5	17.5	17.5	17.5	17.4	17.4	17.4	17.4	17.3	17.3	17.3
Accum 2 (g/m^2)	24.32	26.98	28.88	31.16	33.44	35.34	37.24	38.76	39.9	41.04	42.18	43.32
Power (w)	35.728	30.975	30.625	29.225	24.5	24.36	24.36	24.36	24.36	23.701	23.701	20.76

Source: Author

the collector is shown in Table 6. The evolution of the PV production during the 4th year of deposit accumulation on the collector is shown in Table 7. The evolution of the PV production during the 5th year of deposit accumulation on the collector is shown in Table 8.

Tables 4 to 8 summarize the behaviour of the current, voltage and power characteristics as a function of the evolution of the accumulation of dust on the collector. The accumulation is simulated over 5 years. Table 4 summarizes the behaviour of the panel during the first year of dust accumulation. In Tables 5, 6, 7 and 8, we have, respectively, the 2nd, 3rd, 4th and 5th years.

Figure 10 shows the evolution of the power produced by the panel during the first year of accumulation. Between January and June the power produced by the panel falls more rapidly, for a deposit of 2.66 g; we have a power of 56.9 W in January. In June, for a deposit of 13.68 g on the sensor, we have a power of 39.64 W. Between June and December, that is, the 6 and 12th month, the decrease of power, although present, is less marked; we note a loss of 2 W.

In the second year of accumulation, as shown in Figure 11, the power loss is less regular than in the first year of accumulation. In fact, between the 13 and 14th, 16 and 17th, 23rd and 24th months, the power drops are more significant for the other months. It is also noticed that during the second year of accumulation, the loss of power is very minimal between the 17th and 23rd months.

During the third year of accumulation, between the 25 and 30th months, the power hardly changes despite the accumulation of deposits; it is between the 31st and 33rd months that a significant drop was observed (Figure 12).

In the 4th year of deposit accumulation, Figure 13 shows the shape of the curve is reversed compared to the 3rd year. Between the 36 and 38th months, the decrease in power is slightly visible, although very small. It is between the 38 and 40th months that the decrease in power is most significant. Between the 40 and 48th months, the power continues to decrease but more moderately. These results are similar to those of Diop et al. (2021), Ndiaye et al. (2017) and Neher et al. (2017).

With the 5th year of accumulation (Figure 14), the power is at its lowest with 8.36 W in month 49, 5 W in month 51 and 4.28 W in month 60.

In the first year of accumulation of dust deposits we have for the first month a deposit of 2.66 g and a power of 56.9 W; in the 12th month the deposit was 21.66 on the collector and the power delivered was 36.96 W, that is, a power loss of 19.97 W.

In the second year of accumulation, in the 13th month the deposit is 24.32 g, the power produced is 35.7 W; in the 24th month the accumulation is 43.32 g and the power delivered by the collector is 20.76 W, that is, a power loss of 14.94 W. For the 3rd year, at the 25th month, the accumulation is 45.98 g for a power of 20.4 W; at the 36th month for 64.98 g of accumulation on the collector we have a power of 15.51 W, that is, a power loss of 4.89 W. At the 4th year, for a deposit of 67.64 g, we have a power of 13.77 W in the 37 and 48th month, an accumulation of 86.64 g with a power of 8.29 W, that is a power loss of 5.48 W. In the 5th year of deposit accumulation, the power is 8.15 W, for an accumulation of 89.3 g in the 49th month and in the 60th month the power drops to 4.28 W, for a deposit of 108.3 g; there was a power loss of 3.87 W. It can be seen that the power losses go from almost 20 W in the first year of accumulation to 3.87 W in the last year of accumulation, so there is an inverse evolution between the gradient of loss of the accumulation on the collector. However, the power still increases from 56.9 to 4.28 W in 5 years of dust accumulation on the PV collector. Table 9 summarizes the evolution of PV performance in the absence of deposits. Tables 10 to 14 summarise the evolution of the PV performance with respect to the thickness of the deposit on the collector.

In Figure 15 the collector efficiency decreases with increasing deposition thickness for the first year between the 1st and 7th months. As the deposition thickness increased from 2 to 10 µm the efficiency dropped from 10 to 6%. Between the 8 and 12th months the deposit thickness increased from 12 to 17 µm but the yield remained constant at 6%.

For the second year (Figures 16 and 17), the evolution of the yield goes from 6.2 to 4.2% between 13 and 17th months at the same time as the thickness of the deposit goes from 19 to 26 µm. It remains relatively constant while the thickness increases between the 18 and 24th month from 27 to 33.9 µm.

In the third year (Figures 18 and 19), the yield remains constant between the 25 and 30th months at 3.5% while the thickness increases from 36 to 40 µm. It is between the 34 and 35th months that the yield drops again significantly to 2.7%, with a deposit of 49 µm thickness.

With the 4th year (Figures 20 and 21), the yield is 2.3% at month 39; at 1.45% the deposit thickness is 67.8 µm.

From the 5th year (Figures 22 and 23) to the 50th month, the deposit thickness is 73.5 µm and the yields become almost zero.

This decrease of the production of the PV collector is because desert dust results from the cracks of quartz grains, which have reflecting and absorbing properties. Therefore, when the radiation arrives on the plate covered with a layer of dust, part of the radiation is reflected, part is absorbed and another is transmitted. When the thickness of the deposit increases, the part of the radiation absorbed increases. This reduces the irradiation transmitted to the panel and consequently the energy produced by the panel.

Quick increase in the thickness of deposit affects the PV yield more than the same amount of deposit accumulation but over a longer period of time. It is

Table 6. Summary of power output in Watt in relation to the 3rd year of accumulation Maximum dust deposit in g/m2 in the grid 1

Month	January	February	March	April	May	June	July	August	September	October	November	December
Deposit	2.66	2.66	1.9	2.28	2.28	1.9	1.9	1.52	1.14	1.14	1.14	1.14
Irra-Medium(W/m^2)	570	570	570	570	570	570	570	570	570	570	570	570
Current I (A)	1.2	1.2	1.2	1.2	1.2	1.2	1.16	1.16	1	0.94	0.94	0.94
Voltage V (V)	17	16.9	16.9	16.7	16.7	16.7	16.7	16.6	16.6	16.6	16.5	16.5
Accum 3 (g/m^2)	45.98	48.64	50.54	52.82	55.1	57	58.9	60.42	61.56	62.7	63.84	64.98
Power (w)	20.4	20.28	20.28	20.04	20.04	20.04	19.372	19.256	16.6	15.604	15.51	15.51

Source: Author

Table 7. Summary of the power in Watt produced in relation to the 4th year of accumulation Maximum dust deposit in g/m^2 in the grid 1.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Deposit	2.66	2.66	1.9	2.28	2.28	1.9	1.9	1.52	1.14	1.14	1.14	1.14
Irra-Medium (W/m^2)	570	570	570	570	570	570	570	570	570	570	570	570
Current I (A)	0.84	0.84	0.84	0.65	0.61	0.6	0.6	0.6	0.6	0.58	0.58	0.58
Voltage V (V)	16.4	16.1	16	15.9	15.6	15.1	14.7	14.6	14.3	14.3	14.3	14.3
Accum 4 (g/m^2)	67.64	70.3	72.2	74.48	76.76	78.66	80.56	82.08	83.22	84.36	85.5	86.64
Power (w)	13.776	13.524	13.44	10.335	9.516	9.06	8.82	8.76	8.58	8.294	8.294	8.294

Source: Author

Table 8. Summary of the power in Watt produced in relation to the 2nd year of accumulation Maximum dust deposit in g/m^2 in the grid 1.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Deposit	2.66	2.66	1.9	2.28	2.28	1.9	1.9	1.52	1.14	1.14	1.14	1.14
Irra-Medium(W/m^2)	570	570	570	570	570	570	570	570	570	570	570	570
Current I (A)	0.57	0.45	0.45	0.45	0.43	0.43	0.43	0.43	0.42	0.41	0.41	0.4
Voltage V (V)	14.3	14.2	11.3	11.3	11.2	11.2	11.2	11.2	11	10.9	10.7	10.7
Accum 5 (g/m^2)	89.3	91.96	93.86	96.14	98.42	100.32	102.22	103.74	104.88	106.02	107.16	108.3
Power (w)	8.151	6.39	5.085	5.085	4.816	4.816	4.816	4.816	4.62	4.469	4.387	4.28

Source: Author

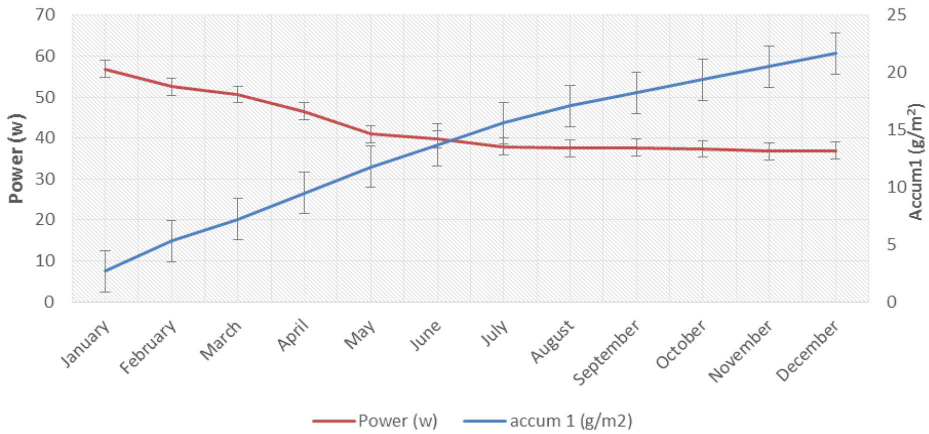

Figure 10. Power output in Watt in relation to the 1st year of accumulation Maximum dust deposit in g/m^2 in the grid 1.
Source: Author

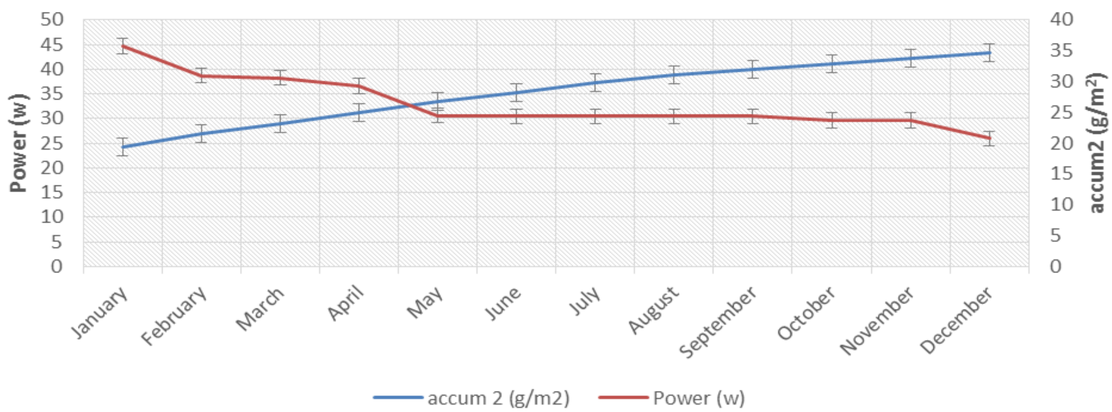

Figure 11. Power output in Watt in relation to the 2nd year of accumulation Maximum dust deposit in g/m^2 in the grid 1.
Source: Author

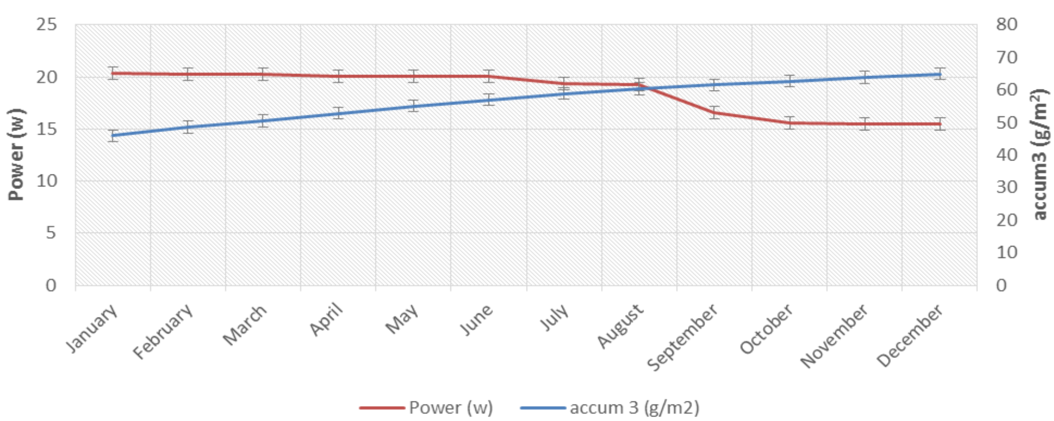

Figure 12. Power in Watts produced in relation to the 3rd year of accumulation maximum dust deposit in g/m^2 in grid 1.
Source: Author

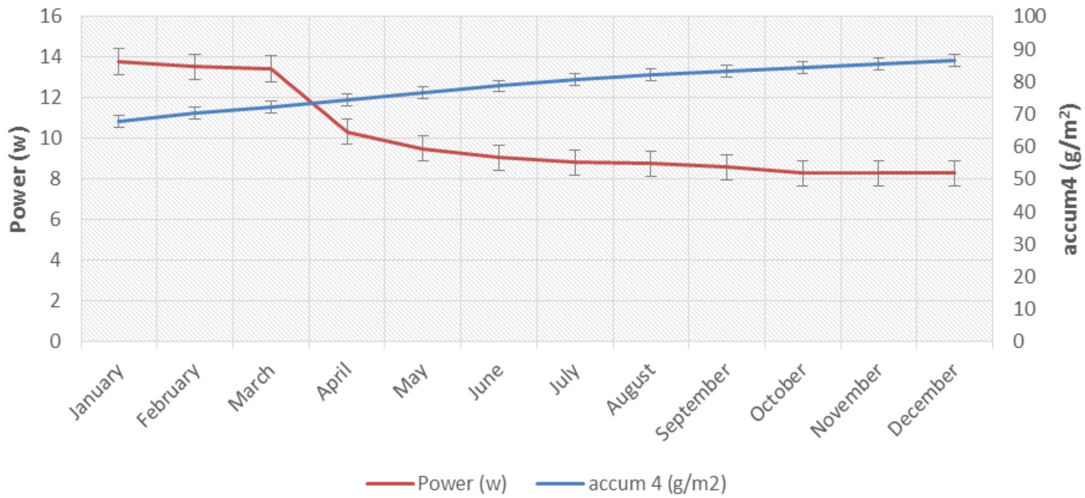

Figure 13. Power in Watt produced in relation to the 4th year of accumulation Maximum dust deposit in g/m2 in the grid 1.
Source: Author

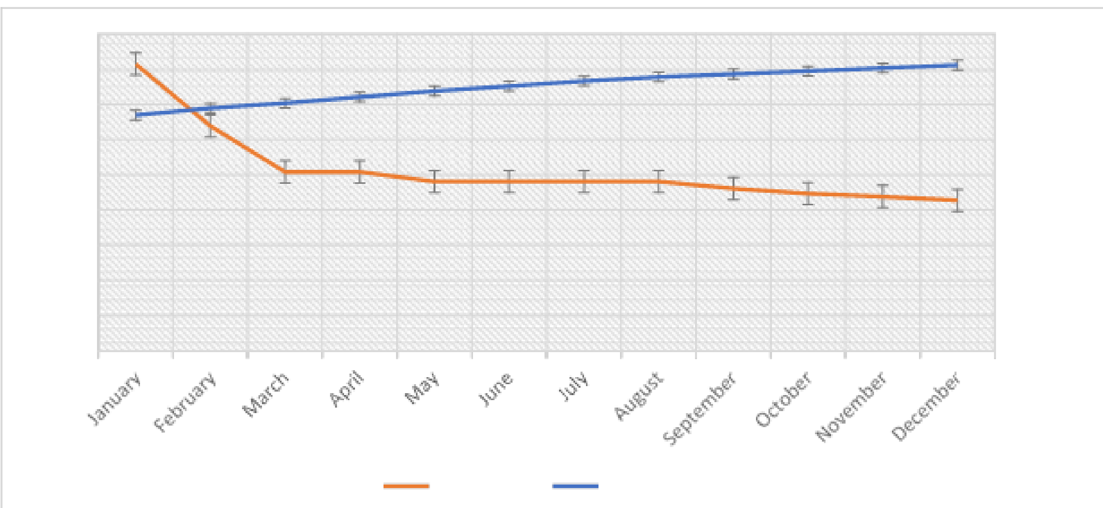

Figure 14. Power in Watt produced in relation to the 5th year of accumulation Maximum dust deposit in g/m2 in the grid 1.
Source: Author

because a sudden accumulation of deposit is synonymous with strong absorption. In fact, the mass deposit is associated with an exponential extinction coefficient. The ratio of the luminance after crossing this medium with the luminance of a source before crossing a medium is equal to $I(\lambda)/I_0(\lambda) = e^{-\tau(\lambda)}$, with optical thickness τ(λ) which measures the part of the energy lost by absorption. As a result, on our solar collector, when the accumulation of deposits grows very quickly, the optical thickness increases the absorption of light exponentially.

CONCLUSION AND PERSPECTIVES

The study reveals good solar potential in the 10° North - 20° North band, which exceeds 500 W/m^2 from February to November. This attests to the good capacity to receive

Table 9. Evolution of the annual PV yield in the absence of deposit.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Power (w)	59.772	58.506	59.84	63.58	56.61	58.328	57.96	58.011	56.834	56.472	56.291	46.18
Efficiency	0.124641	0.111342	0.104238	0.103646	0.092634	0.094381	0.094243	0.098200	0.101038	0.132731	0.116912	0.115870

Source: Author

Table 10. Evolution of PV yield in one year of deposit accumulation.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Efficiency	0.099847	0.092087	0.08887	0.081649	0.071824	0.069638	0.066452	0.065831	0.066142	0.065521	0.064533	0.064842
Deposit thickness (m)	2.08E-06	4.17E-06	5.65E-06	7.44E-06	9.22E-06	1.07E-05	1.22E-05	1.34E-05	1.43E-05	1.52E-05	1.61E-05	1.70E-05

Source: Author

Table 11. Evolution of PV yield after 2 years of deposit accumulation.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Efficiency	0.062680	0.054342	0.05372	0.05127193	0.042982	0.042736	0.042736	0.042736	0.042736	0.041580	0.041580	0.036421
Deposit thickness (m)	1.90E-05	2.011E-05	2.26E-05	2.44E-05	2.62E-05	2.77E-05	2.92E-05	3.04E-05	3.12E-05	3.21E-05	3.30E-05	3.39E-05

Source: Author

Table 12. Evolution of PV yield after 3 years of deposit accumulation.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Efficiency	0.035789	0.035578	0.035578	0.035157	0.035157	0.035157	0.033985	0.033782	0.029122	0.027375	0.0272105	0.0272105
Deposit thickness (m)	3.60E-05	3.81E-05	3.96E-05	4.14E-05	4.31E-05	4.46E-05	4.61E-05	4.73E-05	4.82E-05	4.91E-05	5.00E-05	5.09E-05

Source: Author

Table 13. Evolution of PV yield after 4 years of deposit accumulation.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Efficiency	0.02416	0.02372	0.02357	0.01813	0.01669	0.01589	0.01547	0.01536	0.01505	0.01455	0.01455	0.01455
Deposit thickness in (m)	5.30E-05	5.51E-05	5.65E-05	5.83E-05	6.01E-05	6.16E-05	6.31E-05	6.43E-05	6.52E-05	6.61E-05	6.70E-05	6.78E-05

Source: Author

Table 14. Evolution of PV yield after 5 years of deposit accumulation.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Efficiency	0.0143	0.011210	0.008921	0.008921	0.008449	0.008449	0.008449	0.008449	0.008105	0.007840	0.007696	0.007508
Deposit thickness in (m)	6.99E-05	7.20E-05	7.35E-05	7.53E-05	7.71E-05	7.86E-05	8.00E-05	8.12E-05	8.21E-05	8.30E-05	8.39E-05	8.48E-05

Source: Author

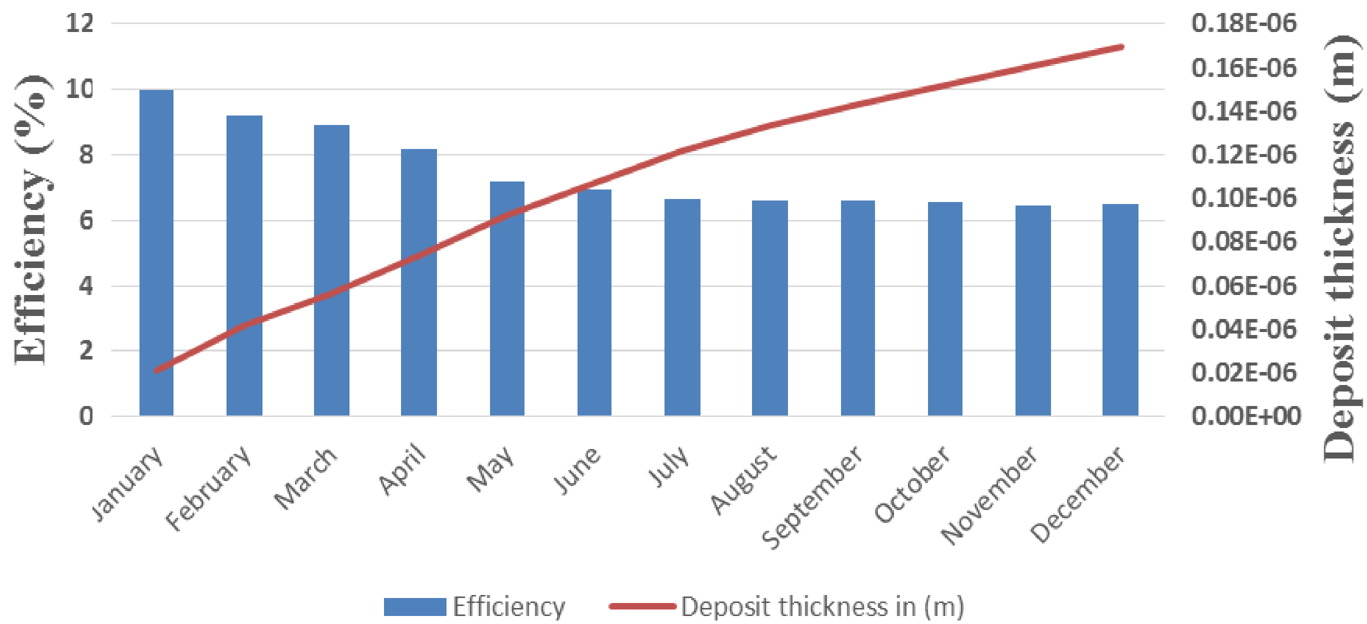

Figure 15. Evolution of PV yield versus deposit thickness in the first year of deposit accumulation.
Source: Author

photovoltaic devices from the countries of the Sahelian zone, in particular Senegal. However, the study of the dust deposit reveals that Senegal characterized by grid 1 is the most impacted from January to July. In this work the results showed that when the dust deposit thickness is equal to 24.4µm the efficiency decreases by half and when it reaches 73.5 µm the PV efficiency starts to become almost zero. The other interesting fact is that it is the rapid increase of the deposit thickness that affects the efficiency more, than when it is more moderate. With this work it will be easier to predict how often the collectors should be cleaned, and after how long without cleaning the sensor will enter a critical phase of production

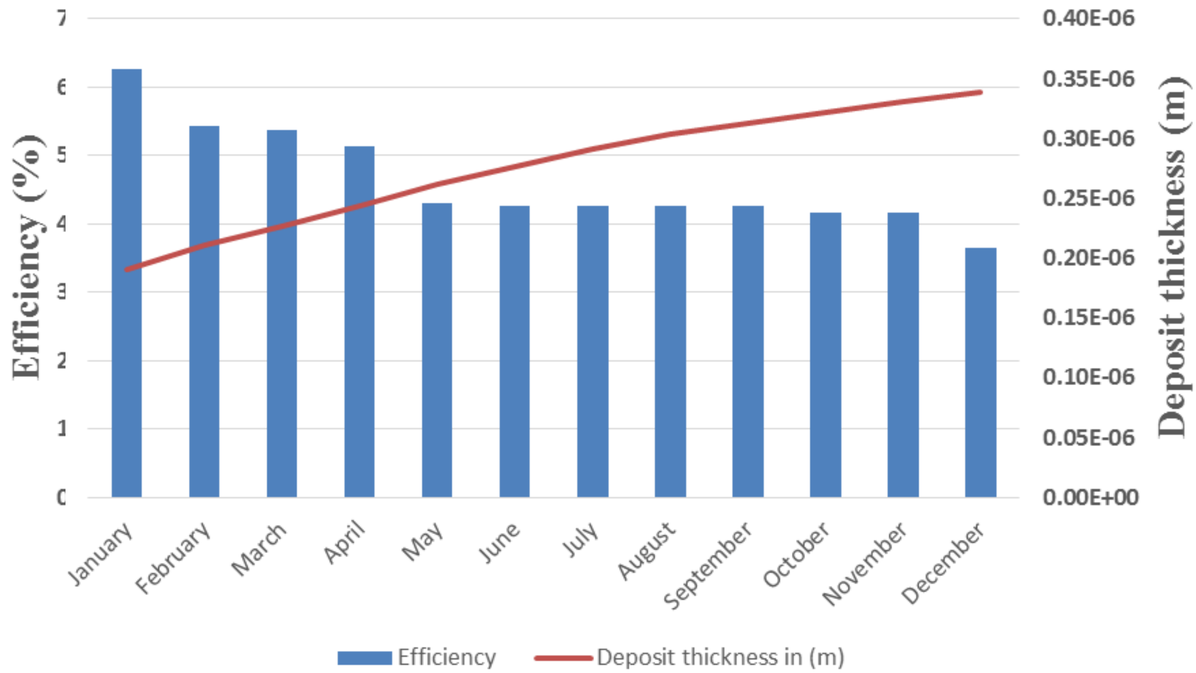

Figure 16. Evolution of PV yield versus deposit thickness in the 2nd year of deposit accumulation.
Source: Author

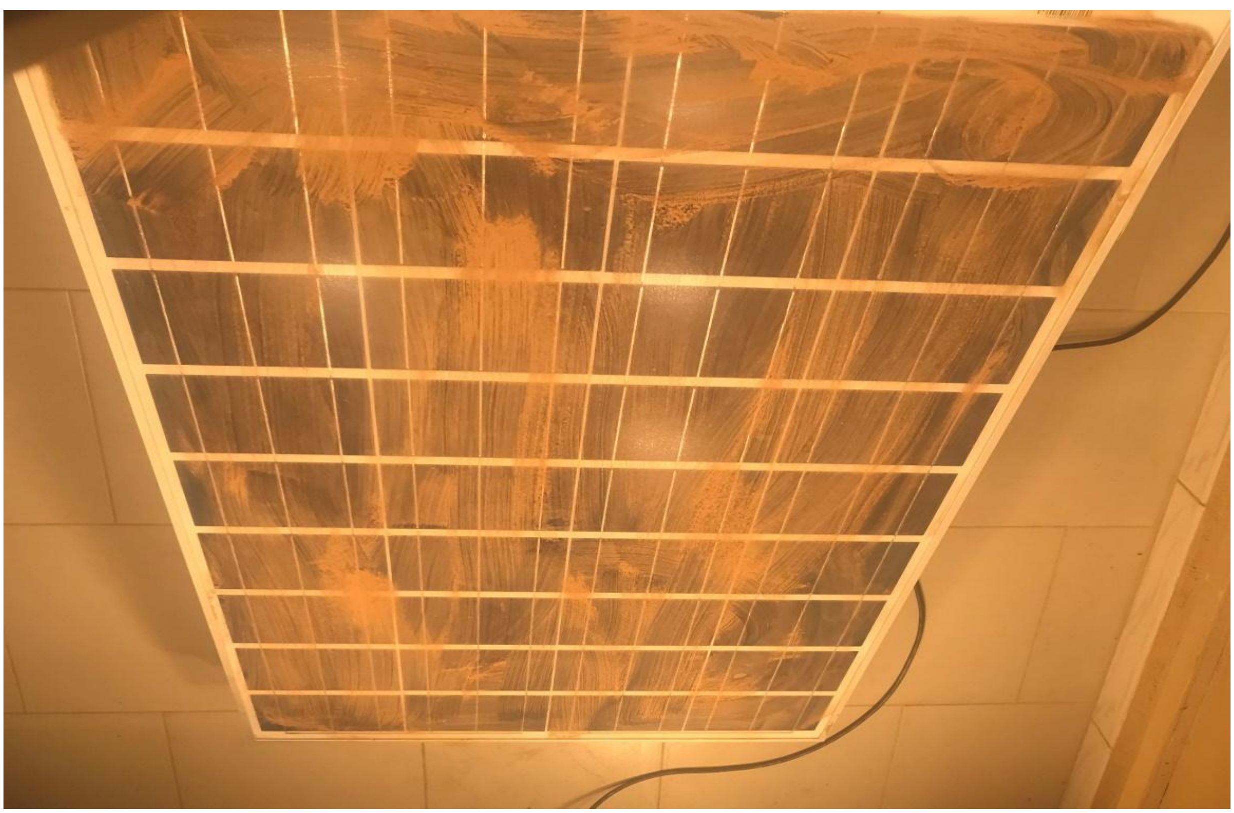

Figure 17. 2nd year of deposit accumulation on the polycrystalline PV panel.
Source: Author

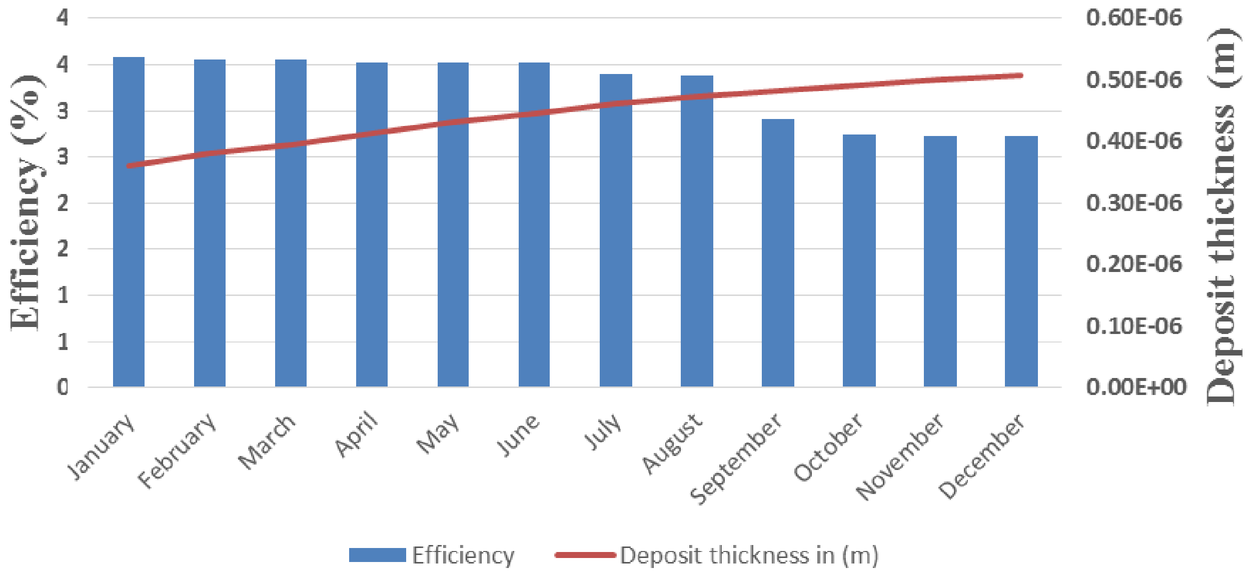

Figure 18. Evolution of PV yield versus deposit thickness in the 3rd year of deposit accumulation.
Source: Author

Figure 19. 3rd year of deposit accumulation on the polycrystalline PV panel.
Source: Author

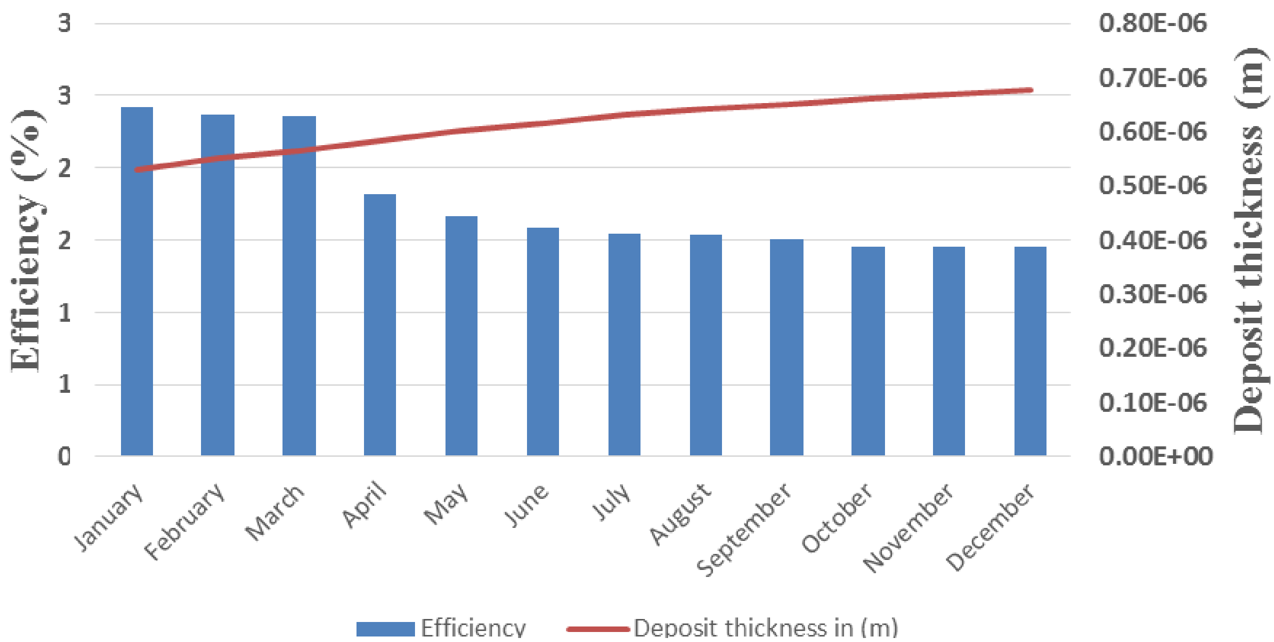

Figure 20. Evolution of PV yield versus deposit thickness in the 4th year of deposit accumulation.
Source: Author

Figure 21. 4th year of deposit accumulation on the polycrystalline PV panel.
Source: Author

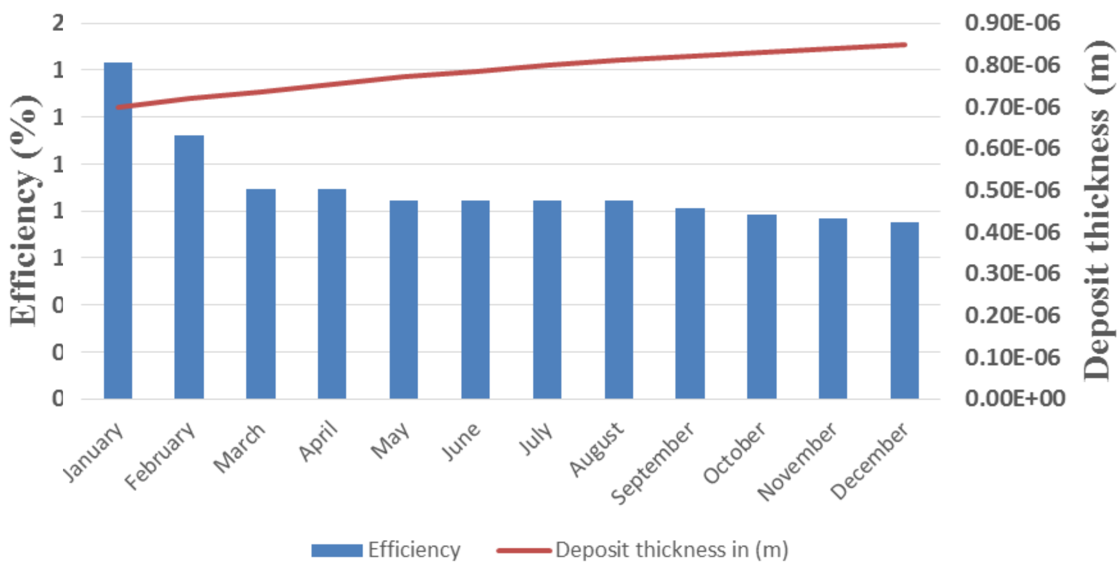

Figure 22. Evolution of PV yield versus deposit thickness in the 5th year of deposit accumulation.
Source: Author

Figure 23. 6th year of deposit accumulation on the polycrystalline PV panel.
Source: Author

in relation to the user's needs.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Bilal BO, Sambou V, Kébé CMF, Ndongo M, Ndiaye PA (2007). Study and Modeling of the Solar Potential of the Nouakchott and Dakar Sites. Journal of Sciences 7:57-66.

Dahmoun WI (2021). "Renewable energies: one of the pivots of sustainable development in Algeria." International Journal of Advanced Research on Planning and Sustainable Development 4.

Diop D, Moulaye D, Abel S, Pascal DB, Serigne AAN, Astou S 2021). "Influence of Dust Deposition on the Electrical Parameters of Silicon-Based Solar Panels Installed in Senegal (Dakar Region). Energy and Power Engineering 13(5):174-189.

Mouratoglou P, Pierre-Guy T (2009). "Photovoltaic solar energy." Industrial Realities 4:91-70. Réalités industrielles - Novembre 2009 - L'électricité solaire et les pays de la Méditerranée (annales.org)

Ndiaye A, Kébé CM, Bilal BO, Charki A, Sambou V, Ndiaye PA (2017). Study of the correlation between the dust density accumulated on photovoltaic module's surface and their performance characteristics degradation. In Innovation and Interdisciplinary Solutions for Underserved Areas (pp. 31-42). Springer, Cham.

Neher Ina, Tina B, Susanne C, Bernd E, Klaus P, Bernhard P, Christophe S, Stefanie M (2017). "Impact of atmospheric aeroosols on photovoltaic energy production Scenario for the Sahel zone." Energy Procedia 150:170-179.

Orange D, Gac JY, Probst JL, Tanr D (1990). "Measurements of Saharan dust deposition. A simple sampling technique: the pyramidal collecting system." Comptes Rendus de l'Academie des Sciences. Série II 311:167-172.

Quilliet A, Peter G (1960). "The surface photovoltaic effect in silicon and its application to the measurement of the lifetime of minority carriers." Journal of Physics and Le Radium 21 p.

Saint-Gregoire P (2009). "Solar photovoltaic energy: fundamental aspects, current situation, and perspectives in the framework of the water problem." (STM 9), no. 16-27.

Soleilhavoup F (2011). "Accumulation and erosion microforms on desert rock surfaces of Sahara." Geomorphologie-Relief Processus Environnement (2):173-186.

Soulouknga, Marcel H, Ousmane C, Serge YD, Timoleon CK (2017). "Evaluation of global solar radiation from meteorological data in the Sahelian zone of Chad." Renewable energies: wind, water and sola 4(1):1-10.

Wilson JIB, Woods J (1973). The electrical properties of evaporated films of cadmium sulphide. Journal of Physics and Chemistry of Solids 34(2):171-181.

Related Journals: