The impacts of artificial light at night in Africa: Prospects for a research agenda

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Artificial light at night (ALAN) has increasingly been recognised as one of the world's most pernicious global change drivers that can negatively impact both human and environmental health. However, when compared to work elsewhere, the dearth of research into the mapping, expansion trajectories and consequences of ALAN in Africa is a surprising oversight by its research community. Here, we outline the scope of ALAN research and elucidate key areas in which the African research community could usefully accelerate work in this field. These areas particularly relate to how African conditions present underappreciated caveats to the quantification of ALAN, that the continent experiences unique challenges associated with ALAN, and that these also pose scientific opportunities to understanding its health and environmental impacts. As Africa is still relatively free from the high levels of ALAN found elsewhere, exciting possibilities exist to shape the continent's developmental trajectories to mitigate ALAN impacts and help ensure the prosperity of its people and environment.

Significance:

We show that the African research community can usefully accelerate work into understudied aspects of ALAN, which demonstrably impacts human and environmental health. Africa presents a unique, and in places challenging, research environment to advance understanding of this global change driver.

Introduction

Since the industrial revolution (post-1750s), global artificial light at night (ALAN) has expanded dramatically.[1,2] ALAN is produced from infrastructure like streetlights, houses, factories, ports, airports, sports stadiums, car parks, billboards and car headlights. This transformation has come with pronounced benefits and costs for society. ALAN has increased work, education and leisure hours.[3] However, there is increasing concern that excessive use of ALAN constitutes a key driver of global environmental change.[4] Alarmingly, a new picture of the breadth of ALAN's potential negative impacts has grown substantially in recent years, and in particular the work has focused on impacts both on human well-being (for an overview see[5-7]) and the wider environment (for an overview see[8-13]). Although its expansion is variable in space and time[14,15], Earth's artificially lit outdoor area is estimated to have grown by 2.2% per year from 2012 to 2016.[14] The power of global satellite observable light emissions increased by at least 49% from 1992 to 2017[2] and 80% of the world's population is now living under skies affected by ALAN[14].

To date, most published studies of the impacts of ALAN have overwhelmingly been biased to Europe and North America.[8] Consequently, there is limited understanding of how ALAN may impact human and environmental health in developing nations and how the expansion of ALAN in these regions may occur. This is particularly true across the African continent.

Here, we report the findings of a literature review of the status of ALAN research across Africa, and discuss the prospects for a research agenda. We did so using expert solicitation of the field (from the authors and our broader network), together with Boolean terms in Google Scholar and SCOPUS ("light pollution AND Africa" and "artificial* + light* AND Africa"), and discarding those not directly discussing or testing for ALAN impacts in Africa – the vast majority. In addition, we conducted direct enquiries to key experts, and ad hoc searching, to identify a broad overview of relevant academic papers, which we summarise below, although we acknowledge that this may not be an exhaustive list.

Using this overview, we elucidate the key topics on which the African research community could usefully focus and accelerate work in this field. We summarise such key themes, across disciplines, to help guide advancement in this field (Table 1). In addition, while the challenges of studying ALAN are cosmopolitan[13], Africa may present unique conditions and opportunities to advance global understanding of this issue. These relate to the quantification of ALAN itself, how development may alter its spread, impacts of ALAN on vector disease transmission, introduction of ALAN in light naïve contexts, and broader influences of ALAN on the environment and on tourism. We also posit that there exists a lack of a culture and capacity in ALAN research in Africa that is hampering progress.

Artificial light at night and the African context

In contrast to much of the rest of the world, much of Africa does not as yet experience significant levels of ALAN, with exceptions being major city centres, most of South Africa, coastal West Africa, and northern Africa (Figure 1). This situation is expected to change rapidly with increasing infrastructure development and urbanisation in Africa as, together with Asia, it is experiencing the fastest rates of urbanisation globally.[32] Even within rural settings, there is increasing interest in the installation of off-grid technology[33], which may potentially increase electrification of sub-Saharan Africa where current rates are the lowest in the world (62.7% in urban areas and 18.9% in rural areas in sub-Saharan Africa, compared to 94.6% and 71.0%, respectively, at a global scale[34]).

Quantification

Quantification of the extent and dynamics of ALAN in Africa is still in its infancy. Indeed, no study has been conducted on how ALAN has changed over Africa's developmental history, perhaps because the relative extent of pristine skies remaining means this issue has been overlooked by researchers.[14] This lack of information is especially worrying because the major contribution globally to the future growth of ALAN will come from middle-income countries, particularly China, India, and those in South America and Africa.

Three factors complicate the quantification of ALAN in Africa. The first is the quantification of ALAN from satellite data, the second is the lack of local-scale measurements, and the third is failure to measure spectra. We expand on each in turn.

First, while satellite data can provide a continental-scale picture of ALAN, as they do elsewhere, African conditions are often not specifically considered when developing such data sets for analysis. (1) Atmospheric conditions in Africa can differ vastly from those of northern latitudes which have strongly influenced how most of the remote-sensing products are calibrated, processed and applied. In particular, the high frequency of atmospheric dust across most of the continent may complicate accurate assessment of the intensity of lights emitted at night. This may be especially pronounced for regions in northern Africa which is estimated to contribute as much as 65% of annual global aeolian dust emissions[35], and is where much of the current ALAN in Africa originates[14]. (2) Processing of ALAN data from satellites commonly screens out the effects of fires by focusing on persistent lighting and excluding pixels with anomalously high radiance that occurs infrequently[36], although the impact of frequent and undocumented fires and the atmospheric effect of smoke on the calibration of satellite data is not well understood. (3) Many sub-Saharan countries are also beleaguered by frequent and intermittent disruptions to the national electrical grid supply.[37] Generators are often used either as a primary source of electricity, or when conventional electrical grids are interrupted. This may in turn lead to underestimation of artificial light emissions, if generators are not in use later at night when the remote-sensing measurements are actually made during pass-overs of satellites. One of the most prominent remote-sensed products in use today, from the Visible Infrared Imaging Radiometer Suite (VIIRS), is derived from satellite passes across Africa in the early morning, around 01:00 local time, which means light sources that are powered from electrical generators that are switched off when citizens are less active are missed completely. (4) The sparse artificial lighting associated with much of rural Africa may not be well detected by remote-sensing sensors, yet it can have localised effects that can be cumulative over larger landscapes. In sum, these four different effects may mean that documented levels of ALAN emissions across the continent may be marked underestimates.

Second, there is a dearth of local-scale measurements of either artificial light emissions or skyglow (the increased sky brightness that results from ALAN that is emitted or reflected upwards being scattered by water, dust and gas molecules in the atmosphere) across the African continent. Few measurements have been made using on-the-ground sensors, such as the Sky Quality Meter[15]. Indeed, although global networks of such devices have grown rapidly, the contribution of Africa is extremely limited. Mapping of variation in ALAN emissions across towns and cities, whether using on-the-ground[18,19,38], aerial[39] or space-borne approaches[40], has also not been conducted in Africa (excepting those satellite sources with essentially global coverage), although this can be invaluable in identifying key sources and how levels and patterns of emissions are changing.

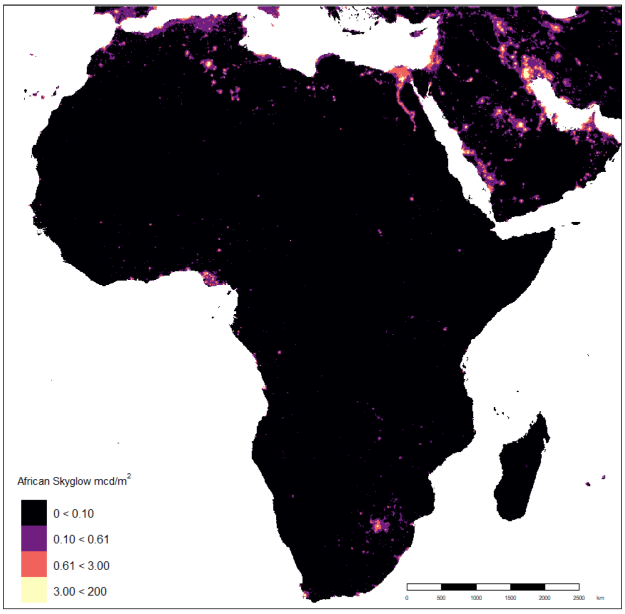
A third challenge to quantifying ALAN across Africa, as it is elsewhere, is the lack of ability to measure its spectral signature.[41] At the time of writing, no publicly readily available satellite colour images for Africa at night presently exist, but techniques to acquire them are available.[40] For Africa, such data have not been obtained, even locally by other means (e.g. night-time aerial flights).

Table 1: Exemplar research themes with key references to advance artificial light at night (ALAN) research in Africa

	Theme	Research area	Key references
1	Quantify the variation in the geography of and timing in ALAN	Measurement	16
2	Addressing atmospheric challenges to quantifying ALAN	Measurement	17
3	ALAN use transitions and trajectories	Measurement	2,17
4	Compare and contrast the remote sensed products that best capture ALAN variation across Africa	Measurement	*research frontier
5	Advancing local scale measurement and quantification of ALAN	Measurement	18,19
6	ALAN mitigation adoption rates in rural areas in Africa	Measurement	*research frontier
7	Relationship between socio-economic context, local economic growth, and ALAN use	Measurement	20
8	Quantifying the change in ALAN across Africa's developmental trajectory	Measurement	*research frontier
9	Accelerating the quantification of spectra in the night environment at ecologically relevant scales	Measurement	19
10	Quantify LED adoption rates across Africa	Measurement	*research frontier
11	Expanding research into the synergetic and/or antagonistic interactions of ALAN and other global change drivers	Measurement / Biological impacts	4
12	Diversify the range of taxa and documented impacts of ALAN on biodiversity, and advance nocturnal ecology	Biological impacts	21 *research frontier
13	Document the link between car headlights and roadkills	Biological impacts	22
14	Interactions of especially African apex predator biology with ALAN	Biological impacts	21,23 *research frontier
15	Advance work in environmental crime and ALAN links	Biological impacts	24 *research frontier
16	Assess how protected areas buffer against ALAN via skyglow	Biological impacts	25
17	Advancing larger scale and longer duration biological experiments	Biological impacts	26
18	Assess the impact of ALAN on species/populations of African taxa, especially those that are light naïve	Biological impacts	*research frontier, examples collated in main text
19	Expanding work on the impacts of ALAN on African marine animals	Biological impacts	27
20	Assess the link between ALAN expansion and astronomy/astrotourism degradation	Astronomy	28
21	Document and alter the lack of culture and capacity impeding ALAN research in Africa	Socio-economic context	*research frontier
22	Assess changes in and application of national/municipal legislation	Socio-economic context	29
23	Assessing the interactions of ALAN with medically important insects, such as disease vectors	Medical impacts	30
24	Impact of ALAN on human physiology and well-being	Medical impacts	7
25	Quantify the relationship between ALAN, human health, and environmental health	Medical impacts	31

**Note that while there is overlap with such work elsewhere in the world, we highlight what we consider to be research frontiers, particularly in Africa, which often reflects a dearth of literature.*

This is important because many of the human and environmental impacts of ALAN are spectrally sensitive, with effects often being exacerbated by emissions at blue wavelengths. Moreover, the spectrum has recently increasingly shifted across much of the world from predominantly narrow wavelength (e.g. from low pressure sodium lamps) to broad wavelength 'white' emissions (e.g. from LED lamps), both as a consequence of retrofitting of older lighting systems and the use of newer technologies in recent developments. Although similar kinds of retrofitting have to some extent occurred in Africa, growth in broad wavelength emissions is likely to occur across much of the continent through the use of such technologies when lighting is first installed in areas.



Source: Data obtained from Falchi et al.[14]

Figure 1. Patterns of skyglow across Africa. The black colour denotes natural night-time illumination levels. The purple colour describes areas in Africa where artificial light at night (ALAN) has polluted the night sky up to the horizon of the landscape but not to the zenith. Areas where skyglow pollution extends to the zenith of the sky are denoted in pink. Lastly, the lightest colour is associated with areas that are polluted to such an extent that no parts of the night sky are visible to human night vision anymore. It is worth drawing attention to the fact that ALAN in Africa is spatially scattered (and thus more widespread than a whole continent map conveys), with large areas of natural night time remaining, and that the highest intensities of skyglow are concentrated around the coastal areas. Given the expansion of ALAN, the figure is an underestimate, but there has been no subsequent calibrated work in Africa since Falchi et al.[14], which may be a fruitful avenue for continued research (see Table 1).

African development and human well-being

The human health consequences of ALAN will be similar to those documented elsewhere[5-7]. However, combined with high poverty rates and lower access to primary health care, the negative impacts of ALAN may exacerbate human health issues across the continent. There is limited understanding of how African countries with different developmental trajectories are adopting new energy portfolios, or how energy expansion will be realised. Such information is critical to further understanding of how ALAN may increase in severity and extent, and is used elsewhere to plan better for, anticipate and mitigate its impact. Estimates made by the International Energy Agency have found that the percentage of the population in sub-Saharan Africa with access to household electrification grew from 20% in 2000 to 43% in 2018 and is projected to reach 66% in 2040 if current stated development policies remain in place.[42] This growth in electrification also considers the projected growth of the human population in sub-Saharan Africa, and means that Africa can expect a substantial increase in ALAN over the next two decades.

The use of newer technologies like LED lights and solar power may reduce adverse human health impacts of lighting with kerosene. However, as is the case in other low-income nations, the increasing adoption of LED lights across Africa is also of concern because the commonly wider spectrum used has been implicated in altering a host of human and ecological processes. While the development of renewable energy is central to the economic development of Africa, careful consideration is needed on how best to mitigate the negative trade-offs that this may bring. The issue is globally pertinent – questionnaires of practitioners in the lighting fraternity have shown that there is little consensus on what the future of 'sustainable LED lighting' should look like, and much work is still required to align such a vision among stakeholders.[43]

Much of the electrification, and by extension the spread, of ALAN that is projected to occur in Africa is expected to take place in rural areas. In such areas the lowest cost option for electrification is quite often 'mini-grid' systems.[44,45] These systems allow for electrification in extremely remote regions completely independently of national grid systems, thereby accelerating the electrification and development of rural communities far beyond the pace that traditional national grid expansion can maintain.[32] This will allow for the penetration of ALAN into virtually completely artificial light naïve landscapes, at a pace that may exceed the global estimates of ALAN growth, and so worsen ALAN impacts in such areas. These mini-grid systems and associated lighting regimes will bring various social and economic benefits to those communities, but possibly also some negative environmental impacts as described above. Lessons from other parts of the world, with a longer history of ALAN, may be useful to inform how to best integrate electricity and lighting into these areas in order to mitigate some of the negative environmental effects that this may bring.

Vector disease transmission

Of particular concern for human health in Africa may be the interactions of disease vectors with ALAN. For example, Africa still has the world's highest rates of malaria, with 213 million cases in 2018, 93% of the global total.[46] Alarmingly, the work to date suggests that ALAN may alter vector borne disease risk (for a review see[47]). Light may modify disease transmission by attracting or repelling vectors, and modulating their biting rates, the long-term survival of vectors, and potentially the success of parasite establishment.[47,48] Some diurnal vector species increase their biting rates when exposed to artificial light (e.g. *Aedes aegypti*[49]), while in other nocturnal species, biting rates are suppressed under artificial light (e.g. *Anopheles gambiae*[50]). This range of responses of mosquitoes to ALAN means the potential interactions between artificial light and disease transmission could usefully be further investigated.[30]

Environmental impacts

Only a handful of studies that we are aware of have directly tested for biological impacts of ALAN in Africa:

1. Lights from sport stadiums were found to benefit urban exploiter bats and allow them to increase their temporal foraging niche.[51]
2. Moth consumption by Cape serotine bats (*Neoromicia capensis*) was found to increase sixfold in experimentally lit conditions, suggesting that specialist moth-eating bats and moths may face increased resource competition and predation risk, respectively.[52]
3. Syntonic bats have also been found to increase their foraging frequency under experimentally lit conditions.[53]
4. Flashing LED light was found to reduce nocturnal livestock predation in Kenya.[54]
5. Manipulating artificial lighting (on and off) in aquatic systems showed that ALAN influenced the behaviour and composition of fish communities in estuarine waters.[55] Artificial light favoured piscivores, presumably through the concentration of prey and improved foraging conditions for predatory fish that use visual cues to hunt.[55]
6. The attraction of fish to light is likely widely true in both the salt- and freshwater bodies of Africa, as illustrated by local fishers on Lake Tanganyika, Tanzania, who use lanterns to improve catch rates by attracting fish to the surface and their nets.[56]

7. Both African sharptooth catfish (*Clarias gariepinus*) and Mozambique tilapia (*Oreochromis mossambicus)* show increased growth rates under artificial light treatments, as the light attracts insects.[57]

8. By applying an innovative transplanting methodology, Foster et al.[58] demonstrated that natural celestial cues are obscured by artificial lighting, with dramatic changes in dung beetle (*Scarabaeus satyrus*) orientation behaviour. For this species, artificial light thus increases individual competition and reduces dispersal efficiency.

Although useful contributions to the global body of evidence, these studies provide limited insight into the diversity and magnitude of biological impacts of ALAN across the African continent.

The potential for negative impacts of ALAN on African species and ecological systems is substantial. Large areas of Africa still possess darker night skies than the global average.[14] Therefore biodiversity in those areas may be more 'light naïve', in that it has not encountered ALAN to the extent and at the intensities to which nature in the Global North has been subjected. Whether 'light naïve' species do indeed suffer greater impact with the addition of ALAN, and what the adaptive capacity is of species to ALAN, remain globally pertinent research questions, and Africa may provide a fruitful testing ground for disentangling such impacts. Because some areas of the continent are intensely artificially lit, opportunities also exist for 'transplant' experiments (see for instance[58]), where taxa may be moved from areas that experience high ALAN to dark skies, and vice versa, to test the influence of altered light regimes or light naïveté on biological responses while accounting for other environmental gradients. In addition, there are opportunities to assess responses to gradients of skyglow, because in many regions dark areas abut intensely lit regions.

We highlight a diverse set of environmental research areas for which Africa might be an ideal living laboratory to advance understanding of impacts of ALAN:

1. Africa arguably hosts the last intact guild of apex predators, most of which are nocturnal[21,23], providing important opportunities to understand the impacts of ALAN upon them. Lions (*Panthera leo*) have been shown to have a higher hunting success during moonless nights, particularly so when attacking humans[59], and given increases in habitat destruction compounded by increased human population increases and expansion, human–lion encounter rates may increase. ALAN, especially through sky glow, may interfere with the moonlight cycles to which African ecosystems have evolved. It is unclear whether light may reduce foraging success, or act as an attractant for activity. LED lights have been used in pilot trials to reduce lion attacks on livestock.[54,60] Other large carnivores like cheetah (*Acinonyx jubatus*) and wild dog (*Lycaon pictus*) are often described as being diurnal to avoid direct competition with more dominant lion. However, evidence suggests that subdominant animals are in fact more nocturnally active than previously thought, particularly so on more moonlit nights.[23]

2. Road networks are expanding on the African continent, and there is a growing realisation that ALAN from cars may act as an overlooked pollutant.[22] Two studies in Tanzania reported that 79% and 63% of all recorded roadkills (excluding birds) were of nocturnal animals[61,62], whilst a study in South Africa reported that 100% and 61% of amphibian and mammal roadkills, respectively, were from nocturnal species[63]. This may be indicative that vehicular movement and 'blinding' by headlights may pose a particular risk for Africa's nocturnal species. This furthermore raises the question of how vehicle headlights (or spotlights on game viewing night drives, a common 'eco-friendly' practice in African protected areas) may impact on the 'fight and flight' responses of nocturnal species, which typically have eyes designed to work optimally under poorly lit conditions and whose vision may be compromised for an unknown period by a sudden exposure to unnatural levels of light.

3. Impacts of ALAN on other major groups of organisms in Africa such as birds, insects and plants are virtually unknown, but may be expected as is the case elsewhere[11,64], and crucially also may alter the ecosystem services they underpin, like pollination[65].

4. The extent to which ALAN also enables environmental crime is unknown and may be significant in Africa. For instance, intertidal poaching for abalone is prevalent across much of the western coast of southern Africa, and skyglow from cities, as well as light emissions from coastal towns, may help orientate poaching activity at night and enable navigation. Similarly, skyglow and point source lights from outside of major protected areas may enable the orientation and navigation for poachers pursuing large game, such as rhinos. In the Kruger National Park, the moon phase plays a role in rhino poaching incidents, with poachers preferring nights with better light conditions.[24]

5. It may be particularly desirable to expand experiments at low latitudes to test the biological impacts of ALAN. This is because of the geographical research bias towards northern latitudes, in regions also already experiencing significant ALAN, and so how such impacts scale to other regions in the globe remains an open question.

6. As is the case elsewhere, protected areas in Africa show increases in ALAN[25], and globally in some protected areas, many species, including mammals, now experience persistent ALAN from skyglow comparable to the light of a full moon.[18] How ALAN, especially where it originates at high levels from urban centres that abut onto protected areas, affects species and ecosystems in regions that are thought to have dark skies, remains a pressing question.

Tourism industry

Tourism makes fundamental contributions to the economies of many African nations. Because ALAN erodes the ability to see celestial objects, its negative impact on imaging astronomy is well appreciated, but less so is its impacts on the bourgeoning astrotourism industry. Astrotourism seeks regions with pristine dark skies in remote locations so that amateur astronomers can view celestial phenomena, especially 'deep sky objects' like nebulae and galaxies, which cannot be detected in more artificially lit areas. It is a rapidly growing tourism sector, and given global declines in the quality of night skies for viewing celestial objects[66], regions which retain dark skies may form focal areas for such activity in future.

A proposed astrotourism route in the southern Northern Cape near Sutherland, South Africa, may increase revenue streams from tourism into a region with few other options for economic development.[67] Indeed, large tracts of Africa are in ideal locations (remote and with dark skies) to promote and develop astrotourism as part of its touristic 'portfolio'. The burgeoning lodge industry, often in wilderness locales, must also focus on maintaining dark skies during its expansion. However, Africa currently only possesses two recognised 'International Dark Sky Reserves' – regions possessing an exceptional or distinguished quality of starry nights and nocturnal environment that is specifically protected for its scientific, natural, educational, cultural, heritage and/or public enjoyment of its unpolluted night skies. Following an intensive review process, to ensure that the dark sky values remain preserved, these areas are designated by the 'International Dark Sky Association' (a global non-governmental organisation mandated to help stop ALAN and protect the night skies).

Culture and capacity

Research into the impacts of ALAN in Africa could usefully be advanced by greater cross-disciplinary work and fostering of appropriate research capacity. The impacts and consequences of ALAN do not yet enter the political and societal discourse in Africa to the extent of other change drivers, such as climate change or the illegal wildlife trade. This is not unique to Africa of course, but certainly the volume of research work across disciplines emerging especially from Asia, North America and Europe, is indicative of a shift in thinking towards the problem. Major funding mechanisms have supported large, long-term projects in the Global North – such as the 'ECOLIGHT' experiment[68], the 'Verlust der Nacht' experiment[69], the 'LightOnNature' experiment[70]. Some government initiatives are opting to change lighting regimes to healthier alternatives and major non-governmental organisations are encouraging the protection of dark places (e.g. International Dark Sky Association). Industry partners are also striving towards more environmentally friendly lighting alternatives. African research and policy must follow suit in such initiatives and indeed has an opportunity to pre-empt the issues bound to emerge, by being proactive in their planning and implementation, which could reduce both human and environmental impacts (for guidance see[29]).

It is imperative that national lighting regulations are kept well updated and informed by contemporary research. Across the continent, it is unclear to what extent such policies exist, let alone whether they are implemented and frequently revisited. For example, the national lighting regulations in South Africa, set out by the South African Bureau of Standards, were last amended in 2007, which leave them sorely lacking behind the development of new lighting technology and the optimal implementation thereof.

These shortcomings mean that robust human capacity to investigate ALAN must still be developed across the continent, and a greater appreciation is required amongst sectors about ALAN's potentially negative effects, techniques to measure it at various spatial scales, and strategies for mitigation tailored to Africa. Skills across academia, the public sector and industry need to be developed continent-wide and used to inform policymakers and other stakeholders of the importance of mitigating the harmful impacts of ALAN while sustainably optimising its economic development.

Conclusion

Given the realised and potential severity of its human health and environmental impacts, the dearth of studies of ALAN in Africa is a surprising oversight by its research community. If we are to understand the magnitude and the extent of the impacts of ALAN in Africa, we must enhance both the fundamental knowledge of its effects, and develop the technical capacity to do so. Africa has the opportunity to learn lessons from other parts of the world and benefit from technological advances in terms of implementation of ALAN mitigation measures. These mitigation strategies are well known, practical and relatively straightforward to implement. However, how to operationalise such mitigation measures in an African policy context requires greater awareness across societal sectors and the willingness to do so. With currently relatively low levels of ALAN compared to the global situation, many African nations can strategically plan and pro-actively implement mitigation measures without increased risk or increased cost to development. There is real, but diminishing, opportunity to ensure that the expansion of ALAN in Africa does not compromise its human and environmental health.

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Competing interests

We have no competing interests to declare.

Authors' contributions

B.W.T.C.: Conceptualisation, methodology, data collection, validation, writing – the initial draft, writing – revisions, project leadership, project management, funding acquisition. I.P.J.S.: Conceptualisation, methodology, writing – revisions, funding acquisition. S.A.: Methodology, data collection, data analysis, validation, writing – revisions. K.J.G.: Conceptualisation, methodology, writing – revisions, student supervision, funding acquisition.

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