Impact of climate change on mycetoma distribution and etiology in Senegal: The Role of Reduced Rainfall

ABSTRACT

Aims: To check whether climate change, through a drop in rainfall, has led to an increase in the range of mycetomas in Senegal and to verify if eumycetomas occur with predilection in the most arid areas with low rainfall.

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Methodology: we conducted a retrospective, descriptive study in which all cases of mycetoma (2000-2022) followed up in the dermatology and orthopaedics referral units of the country's university hospital centres and hospitals in endemic areas were collected. Data on isohyets (1947-2022) were provided by the Agence Nationale de l'Aviation Civile et de la Météorologie. Analyses were performed with SPSS version 18. All p ≤0.05 were considered statistically significant.

Results: Analysis of precipitation showed a decrease of 200 mm in the national average. The 800 isohyets moved southwards. With 291 cases, we observed a widening of the range of mycetomas in Senegal, with cases located in areas receiving more than 800 mm of rainfall. Fungal mycetomas accounted for almost half of the cases (49.8%, n=155) and were more likely to have black grains and were statistically correlated with rainfall of less than 400 mm (*P*=0.002), corresponding to the northern zone. Actinomycetoma was more frequent above 400 mm, with 60% (p=0.002).

Conclusion: Climate change has extended the range of mycetomas in Senegal by reducing rainfall. The fungal forms are becoming more common and predominate in arid zones with rainfall of less than 400 mm. The rise of eumycetomas is worrying because efforts to treat eumycetoma are limited and would benefit from scaling up, as existing treatments are inaccessible, expensive and not universally covered by international organisations or ministerial disease control programmes

Keywords: Mycetoma, rainfall, climate change, Senegal

I-Introduction:

Mycetomas, neglected tropical diseases (NTDs), predominantly affect young males living in dry, arid rural areas [1, 2, 3]. Affecting poor populations, they are a drag on economic development because of the Disability Life Years (DALYs) associated with chronicity, functional impotence and limb amputation. Rainfall of less than 800 mm is the main contributing factor [2]. While actinomycetoma can be treated medically with antibiotics, eumycetoma has always been a therapeutic problem due to two obstacles. Firstly, the inconsistent efficacy of antifungal agents such as itraconazole and terbinafine, and secondly, the inaccessibility of the latter, which remain expensive and out of reach for our patients despite ministerial programmes on NTDs. For example, a weekly course of treatment costs US$144, well above the minimum wage, and lasts at least 12 months. This barrier to treatment is more worrying given that recent studies on the subject have reported an increase in eumycetoma cases in Senegal, with the incidence of the disease rising to the point where it is now the predominant form of the disease [4,5].

The aetiological profile of mycetoma in the country changed, as actinomycetoma was by far the predominant form, accounting for more than 2/3 of cases [3]. This transitional dynamic confirms the findings of Ndiaye B et al in 1995, who predicted this development [1]. The authors postulated that "The major climatic changes of the last decades could modify the mapping of mycetomas in Senegal. Since the droughts of the 1970s, the mapping of isohyets in Senegal has undergone profound changes. The 800 isohyet has shifted southwards by more than 100 km. This could

have implications on the frequency and distribution of mycetoma cases in the country. Given the incubation period and duration of the disease, we believe that these changes will only be observed after a latency period of several years". Indeed, their paper highlighted a decrease in rainfall in Senegal, with a progression of low isohyets from north to south. Given that 47 years earlier, REY et al. had first established the correlation between fungal forms and rainfall below 500 mm [6], we believe that the increase in eumycetomas is linked to a decrease in rainfall in Senegal, which, through climate change, provides ideal environmental conditions for the development of fungal pathogens. In order to verify this postulate, we carried out this study with the following objectives:

1. To check whether climate change, through a drop in rainfall, has led to an increase in the range of mycetomas in Senegal.
2. To confirm whether eumycetomas occur with predilection in the most arid areas with low rainfall.
3. Aetiologies according to rainfall range
4. National mapping of the different types of mycetoma grains

II. Materials and methods

Recruitment and ethical aspects

This was a retrospective, descriptive, multicentre, "one health" study involving the records of patients with mycetoma from January 2000 to December 2022 (22 years). Cases were collected from the reference centres for the management of mycetoma in the capital, Dakar: CHU Aristide Le Dantec and the Institutd'hygyène social, and the orthopaedic departments of CHU Aristide Le Dantec and the Hôpital Adrissa Pouye. Recruitment was also carried out in the dermatology departments of hospitals located in mycetoma endemic areas, namely the regions of Thiès (west), Louga (north), Saint-Louis (north), Kaolack and Touba (centre).

Positive diagnosis were made clinically, parasitologically and histopathologically. The aetiology was determined by grain colour and parasitological identification (direct examination, culture or PCR). Red and black grains were of bacterial and fungal origin, respectively. In the case of white or yellow grains, where the parasitological examination was inconclusive, therapeutic arguments were used to decide the aetiological group. Favourable evolution under sulfamethoxazole-thrimetoprim alone or in combination with amoxicillin-clavulanic acid and, inconsistently, streptomycin confirmed the actinomycosis origin. Failure of this strategy indicated a fungal origin.

Precipitation and isohyets data

These were provided by the National Agency for Civil Aviation and Meteorology (ANACIM), the Senegalese agency responsible for meteorological monitoring. The records covered average rainfall from 1947 to 2022, represented by latitude and divided into three periods: [1947-1969], [1970-1992] and [1993-2022]. The first two periods were replicas of maps produced by Ndiaye B et al in 1995, which had previously shown a southward progression of the isohyets [1]. The last map, [1993-2022], is a chronological continuation of the previous ones and is used to assess the future of these rainfall dynamics. This period is considered contemporary with our study because it is long enough to provide favourable climatic and environmental conditions for the development of the pathogens that infected our cases. It also covers the incubation and development period of the disease.

Data analysis

The data wereanalysed using SPSS Version 18 software. The statistical tests used were Pearson's chi-square, with the probability calculated. Any $P \leq 0.05$ was the significance threshold.

III. RESULTS

III.1.1Epidemiological aspects

We collected 291 cases, which corresponds to a frequency of 14.55 per year.

The mean age was 40.44 years with a range of [17-79 years]. The median age of our cases was 39 years.

The population consisted of 214 men (74%) and 77 women (26%), giving a sex ratio of 2.77.

III.2Analysis of isohyets and precipitation dynamics from 1947 to 2022

The northerly the region was located, the lower the rainfall, ranging from 200 mm to 600 mm over the three periods.

A decrease in rainfall of around 200mm was observed across the country (Table 1) and a southward progression of low isohyets. The 800mm isohyet, located at 14.2° latitude in 1947-1969, moved southwards to 13.2° latitude between 1993 and 2022 (Figure 1). This isohyet, which runs from east to west, divided the country in the first period into two relatively equal northern and southern parts. The north, where rainfall was below 800 mm, and the south, where it was above 800 mm. From its new position, in this case between 1993 and 2022, the regions on its northern slope represented more than two-thirds of the country**.**

The mycetomic area was initially limited in the north by Matam (the extreme north of the country) and in the south by the northern half of the central and eastern regions. From west to east these were the regions of Fatick, Kaolack and Tambacounda. Following the new position of the 800 mm isohyet, the mycetoma area extended southwards, this time encompassing all three of the above regions in its spectrum, with the exception of the extreme south of Tambacounda, which recorded more than 800 mm.

Casamance (the southern region comprising Ziguinchor, Kolda, Sédhiou and Vélingara), which used to receive between 1100 mm and 1600 mm of rainfall, has received between 800 mm and 1200 mm of rainfall annually since 1993. The northernmost parts of Kolda and Sédhiou are now in the classic Mycetome band, whereas these two regions received at least over 1000 mm before 1970.

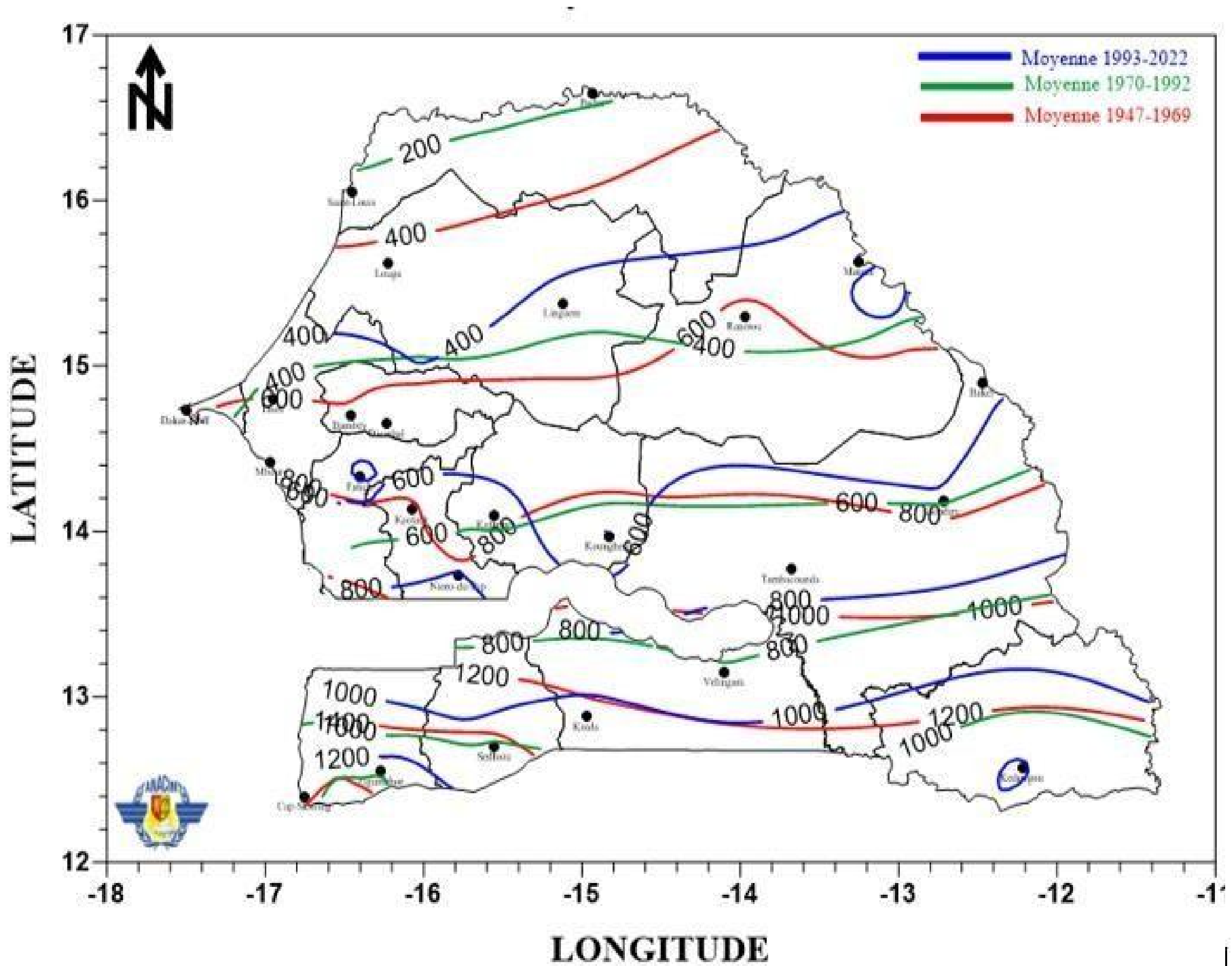

Figure1: Isohyetdynamicsbetween1947and2022

The regions of Saint-Louis, Louga and Matam, which recorded rainfall between 400 and 600 mm (1947-1969), are now below 400 mm range. The same applies to the Thiès-Dakar-Diourbel region, which has gone from 600-800 mm to 400-600 mm. Kaolack, the central zone, where average rainfall remained constant between 1947 and 1992, saw a drop of 200 mm between 1993 and 2022. The largest decrease in rainfall is in Fatick, with a difference of 400 mm. Ziguinchor shows a decrease of 300 mm, from 1200-1600 mm to 1000-1200 mm (Table 1).

Table1:Distributionofrainfallintheregionsaccordingtoperiod

Region	1947-1969	1970-1992	1993-2022
SaintLouis	400-600mm	200-400 mm	200-400mm
Louga	400-600mm	200-400 mm	200-400mm
Thiès	600-800mm	400-600 mm	400-600mm
Dakar	600-800mm	400-600 mm	400-600mm
Diourbel	600-800mm	400-800 mm	400-600mm
Fatick	800-1000mm	400-800 mm	400-600mm
Kaolack	800-1000mm	800-1000mm	600-800mm
Tambacounda	800-1000mm	500-700 mm	600-1000mm
Ziguinchor	1200-1600mm	1200mm	1000-1200mm

III.3Distribution of aetiology by origin

Fungal or bacterial origin was reported in 255 cases. Actinomycetoma was reported in 50.2% of cases (128/255) and eumycetoma in 49.8% (127/255). Of these, the geographical origin was reported in only 218 cases (Figure 2).

Figure 2 shows the aetiological distribution according to the regions shown on the x-axis. The further the region is to the left of the axis, the further north it is in the country.

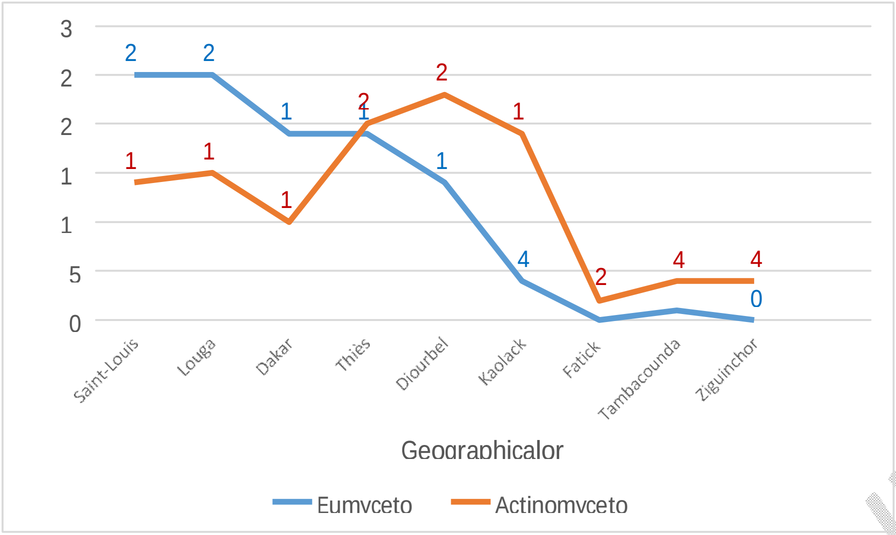

Figure2: Representationofaetiologiesaccordingto Geographicalorigin(presented from north to south, left to right)

It illustrious s a south-north gradient for fungal mycetomas. The curve for bacterial forms is jagged, with peaks in Thiès-Diourbel-Kaolack.

Eumycetomas were predominant in the northern zone (rainfall less than 400 mm), corresponding to Saint-Louis (n=25/14) and Louga (n=25/15). They were also more common in Dakar, further west (n=19/10).

As for the actinomycetomas, they were mostly found in the central regions (rainfall greater than 400 mm). These were Diourbel (n=23/14), Kaoloack (19/4) and Fatick (n=2/0). The same was true for the south-eastern and southern zones (rainfall above 400 mm), namely Tambacounda (n=4/1) and Ziguinchor (n=4/0).

There was a statistically significant correlation between aetiology and isohyets below or above 400 mm (*P*=0.002) (Table 2).

Table2:Correlationbetweenrainfallandaetiology

Rainfall		Etiology		Total	*P*
		Fungal	Actinomycosis		
<400 Saint Louis-Louga(north)	Numberof cases	50	29	79	0,002
>400 Restofthe country (centre-south)	Numberof cases	57	82	139	

Total	Numberof cases	107	111	218	

Thiès, 70 km east of Dakar, was the aetiological transition point where both bacterial and fungal forms were relatively common. Eumycetoma was predominant on its northern slope, whereas actinomycetoma was predominant on its southern slope.

III.4Distribution of seed colour according to rainfall

The colour of the grain was reported in 184 cases. In descending order, the grains were black in 84 cases (45.6%), white in 47 cases (25.5%), red in 44 cases (24%) and yellow in 9 cases (4.9%).

Black grains were more common in areas with low rainfall (< 400 mm), where they were the majority, while above 600 mm they became rare and were dominated by red grains, which peaked between 400 and 600 mm (Figure 3).

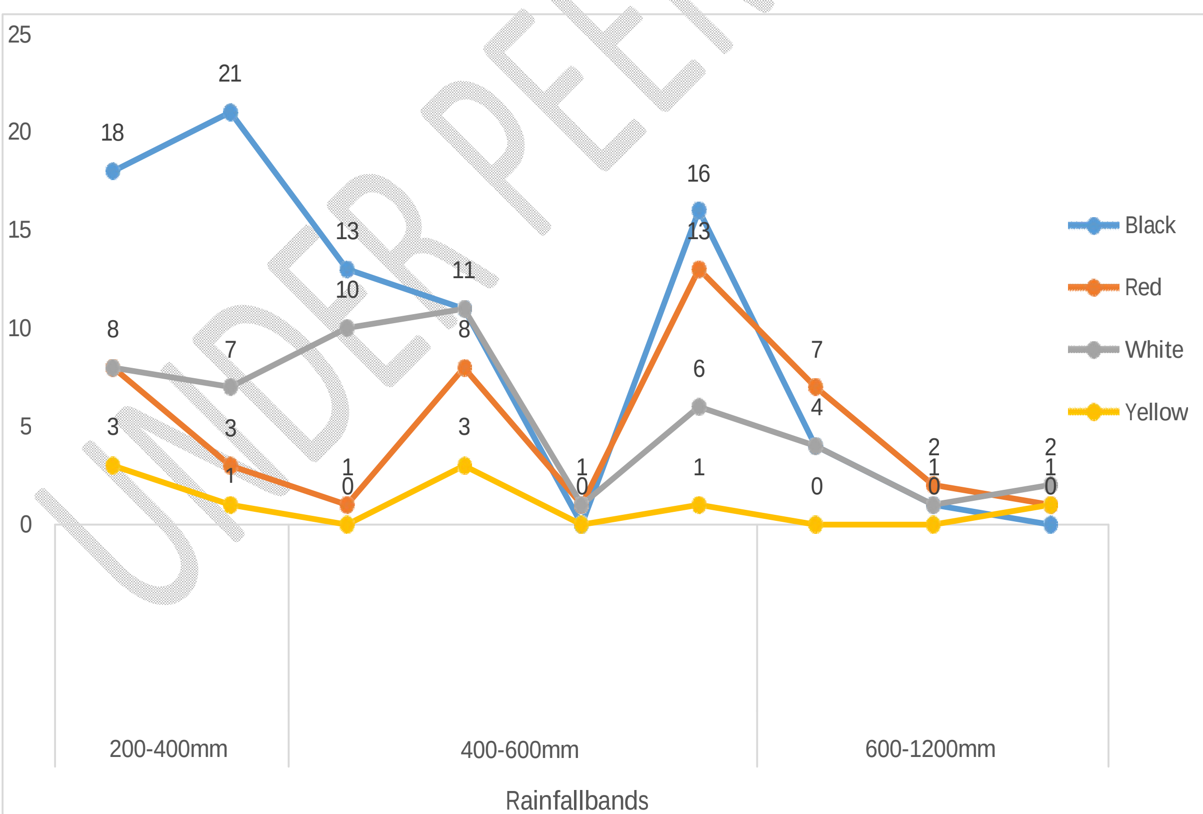

Figure3:Representationofgraincolouraccordingtorainfall

III.5 Grain mapping

Red and white grains were ubiquitous throughout the country, in varying proportions (**Figure 4).** Black grains were also widespread, with the exception of Fatick and Ziguinchor, where they were absent. Yellow grains were not observed on the Dakar-Tambacounda axis passing through Fatick and Kaolack.

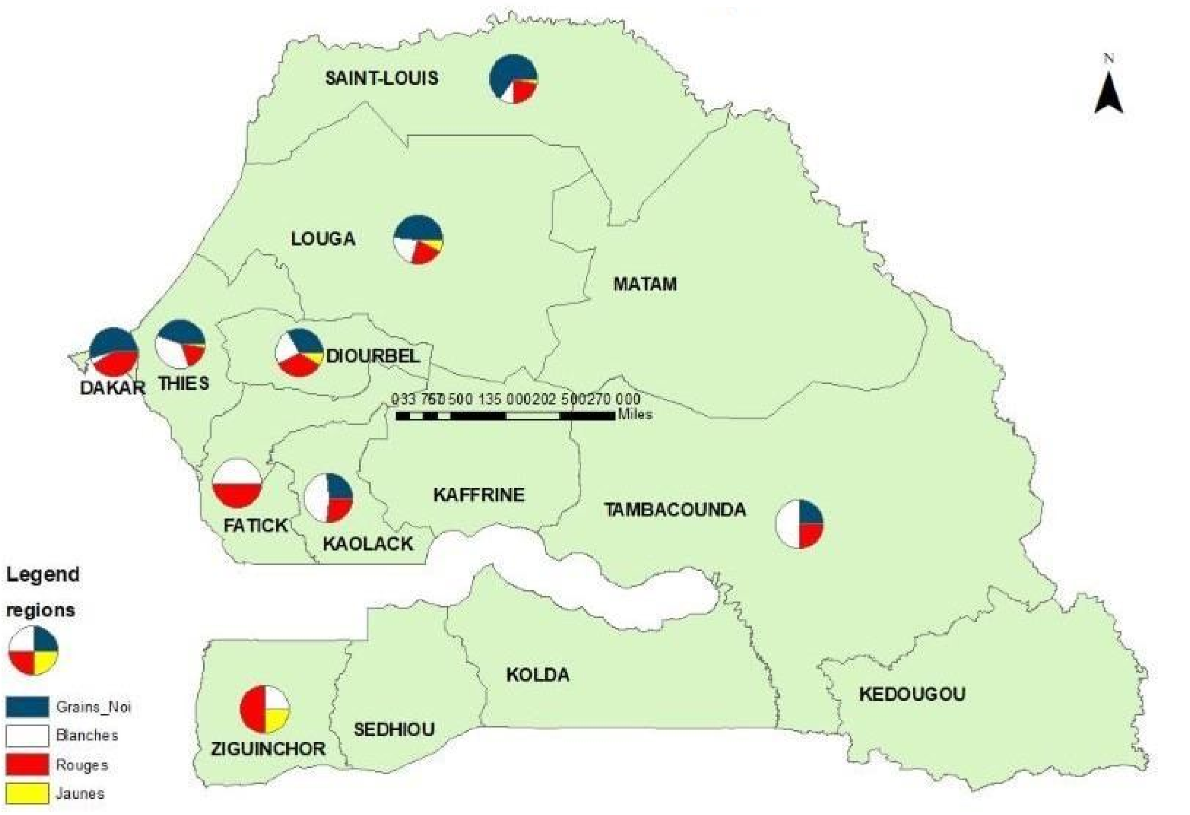

Figure4:Mapshowingthedistributionofdifferenttypesofgrain

IV. Discussion

We have found that mycetoma predominates in young men, most of whom are farmers. An increase in the incidence of mycetoma in Senegal has been observed in parallel with a reduction in rainfall of around 200 mm per region. New outbreaks of mycetoma have been observed, particularly in the eastern and southern regions of Tambacounda and Ziguinchor. This study shows an aetiological transition with a marked increase in eumycetoma, which tends to balance the actinomycetoma forms that have always predominated [3]. Actinomycetomas are more common when rainfall exceeds 400 mm, whereas fungal forms are more common when rainfall is low, below 400 mm.

Outbreaks of red grain mycetoma are spreading southwards, although Thiès is still the most affected region and, to a lesser extent, the area between 400 and 600 mm. However, the main foci of black grain mycetoma are below 400 mm, corresponding to Saint-Louis and Louga, while these types of grains are not found above 600 mm. The difficulty of access to PCR was an obstacle to species identification in all cases.

Although our aim was not to describe the epidemiological aspects of the classical male predominance [7,8], we postulate that there are one or more intrinsic factors predisposing to the development of the disease, since not all people exposed to the same environmental and climatic conditions develop the disease. This is all more likely as a mutation in the gene for chitotriosidase, a macrophagic enzyme involved in the phagocytosis and digestion of pathogens, has recently been identified in *M. mycetomatis* mycetoma. Individuals with genetic mutations leading to a deficiency in its activity are at increased risk of eumycetoma [9].

Global warming, the main cause of reduced rainfall, has led to an increase in the range of mycetoma in Senegal. Between 1947 and 2022, the 800 isohyet, which is considered the upper limit of the mycetoma zone (beyond which mycetomas do not occur), moved significantly southwards, creating new foci and increasing prevalence in other regions. Our results confirm the hypothesis of Ndiaye B et al in 1995 who predicted changes in the frequency and distribution of mycetoma in Senegal [1]. Based on a comparison of isohyet maps of Senegal for the periods 1947-1969 and 1970-1992, the authors found a southward shift of the 800 mm isohyet. Our study describes the same trend in precipitation, with the isohyet now located at 13° N, whereas in 1969 it was between 14 and 15° N in the same hemisphere.

Although there were no cases in Tambacounda [1] in the series reported by B Ndiaye in 1995, we have described 5 cases. In Dakar and Kaolack, the incidence increased from 4.95 to 12% and 5.95 to 9% respectively. While the incidence remained stable in Thiès (about 16%), it decreased in Fatick (from 3.95% to 1%), despite a decrease in rainfall. This epidemio-evolutionary profile in Fatick, which recorded the lowest incidence (outside Casamance) between 1983 and 1993, suggests three hypotheses:

- This is a non-endemic region.
- Silvopastoral activities are less common here.
- There are individual protective factors.

Mycetoma occurs above 800 mm. We have reported indigenous cases from Ziguinchor where rainfall is between 1000 and 1200 mm. Although these cases are not sufficiently representative (n=4), the increase in their frequency from 1% in the Ndiaye B series to 2% in this study is noteworthy [1]. Their steady increase may be due to the emergence of an environmental ecosystem conducive to the development of pathogens.

We confirm REY's postulate and establish the relationship between the two types of mycetoma and rainfall. The lower the rainfall, the greater the prevalence of eumycetoma, which is statistically associated with rainfall of less than 400 mm (p=0.002). In contrast, the predominance of actinomycetoma is clear above 400 mm.

Eumycetomas are becoming more common in Senegal. Their prevalence is increasing while that of actinomycetoma, once in the majority, is decreasing. Since 1995, we have observed a decrease in actinomycetoma cases and an increase in the fungal forms [1,3-5]. In the present series, these fungal forms account for almost half of the cases (49.8%) and are more likely to be black-grains.

These upheavals in health parameters as a result of environmental changes demonstrate the ONE HEALTH context in more ways than one. We are demonstrating here the negative impact of clinical changes on human health by creating conditions that facilitate the proliferation of pathogens that are not only harmful to human health, but also responsible for a DALYS. This is more so as it affects a rural population that is traditionally poor and often forgotten by health systems. In Senegal, as in most endemic countries, mycetoma is the epitome of NTDs. Although there has been an international upsurge [10], curing the disease does not seem to be the focus of attention. Efforts to treat eumycetoma are limited and would benefit from scaling up, as existing treatments are inaccessible, expensive and not universally covered by international organisations or ministerial disease control programmes. For example, the cost of a weekly course of itraconazole in Senegal is estimated at US$144 (€100), which is unaffordable for poor patients who have to pay out of pocket for at least 12 months.

The limitations of this study were

- the unavailability of the 250-500 mm isohyet map, as shown by REY et al [6].
- Failure to identify the species in all cases
- unavailability of PCR

Conclusion

An increase in the range of mycetomas has been established in Senegal in parallel with climate change through a drop in rainfall. New outbreaks of mycetoma have been observed, particularly in the eastern and southern regions. There has been an aetiological transition, with a clear increase in eumycetomas tending to equalize with actinomycetomas forms.

Actinomycetomas are more common when rainfall exceeds 400mm, while fungal forms are more prevalent when rainfall is low, below 400mm. These upheavals in health parameters as a result of environmental changes demonstrate the "ONE HEALTH" context in more ways than one. The application of the recommendations of the Conferences of the Parties (COP) is more than imperative. Therefore, it is crucial to develop further studies on the therapy of eumycetoma in Senegal.

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Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

Details of the AI usage are given below:

1.***Deepl translation*** was used to improve the English langage

References

1-B.Ndiaye, Develoux M, Dieng MT, Ndiaye PD.et al. Les mycétomes à la clinique dermatologique de Dakar(Sénégal).Aspects épidémiologique. A propos de 111 cas. Med.Afr.Noire.1995 ; 42

2-Develoux M, Enache-Angoulvant E. Le diagnostic biologique des mycétomes. Rev Fr Lab 2011; 430:61-7.

3-Dieng MT, Sy MH, Diop BM, Niang SO, Ndiaye B. [Mycétome: 130 cas]. Ann Dermatol Vénéréol. 2003; 130 (1): 16-9. Midi: 12605151 [PubMed/NCBI] [Google Scholar]

4-Badiane AS, Ndiaye M, Diongue K, Diallo MA, Seck MC, Ndiaye D. Geographical distribution of mycetoma cases in Senegal over a period of 18 years. Mycoses. 2020; 63(3):250-256. doi: 10.1111/ myc.13037. PMID: 31765040.

5-Sow D, Ndiaye M, Sarr L, Kanté MD, Ly F, Dioussé P, Faye BT, Gaye AM, Sokhna C, Ranque S, Faye B. Mycetoma epidemiology, diagnosis management, and outcome in three hospital centres in Senegal from 2008 to 2018. PLoS One, 2020; 15(4):e0231871. Doi: 10.1371/journal.pone.0231871. PMID: 32330155; PMCID: PMC7182189.

6.**Rey, M, Baylet, R, Camain, R**. Données actuelles sur les mycétomes. A propos de 214 casafricains. Ann. Dermatol. Syph 1962, 89 :511–527.

7. **Fahal A, Mahgoub el S, El Hassan AM, Abdel-Rahman ME**. Mycetoma in the Sudan: an update from the Mycetoma Research Centre, University of Khartoum, Sudan. PLoSNegl Trop Dis. 2015 Mar 27;9(3):e0003679. doi: 10.1371/journal.pntd.0003679. PMID: 25816316; PMCID: PMC4376889.

8. **Wendy W J Van de Sande, Ahmed H Fahal**. An updated list of eumycetoma causative agents and their differences in grain formation and treatment response. Clin Microbio Rev, 2024 13;37(2): e0003423. doi: 10.1128/cmr.00034-23

9. **Verwer PE, Notenboom CC, Eadie K, Fahal AH, Verbrugh HA, van de Sande WW.**A polymorphism in the chitotriosidase gene associated with risk of mycetoma due to Madurellamycetomatis mycetoma. A retrospective study. PLoSNegl Trop Dis. 2015 Sep 2;9(9):e0004061. doi: 10.1371/journal.pntd.0004061. PMID: 26332238; PMCID: PMC4558086

10. **Ahmed Fahal, Dallas J Smith, Borna Nyaoke , Kingsley Asiedu , Fabiana Falves , Supriya Warusavithanas et al**. Towards enhanced control of mycetoma: a roadmap to achieve the UN's sustainable development goals by 2030. Trans R Soc Trop Med Hyg. 2024; 26:trae016. doi: 10.1093/trstmh/trae016