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Not peer-reviewed version

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Posted Date: 22 January 2024

doi: 10.20944/preprints202401.1542.v1

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Review

Environmental Stressors of Mozambique Soils Quality

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Abstract: Mozambique is one of the poorest countries of the world. However, it has natural resources and if they are managed under sustainable development principles, Mozambique can overcome the current problems. In the present socio-economic status, soil is one of its most important resources and must be protected from pollution and from degradation. This review focuses on the identification and discussion of the main soil quality stressors, namely: soil fertility; deforestation and its sources: agriculture, timber harvesting, charcoal production and uncontrolled fires; mining activities, manly gold artisanal explorations and industrial open-pit coal mining. The sustainable use of the natural resources is mandatory to allow future generations to continue profiting for this nature-based wealth.

Keywords: soil quality; environmental stressors; soil pollution; deforestation; illegal gold mining; agriculture

1. Introduction

Mozambique is a country located in Southern Africa, bordered in the north by Tanzania, in the west by Malawi, Zambia and Zimbabwe, in the south by South Africa and Eswatini, and has a coastline bathed by the Indian Ocean (Figure 1). It is organized into ten provinces (Northern provinces: Cabo Delgado, Niassa and Nampula; Central provinces: Tete, Manica, Zambezia and Sofala; Southern provinces: Gaza, Inhambane and Maputo) and one capital city (Maputo city). Although Mozambique's wealth of natural resources, in terms of socio-economic indicators, it is one of the poorest countries of the world [1,2]. According the United Nations Refugee Agency (UNHCR) it ranks 185 out of 191 countries on the 2022 Human Development Index [3].

The civil war that lasted from 1977 to 1992 devastated Mozambique and was one key factor for the current socio-economic situation. To escape from guerrilla activities, people moved from rural areas to urban centers, resulting in an accelerated urbanization, and large parts of the country were almost inhabited, with the following consequences [4,5]: marked reduction in cash crop sector; many farmers returned to subsistence agriculture; reductions in cattle production; and, lost of basic infrastructure. After the civil war, people resisted to return to former farmers and resume subsistence farming close to urban centers [4].

These demographic modifications were particularly impactful on the socio-economic structure of Mozambique because agriculture is the basis of its economy [1] and it is a low industrialized country [6]. The arable land in Mozambique is about 36 millions hectares, but only about 10% of this area is being used, mainly by family farming (about 90% of the used arable land) in small agricultural fields (smaller than 2 hectares) [7]. Agriculture employs more than 67% of the population (total Mozambique population of about 30 [1]), mainly for subsistence, and contributes to about 22% of GDP [7].

Figure 1. Mozambique map with its provinces. With permission from reference [8].

Geographically, Mozambique is located in a high-risk zone of extreme weather events (cyclones, droughts and floods) and particularly vulnerable to climate change [1,3]. Cycled natural disasters are afflicting Mozambique, which has a limited responsiveness capability, with great destructive potential, aggravating humanitarian crises, hampering development and creating huge public health challenges (Figure 2) [9]. Indeed, as shown in Figure 2, these extreme weather events affect higher percentages of the global population. Moreover, since 2017 terrorist attacks in the north districts forced the migration of local habitants to other safer places.

Mozambique's natural resources are the basis for the next years projections of its economic growth, namely renewable energy sources, mineral resources, agro-ecological regions and forest and wildlife resources [1]. However, the use of sustainable exploitation strategies are mandatory to assure that future generations will continue profiting from the soil, water and air of Mozambique.

The lack of large industrial areas and the inexistence of intensive agriculture in Mozambique result in the inexistence of accumulated toxic pollutants areas in the country [6]. However, the overpopulation in megacities without infrastructures results in specific pollution problems [6,10]. Moreover, there are some unsustainable and/or unregulated practices that may contribute with toxic pollutants release and/or soil degradation and, consequently, constitute stressors that may affect environmental quality. The release into environment of mercury from artisanal gold mining is a typical example of highly polluting activity [11,12]. Deforestation for illegal timber commerce [13], conversion of forest soil into crop cultures [14] and charcoal production [15], are examples of activities that degrade soil quality.

This review focuses on the analysis of the literature about the environmental stressors that may contribute to the degradation of the soil quality in Mozambique. Soil quality is directly related with good quality and high yield of food, which is mandatory in a country like Mozambique. Indeed, in the current development stage of Mozambique it of vital importance that soil sustainability is maintained and/or improved. It is about time to follow sustainable practices that assure that the current fertile soil will produce enough good food for the present and future generations.

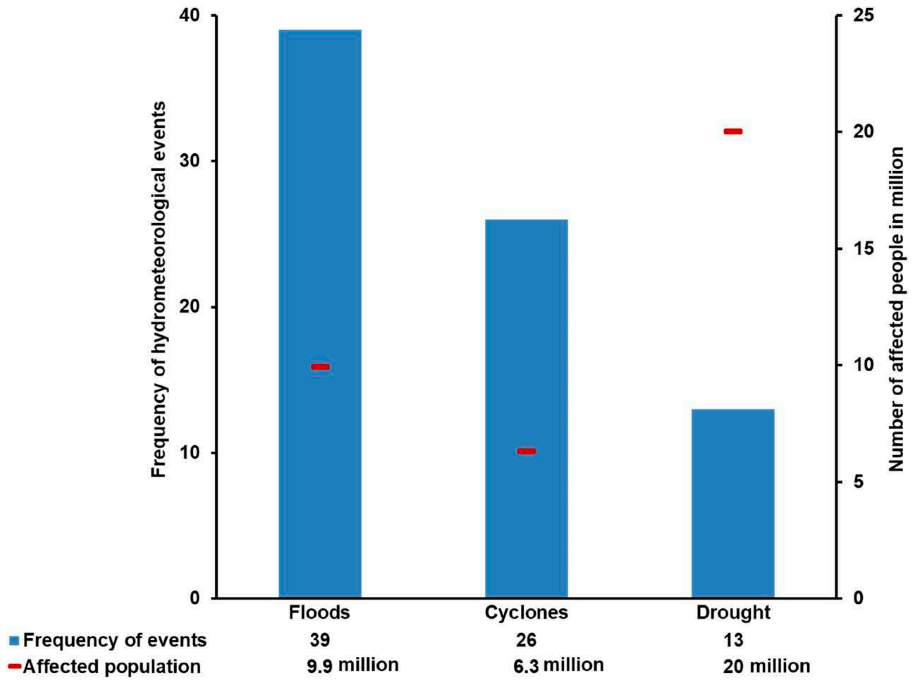

Figure 2. Number of extreme weather events and number of people affected in Mozambique between 1956 and 2020. With permission from reference [9].

2. Soil fertility

Mozambique soils are characterized by a low fertility, which limits food production [16]. The mineralogy of Mozambique soils is characterized by kaolinite and iron and aluminum oxides and hydroxides, that have the lowest Cation Exchangeable Capacity (CEC) of the common soil minerals [16]. In a 2006 study, CEC ranged from 0.4 to 14.5 $cmol_c$ kg^{-1} with seventy-five percent of the samples with less than 7.5 $cmol_c$ kg^{-1}, conferring this soils with a low to moderate fertility [16]. Also, these minerals possess relatively high phosphorous adsorption capacities, which contribute to the reduction of this nutrient availability for plants.

A critical nutrient for maize production, which is the main crop in the country, is nitrogen, and Mozambique soils are deficient of this nutrient [16]. In 1983 a study showed that the loss rates of the NPK nutrients were high (21-40 kg/ha for N, 8-15 kg/ha for P and 21-40 kg/ha for K), and the total nutrient loss increase rates between 1983 and 2000 was severe for nitrogen (in the range between 7 and 11 kg/ha) [17]. Indeed, maize and cassava are the cropping systems with the highest nutrient depletion, both in small and in large scale cropping systems [4].

Another factor that affect soil fertility is agricultural practices, namely excessive soil tillage with no soil cover [18]. Conventional tillage provokes the degradation of the soil, with consequent fertility depletion, mainly through the decomposition of organic matter, with disruption of the soil structure and decrease of the aggregate stability [18]. Moreover, soil erosion provoked by the wind and rainwater is a direct consequence of unsustainable conventional tillage practices. Conservative agriculture follows three principles: (i) minimal soil disturbance; (ii) crop residue retention; and (iii) crop diversification through rotation or intercropping [18,19]. The use of cover crops also reduces erosion and contributes to carbon sequestration by increasing soil organic matter. Moreover, there is an increased in the water retention and reduced evaporation from the soil, which is critical for the Mozambique rain and dry seasons climate.

Slash and burn agricultural system is a common practice all over the world and one of the main livelihood in family farming [20]. These agricultural practices consist in cutting, burning and farming different forest areas in rotation, with long forest-fallow of 50 to 100 years, to allow for forest and soil restoration [20]. Currently, shorter forest-fallow periods are being used, which is a form of deforestation, with all the associated problems related with economic, social and environmental lack of sustainability [20].

3. Deforestation

Mozambique made a series of commitments with United Nation organizations related with the conservation of its forest and its ecosystem services, namely [9]: Aichi Targets of the United Nations Convention on Biological Diversity (UNCBD), the REDD + (Reducing Emissions from Deforestation and forest Degradation) mechanism of the United Nations Framework Convention on Climate Change (UNFCCC), the Land degradation neutrality (LDN) initiative of the United Nations Convention to Combat Desertification (UNCCD), and the Sustainable Development Goals (SDG), particularly the SDG target 15.3 dedicated to the restoration of degraded land and soil. These commitments are in line with the recognition that Mozambique growth is foreseen on the sustainable management of its natural resources.

Nevertheless, deforestation is an ongoing process in Mozambique, and the analysis of the land cover change between 2001 and 2016 showed a significant loss of forest, of about 1.3 Mha, mainly to the conversion to cropland [9]. In the south of Mozambique, in the biodiversity hotspot of the Licuáti Forest Reserve, the annual rate of deforestation between 1990 and 2001 was 0.8% and between 2013 and 2013 was 2.3% [21]. In an area of 7,500 km^2 of the Manila province, center of Mozambique, and between the years 2007 and 2010, biomass was lost at a rate of 2.8±1.9% per year, and small-scale agriculture was the direct cause of 46±17% of the total loss, construction and miscellaneous activities 24±11%, charcoal production 18±9%, logging 9±5% and commercial agriculture 3±2% [22].

The main causes for deforestation seems to be: agriculture fields expansion, charcoal production; fuelwood extraction; and, timber harvesting [21]. Among other ecosystems services that are lost as consequence of deforestation, like for example timber and water provision, biodiversity and carbon sequestration, soil quality is particularly affected and the lost of agriculture productivity and desertification are menaces.

3.1. Agriculture

Before the independence from Portugal, in 1975, the agricultural sector of Mozambique was constituted by big farms, that produced crops for exportation, medium and large farms, dedicated to extensive livestock farming, oilseeds and tobacco, and small and medium farms that produce products for local consumption. After the independence, the land become state property and many private agricultural companies were nationalized, resulting in the massive abandonment of foreign investors and technicians with the consequent economic disarticulation of the production and crisis. The civil war, that lasted from 1977 to 1992, further complicated this scenario of productive/economic disruption. Nevertheless, Mozambique has a significant potential for agriculture because of the tropical climate, enormous extensions of arable land and it has rivers and lakes spread throughout the territory, with water all over the year [23]. However, a low agricultural productivity is observed, mainly due to the use of traditional agronomic technologies, lack of an efficient advisory public service and low yield seeds [23].

The majority of the population is dedicated to subsistence agriculture in small family farms. In the decade between 2000 and 2010 two state programs were lunched, PROAGRI (National Program for the Agrarian Development) and the Green Revolution, to stimulate private and foreigner investment in the modernization of agriculture [23]. A join program between Mozambique, Brazil and Japan (PROSAVANA program), with the objective to develop agriculture in the 6 million ha of land in the Nacala corridor (provinces of Nampula, Niassa and Zambézia), was created to produce mainly soy, cotton and maize [23,24]. The "National Biofuels Strategy and Policy" opened opportunities for large biofuel production projects, and among others a project is expected to accommodate a sugarcane/ethanol plantation with 30,000 hectares of the Massingir minor town, close to the dam to be used in the irrigation [25]. A 400 ha organic coffee plantation, involving 1,600 farmers, in the Chimanimani National Park (Manica province) started in the year 2020 (Agrotur project) [26].

Although many other agriculture megaproject are being implemented, in 2020 the number of large farmyards was 873, which is less than 1% of the global number of 4.3 millions of agricultural and livestock farms [27]. Moreover, the global cultivated land was 5.5 Mha, 5.5% use pesticides, 8.8% use manure, 7.8% use chemical fertilizers and 9.1% use water [27]. Meanwhile, many forest areas are being changed for planting different crops, such as corn, soybeans, sesame, cabbage, lettuce, kale, sweet potatoes, carrots, beans, bananas, fruit plants, among others [28].

This process of land reconcentration in Mozambique is an ongoing strategy to increase food production, enough for the country and for export [13,29]. However, there are many conflicts between big agricultural companies and local inhabitants who gave up of their small family farms or still have their property [30], and the social, economic and environmental sustainability of this process should be assessed. From the environmental point of view, and specifically about the quality of the soil, the risks of soil degradation resulting from intensive monoculture farming are significant, and sustainable agricultural practices should be implemented.

3.2. Timber harvesting

The latest forest inventory from 2005 estimated a forest cover of 40 Mha (51% of the country) and about 67% of that area corresponds to productive forest, while the rest fall into conservation areas and topological or ecological inaccessible land [31]. In the period between the years 2012 and 2022, Mozambique lost 4.03 Mha of tree cover, equivalent to a 14% decrease in tree cover since 2000 and 1.43 Gt of equivalent carbon dioxide emissions [32]. Logging has been one of the steady drivers to deforestation in Mozambique, and this practice has been carried out by companies and by the population when looking for construction material and firewood [33]. Besides the legal timber harvesting done by companies that possesses legal authorization (land title – DUAT's), there is illegal harvesting and trafficking of the most precious tree species in the north of the country, across the Ruvuma river, into Tanzania [34,35].

To re-establish the commercial tree plantation sector, the Government of Mozambique issue in 2009 the National Reforestation Strategy (NRS) to increase the forest plantation area from 24,000 ha to 1 million ha by 2030 [35]. The NFS had an investment of USD 2 to 4 billion that could only be achieved with international investors. This project was in line with the economic development of the country based on its natural wealth, i.e. the agriculture and forest sectors.

3.3. Charcoal production

Woodlands occupied areas are the predominant land cover in Mozambique, corresponding to 51% of the total country area [36]. Woodlands are responsible for several ecosystems services and the most important are: charcoal; firewood; woody construction materials; thatching grass; food; medicinal plants; and, livestock forage [36].

One of the most important ecosystems service in Mozambique is the charcoal production, with an estimated market value of US$400 million a year [37]. Wood fuels account for 81% of energy consumption, with charcoal being the dominant fuel in urban centers [36]. Fuelwood collection is mainly consumed in rural areas and charcoal production is driven by urban demand [15]. Depending on the region, charcoal production is responsible for a significant fraction of deforestation together with agricultural expansion [15]. In wet woodlands, charcoal production is a secondary product to agriculture, while in semiarid regions the contrary is observed [15]. Nevertheless, charcoal production is a key component in carbon dioxide emission accountability in current carbon balance towards neutrality assessments.

 doi:10.20944/preprints202401.1542.v1

The most desirable tree for charcoal production is Mopane (*Colophospermum mopane*) [36,37]. Its straight trunk charcoal process and its dense timber (1.02-1.14 g cm^{-3}), produce charcoal with high caloric power in kilns with trees that are felled around the kilns place (with an average cutting area of 0.28 ha) [15]. Kilns are located in area where suitable trees exists, as well as access to trails and roads, and produce an average of 104 sacks of 15 kg [15,21].

Although charcoal production is a cash income for rural very poor people, in some areas the only livelihood possible, the net result may be not that beneficial to local producers and local environment (degradation of natural resources). Indeed, intermediates are responsible for the large-scale export of charcoal to far way cities and earn the main financial benefits [36].

3.4. Uncontrolled fires

Natural and anthropogenic fires are a driving ecological force maintaining savanna ecosystems worldwide [37]. Most rural communities continue to use fire to manage land fields [37.] Uncontrolled fires in Mozambique have been carried out mainly by the population in order to open agricultural fields and also for the purpose of hunting some wild animals. Excessive cutting of plants and uncontrolled fires cause soil degradation, destruction of forests and loss of habitats. According to [38], fires destroy the habitat and kill the insects that pollinate the flowers of agricultural crops, resulting in a decrease in agricultural yield and an imbalance in the food chain (insects are food for other animals).

According to the some authors [39], slash and burn is believed to be one of the causes of uncontrolled fires in Mozambique, although other reasons such as pasture renewal, hunting, charcoal production and harvesting honey can also play an important role [28].

This practice of uncontrolled burning can lead to soil degradation, such as increased soil density, and consequent difficulty in infiltrating water into the soil, it also threatens soil microorganisms that help in the decomposition of organic matter, porosity, aeration, infiltration and drainage of soils [40].

4. Mining

Mozambique has abundant mineral resources, including fossil fuels, such as natural gas, thermal and metallurgical coal, and important reserves of non-fuel minerals, in particular minerals and heavy sand deposits [28]. The extraction of mineral resources such as coal, gold and heavy sand is done in large exploitation by companies and, in small scale and usually illegally, by individuals (artisanal extraction).

If mining activities are carried out without impact minimization strategies, environmental damages are expected [41]. The negative impacts of mineral extraction include water pollution, soil degradation, deforestation, air pollution and changes in the balance of some ecosystems. Artisanal extraction of gold also causes soil erosion and pollution resulting in a soil unsuitable for food production.

One of the mining activities that is widely practiced in the province of Manica is the extraction of alluvial gold by companies and artisanal mining [42]. About 20,000 people are involved in artisanal gold mining in the center of Mozambique [43]. This artisanal and small-scale gold mining (ASGM) is an informal economic activity [44], but it is the only income to otherwise-jobless people [45,46]. Taking into consideration this social and economic role, ASGM is suppose to become regularized instead of prohibited [45,46].

Artisanal gold mining consists of the removal of large quantities of sediments, and raw sediments and processing waste end up covering surface soils rich in minerals and nutrients, altering the natural characteristics of the soils and leaving them infertile for agricultural practice [33,42]. Also, river waters that are used in agriculture irrigation become polluted. The occupation of many hectares of land by companies for the extraction of gold has been registered as well as the occupation of some agricultural fields, belonging to small agricultural producers, has occurred [47].

A particular critical problem associated with the artisanal gold mining is the use of mercury in the final extraction step [11,12]. Liquid mercury is used for the amalgamation process, in which there is the separation of gold by the remaining components of the ores. The use of mercury in gold extraction compromises the health of people involved in artisanal mining activities and also the environment, specifically the pollution of river waters, groundwater and soil [11,12].

In the northwest of Mozambique, in the province of Tete, potential environmental impacts are related with open-pit coal mining megaprojects [48,49]. Physico-chemical analysis of the water from the Revúbuè and Moatize rivers in the surroundings of the coal mining at Moatize district (Tete) showed some contamination of iron and magnesium [48]. In another study on this same region, about the water, sediments and soil from the rivers Zambezi, Revúboè, Moatize and Muarazi, showed that all rivers were contaminated with arsenic, chromium and manganese during the wet season and, arsenic, chromium, manganese, lead and nickel in the dry season [49]. Also, the soils from the Moatize and the tributary Murrowgoze rivers were highly polluted [49].

5. Conclusions

Mozambique currently environmental soil problems are caused by strong pressure on natural resources, both by the population and companies in various areas of exploration. With regard to the population, training is needed in the following priority areas: sustainable agricultural and forestry practices, which protect and improve soil quality; and, non-polluting technologies for artisanal gold extraction, which protect human and environmental health. Companies should follow environmental quality international standard regulations in order to become economical and social sustainable.

Sustainable development management of the natural resources explorations is mandatory in order to assure that future generations will continue to will continue to enjoy the natural wealth of Mozambique.

Author Contributions: Conceptualization - M.P. and J.E.S.; writing—original draft preparation, M.P. and J.E.S.; writing—review and editing, M.P. and J.E.S.; supervision, J.E.S.; funding acquisition, M.P. and J.E.S.; Soil collection - M.P. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: We acknowledge FCT for funding the R&D Unit CIQUP (UIDB/000081/2020) (https://doi.org/10.54499/UIDB/00081/2020) and the Associated Laboratory IMS (LA/P/0056/2020).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Report: Voluntary National review of Agenda 2030 for Sustainable Development, Mozambique. VNR2020 – Voluntary National Report: Our Commitment to Sustainable Development for All. 2020.
2. World Food Programme. Mozambique Annual Country Report 2022 – Country Strategic Plan 2022-2026. 2022.
3. The UN Refugee Agency. Annual Results Report 2022 Mozambique. UNHCR, 3 of May, 2023. www.unhcr.org.
4. Folmer, E.C.R.; Geurts, P.M.H.; Francisco, J.R. Assessment of soil fertility depletion in Mozambique. *Agriculture, Ecosystems and Environment* **1998**, *71*, 159-167.
5. Zaehringer, J.G.; Atumane, A.; Berger, S.; Eckert, S. Large-scale agricultural investments trigger direct and indirect land use change: New evidence from the Nacala corridor, Mozambique. Jou*rnal of Land Use Science* **2018**, *13*, 325-343.
6. Batista, M.J.; Quentala, L.; Dias, R; Ramalho, E.; Fernandes, J.; Milisse, D.; Manhiça, V.; Ussene, U.; Cune, G.R.; Daudi, E.X.; Oliveira, J.T. Geochemical characterisation of soil of Beira city, Mozambique: Geogenic origin and relation with land cover. *Journal of Geochemical Exploration* **2018**, *187*, 184-200.
7. Marassiro, M,J.; Romarco de Oliveira, M.L.; Pereira, G.P. Family farming in Mozambique: Characteristics and challenges. *Research, Society and Development* **2021**, *10*, e22110615682. doi: http://dx.doi.org/10.33448/rsd-v10i6.15682
8. Cianciullo, S.; Attorre, F.; Trezza, F.R.; Rezende, M.; Ntumi, C.; Campira, J.; Munjovo, E.T.; Timane, R.D.; Riccardi, T.; Malatesta, L. Analysis of land cover dynamics in Mozambique (2001–2016). *Rendiconti Lincei. Scienze Fisiche e Naturali* **2023**, *34*, 81–92. doi: https://doi.org/10.1007/s12210-023-01133-9

9. Mugabe, V.A.; Gudo, E.S.; Inlamea, O.F.; Kitron, U.; Ribeiro, G.S. Natural disasters, population displacement and health emergencies: multiple public health threats in Mozambique. *BMJ Global Health* **2021**, *6*, e006778. doi: 10.1136/ bmjgh-2021-006778
10. Bernardo, B.; Candeias, C.; Rocha, F. Soil Risk Assessment in the Surrounding Area of Hulene-B Waste Dump, Maputo (Mozambique). *Geosciences* **2022**, *12*, 290. doi: https://doi.org/10.3390/ geosciences12080290
11. Abdelaal, A.; Sultan, M.; Abotalib, A.Z.; Bedair, M.; Krishnamurthy, R.V.; Elhebiry, M. Emerging mercury and methylmercury contamination from new artisanal and small-scale gold mining along the Nile Valley, Egypt. *Environmental Science and Pollution Research* **2023**, *30*, 52514–52534. doi: https://doi.org/10.1007/s11356-023-25895-9
12. Leuenberger, A.; Winkler, M.S.; Cambaco, O.; Cossa, H.; Kihwele, F.; Lyatuu, I.; Zabre, H.R.; Farnham, A.; Macete, E.; Munguambe, K. Health impacts of industrial mining on surrounding communities: Local perspectives from three sub-Saharan African countries. *PLoS ONE* **2021**, 16, e0252433. doi: https://doi.org/10.1371/journal. pone.0252433
13. Bey, A.; Meyfroidt, P. Improved land monitoring to assess large-scale tree plantation expansion and trajectories in Northern Mozambique. *Environ. Res. Commun.* **2021**, *3*, 115009. doi: https://doi.org/10.3390/ geosciences12080290
14. Temudo, M.P.; Silva, J.M.N. Agriculture and forest cover changes in post-war Mozambique, *Journal of Land Use Science* **2012**, 7, 425-442. DOI: 10.1080/1747423X.2011.595834
15. Sedano, F.; Silva, J.A.; Machoco, R.; Meque, C.H.; Sitoe, A.; Ribeiro, N.; Anderson, K.; Ombe, Z.A.; Baule, S.H.; Tucker, C.J. The impact of charcoal production on forest degradation: a case study in Tete, Mozambique. *Environ. Res. Lett*. **2016**, 11, 094020. doi: 10.1088/1748-9326/11/9/094020
16. Maria, R.M.; Yost, R. A Survey of Soil Fertility Status of Four Agroecological Zones of Mozambique. *Soil Science* **2006**, 171, 902-914. doi: 0038-075X/06/17111-902–914
17. Stoorvogel, J.J.; Smaling, E.M.A. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Wageningen (The Netherlands), The Winand Staring Centre. Report 28, 4 Volumes; Volume 1. 1990. ISSN: 0924-3062.
18. Chichongue, O.; van Tol, J.; Ceronio, G.; Preez, C.D. E↵ects of Tillage Systems and Cropping Patterns on Soil Physical Properties in Mozambique. *Agriculture* **2020**, 10, 448. doi:10.3390/agriculture10100448
19. Muatendauafa, A.S.R.; Francisco, A.; Zuarica, F.J.E.; Alface, L.A.; João, X.S. Importance of Conservation Agriculture in Soil Preservation in Vanduzi District in Mozambique. *RECIMA21 - Revista Científica Multidisciplinar* **2023**, 4, 1-20. ISSN 2675-6218
20. Serrani, D.; Cocco, S.; Cardelli, V.; D'Ottavio, P.; Rafael, R.B.A.; Feniasse, D.; Vilanculos, A.; Fernández-Marcos, M.L.; Giosué, C.; Tittarelli, F.; Corti, G. Soil fertility in slash and burn agricultural systems in central Mozambique. *Journal of Environmental Management* **2022**, 322, 116031. doi: https://doi.org/10.1016/j.jenvman.2022.116031
21. Tokura, W.; Matimele, H.; Smit, J.; Hoffman, M.T. Long- term changes in forest cover in a global biodiversity hotspot in southern Mozambique', *Bothalia* **2020**, 50, a1. doi: http://dx.doi. org/10.38201/btha.abc.v50.i1.1
22. Ryan, C.M.; Berry, N.J.; Joshi, N. Quantifying the causes of deforestation and degradation and creating transparent REDD+ baselines: A method and case study from central Mozambique. Applied Geography 2014, 53, 45-54. doi: 10.1016/j.apgeog.2014.05.014
23. Rosário, N.M. Agronegócio em Moçambique: uma breve análise da situação de estrangerização do agronegócio. *Sociedade e Território – Natal* **2019**, 31, 183–200. ISSN:2177-8396
24. Zaehringer, J.G.; Atumane, A.; Berger, S.; Eckert, S. Large-scale agricultural investments trigger direct and indirect land use change: New evidence from the Nacala corridor, Mozambique. *Journal of Land Use Science* **2018**, 13, 325-343. DOI: 10.1080/1747423X.2018.1519605
25. Nhantumbo, I.; Salomão, A. Biofuels, land access and rural livelihoods in Mozambique. 2010. International Institute for Environment and Development (IIED). London. ISBN: 978-1-84369-744-2
26. Mozambique: Chimanimani organic coffee project with 1,600 farmers to be largest plantation. Available online: https://clubofmozambique.com/news/mozambique-chimanimani-organic-coffee-project-with-1600-farmers-to-be-largest-plantation-photos-210098/ (accessed on 17 January 2024).
27. MADER. Inquérito Agrário Integrado 2020: Marco Estatístico. República de Moçambique. Ministério da Agricultura e Desenvolvimento Rural. Direção de Planificação e Políticas. Moçambique. 2021. Available

online: https://www.agricultura.gov.mz/wp-content/uploads/2021/06/MADER_Inquerito_Agrario_2020.pdf (accessed on 17 January 2024)
28. Serra, C.M.; Dondeyne, S.; Durang, T. (Coordenadores) O Meio Ambiente em Moçambique: Notas para reflexão sobre Notas para reflexão sobrea situação actual e os desafios para o futuro a situação actual e os desafios para o futuro. Grupo Ambiente – Parceiros de Cooperação. Maputo, Moçambique Maputo, Moçambique. Junho 2013. (Available from: https://biblioteca.biofund.org.mz/biblioteca_virtual/o-meio-ambiente-em-mocambique-notas-para-reflexao-sobre-a-situacao-actual-e-os-desafios-para-o-futuro/)
29. Bruna, N. Land of Plenty, Land of Misery: Synergetic Resource Grabbing in Mozambique. Land 2019, 8, 113; doi:10.3390/land8080113
30. Land of plenty, Land of but a few. Available online: https://terradealguns.divergente.pt/en/ (accessed on 17 January 2024).
31. Marzoli, A. Inventário Florestal Nacional. Projecto de Avaliação Integrada das Florestas de Moçambique (AIFM). 2007. DNTF, Maputo, Mozambique. (https://biblioteca.biofund.org.mz/wp-content/uploads/2019/01/1548752956-F226. National%20Forest%20Inventory_Mozambique.pdf)
32. Global Forest Watch https://www.globalforestwatch.org/dashboards/country/MOZ/?category= forest-change&lang=en&location=WyJjb3VudHJ5IiwiTU9aIl0%3D&map=eyJjYW5Cb3VuZCI6dHJ1ZX0%3D (accessed on 19 January 2024)
33. Garcia, M.F.R.; Bandeira, R.R.; Lise, F. Influências ambientais na qualidade de vida em Moçambique. *Revista Eletrônica Acolhendo a Alfabetização nos Países de Língua Portuguesa* **2009**, vol. III, 69-93. ISSN: 1980:7686
34. Lukumbuzya, K.; Sianga, C. Overview of the Timber Trade in East and Southern Africa: National Perspectives and Regional Trade Linkages. 2017. 53 pp. TRAFFIC and WWF. Cambridge, UK. TRAFFIC.
35. Mbanze, A.A.; Shuangao, W.; Mudekwed, J.; Dias, C.R.; Sitoe, A. The rise and fall of plantation forestry in northern Mozambique. *Trees, Forests and People* **2022**, 10, 100343. doi: 10.1016/j.tfp.2022.100343
36. Woollen, E.; Ryan, C.M.; Baumert, S.; Vollmer, F.; Grundy, I.; Fisher, J.; Fernando, J.; Luz, A.; Ribeiro, N.; Lisboa, S.N. Charcoal production in the Mopane woodlands of Mozambique: what are the trade-offs with other ecosystem services? *Phil. Trans. R. Soc. B* **2016**, 371, 20150315. http://dx.doi.org/10.1098/rstb.2015.0315
37. Shaffer, L.J. Indigenous fire use to manage savanna landscapes in southern Mozambique. Fire Ecology 2010, 6, 43-59. doi: 10.4996/fireecology.0602043
38. Mahamane, M.; Zorrilla-Miras, P.; Verweij, P.; Sitoe, A.; Ryan, C.; Patenaude, G.; Grundy, I.; Nhantumbo, I.; Metzger M.J.; Ribeiro, N.; Baumert, S.; Vollmer, F. Understanding Land Use, Land Cover and Woodland-Based Ecosystem Services Change, Mabalane, Mozambique. *Energy and Environment Research* **2017**, 7, 1-22. ISSN 1927-0569
39. Stewart, B.A.; Robinson, C.A., Are agroecosystems sustainable in semiarid regions? *Adv. Agronomy* **1997**, 60, 191-228. doi: 10.106/S0065-2113(08)60604
40. Moyo, S; O'Keefe, P.; Sill, M. The Southern African Environment: Profiles of the SADC Countries. Earthscan (New York). 2013. ISBN 9781853831713.
41. Nwadialor, I.J. Minimizing the impact of mining activities for sustainable mined-out area conservation in Nigeria. FUTY Journal of the Environment 2011, 6, 68-80. doi: 10.4314/fje.v6i2.6
42. Raso, E.F.; Savaio, S.S.; Mulima, E.P. Impact of artisanal gold mining on agricultural soils: Case of the district of Manica, Mozambique. *Revista Verde* **2022**, 17, 44-50. doi: 10.18378/rvads.v17i1.8486
43. Dondeyne, S.; Ndunguru, E.; Rafael, P.; Bannerman, J. Artisanal mining in central Mozambique: Policy and environmental issues of concern. *Resources Policy* **2009**, 34, 45–50. doi:10.1016/j.resourpol.2008.11.001
44. Mujere, N.; Isidro, M. Impacts of Artisanal and Small-Scale Gold Mining on Water Quality in Mozambique and Zimbabwe. in McKeown, A.E.; Bugyi, G. (Ed.) Impact of Water Pollution on Human Health and Environmental Sustainability. Chapter 5. 2016. DOI: 10.4018/978-1-4666-9559-7.ch005
45. Hilson, G.; Mondlane, S.; Hilson, A.; Arnall, A.; Laing, T. Formalizing artisanal and small-scale mining in Mozambique: Concerns, priorities and challenges. *Resources Policy* **2021**, 71, 102001. https://doi.org/10.1016/j.resourpol.2021.102001
46. Dondeyne, S.; Ndunguru, E. Artisanal gold mining and rural development policies in Mozambique: Perspectives for the future. *Futures* **2014**, 62, 120–127. //dx.doi.org/10.1016/j.futures.2014.03.001
47. Júnior, A.; Ibraimo, M.; Mosca, J. Exploração artesanal de ouro em Manica. *Observatório do Meio Rural* **2016**, N. 38, 1-20. Available online: https://omrmz.org/observador/or-38-exploracao-artesanal-de-ouro-em-manica/ (accessed on 17 January 2024)

 doi:10.20944/preprints202401.1542.v1

48. Macie, A.E.A.; Bacci, D.C. Coal Mining at Moatize, Tete Province, Northwest of Mozambique: A Socio Environmental Analysis. *International Journal of Engineering Research & Technology* **2017**, 6, 433-442. ISSN: 2278-0181
49. Marove, C.A.; Sotozono, R.; Tangviroon, P.; Tabelin, C.B.; Igarashi, T. Assessment of soil, sediment and water contaminations around open-pit coal mines in Moatize, Tete province, Mozambique. *Environmental Advances* **2022**, 8, 100215. https://doi.org/10.1016/j.envadv.2022.100215