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Mining the Web of Science for African cities and climate change (1991–2021)

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This study provides a synthetic overview of thirty years of research devoted to urban climate change in Africa. Which cities in Africa are being researched on the impacts of climate change affecting them? What are the main social and urban issues and how are they linked? Is the development of climate services envisaged for these cities? Related to which local issues? Some answers are drawn by text mining the metadata of more than a thousand articles published in the 1991–2021 period and recorded in the Web of Science. The evidences produced are based on the design and exploitation of a taxonomy of keywords forming a set of issues and on their articulation in a network based on their co-occurrences in the articles' metadata. Forty-eight African countries and 134 cities are cited, Cairo, Dar es Salaam, Cape Town, Accra, Lagos, Durban, Nairobi, Addis Ababa, Kampala and Johannesburg being the cities deferring the largest number of studies. The salient urban climate change issues-health, water, energy, social issues and governance, followed by agriculture and food, mitigation, heat, urban territories, risks and hazards-are generally addressed in their interdependences. Urbanization and the implementation of associated policies, as well as the management of water resources, floods health and energy, and land use and land cover changes to a less extent, are proving to be the most pressing challenges. In view of the intricacy of these issues, climate services appear underdeveloped in African cities and barely confined to the acquisition and modeling of environmental data for decision-making in adaptation planning.

KEYWORDS

climate change, African cities, text mining (TM), Web of Science (WOS), socio-ecological issues, climate services

1. Introduction

Urban areas are particularly exposed to climate change, both as contributors (large consumers of energy, particularly fossil fuels, and sources of greenhouse gases) or as subjects to its impacts. One of the clear transformations linked to urbanization is the increasing artificialisation of surfaces, which has a strong influence on living conditions, in particular with the thermal degradation of urban spaces and various negative effects on public health (Harlan and Ruddell, 2011; UN-Habitat and WHO, 2020). It is anticipated that climate change risks to cities will rise rapidly in the mid- and long-term with further global warming, especially in places already exposed to high temperatures or along coastlines (Pörtner et al., 2022). This exposure to climate-related hazards interacts with non-climatic factors like informality and precariousness in housing, high levels of poverty, as well as limited access to basic services. These perspectives highlight the need to strengthen multi-level climate governance and the integration of climate concerns into urban planning.

A few features decline in a specific way for cities of the African continent. While high-income countries have the highest percentages of urbanized population, Africa and Asia currently have the fastest urbanization rates (WUP, 2019), a trend that is expected to continue in the coming decades. In this region, the proportion of urban population increased by 1.1 per cent annually between 2015 and 2020. By mid-century, the urban population of Africa is likely to almost triple. As a consequence, 22% of the world's urban population will be concentrated in Africa by 2050. In 2018, Cairo, Kinshasa and Lagos were the only African megacities. Two more are expected to emerge by 2030: Dar es Salaam in Tanzania and Luanda in Angola are each expected to grow beyond 10 million inhabitants. The number of big cities with five to ten million people in Africa is also projected to increase from five in 2018 to thirteen in 2030 (WUP, 2019).

About one-third of African cities with populations over 300,000 are located in areas that are at high risk from two climate hazards (Pörtner et al., 2022) and it is estimated that about 70% of African cities are highly vulnerable to climate shocks (see the Verisk Maplecroft Climate Change Vulnerability Index[1]). Adaptation measures are concentrated in more developed countries (Olazabal et al., 2019). Indeed, around 80% of European cities with over 500,000 residents have mitigation and/or adaptation plans (Reckien et al., 2018). By contrast, 89% African cities with more than one million inhabitants have not reported any adaptation initiatives (Araos et al., 2016).

The objective of this study[2] is to take stock of the work already carried out on the impacts of climate change on large cities in Africa and on the related problems they face. It is also a question of identifying the areas of the continent where this work particularly focuses and any neglected areas. To do this, we use the opportunity offered by the availability of a very large number of scientific articles metadata (including titles, keywords and abstracts of publications) on the Web of Science combined with computer-based text mining, an approach required by the size of the textual corpus collected, by the possibility of future updating of the analysis and by its replicability.

The data acquired and their pre-processing are described in Section Data, additional information and pre-processing. The distribution of African countries and cities that have been the subject of studies related to climate change between 1991 and 2021, as well as the main topics covered are presented in Section African city distribution and related issues. At the city level, the various climate change issues are generally not independent of each other. One way to capture these interactions as they are conceived in research works is to establish a kind of semantic network (based on article metadata). Section Network of African cities and climate change issues sets out this analysis and offers an interpretation of the main evidence produced. A synthesis of these results is made in Section Discussion and conclusion, accompanied by a discussion.

1 See https://www.maplecroft.com/risk-indices/climate-change-vulnerability-index/ (accessed April 25, 2022).

2 It should be noted from the outset that this study does not intend to be a bibliometric analysis of scientific productions, but rather an analysis of the theme of the links between African cities and climate change based on these productions.

2. Data, additional information and pre-processing

The analysis of scientific production linking African cities and climate change is based on data made available on the Web of Science platform (hereinafter WoS). Global city and country name information is taken from the GeoNames platform (Section Web of science and geonames data). The search of text segments from the WoS is based on lexical processing (Section Lexical information processing) and on the development of a taxonomy of key expressions (Section Issues as a taxonomy of keywords).

2.1. Web of Science and geonames data

The Web of Science[3] (WoS) online platform provides metadata for scientific articles on all contemporary research topics. When they are complete, the metadata of an article include in particular the names and affiliations of the authors, the title, year of publication, key expressions and summary of the article, the WoS categories or scientific areas concerned, and various information on the journal, book or scientific event where the article was published or presented. Performed on June 7, 2021, the search for articles using the regular expression "*urb* AND clim**" collected the metadata of 24,757 articles, the oldest dating back to the 80's. The text mining of this corpus covers only the titles, key expressions and abstracts of the articles. As will be seen, authors' affiliations are used in a separate analysis.

Several other bibliometric database has been investigated (Gaston, 2021). The largest ones brought thousands of papers (Isidore[4]: 13,695 papers; the data base of the International Association of Urban Climate: 7,955 papers) but (1) the huge majority of them were already in the WoS data base or (2) the set of metadata was not complete enough to allow the planned information retrieval. We searched also for papers in French but only 64 of them were found on our topic in the ProQuest data base.[5] Always with the same query used with the WoS, Dimensions (Hook et al., 2018) provided 94 papers only. Finally, in order to have homogeneous set of metadata and to ease the replication of the approach, we decided to limit the corpus to WoS meta-data with no constraint put on the publication year.

The analysis also requires the use of additional geographic onomastic information: country names, city names, plus words (e.g., demonyms, the name of peoples) and forms (e.g., adjectival forms) derived from these names. The source of this information is the free GeoNames[6] geographical database. The notion of "country" used by the database is geographical rather than political. Thus, for example, the island of La Réunion (French

3 See https://clarivate.com/webofsciencegroup/solutions/web-of-science/ (accessed March 31, 2022).

4 ISIDORE - unified access to research data in the Humanities and Social Sciences https://isidore.science/vocabularies (accessed November 28, 2022).

5 ProQuest LLC https://about.proquest.com/ (accessed November 28, 2022).

6 See http://www.GeoNamess.org/ (accessed March 31, 2022).

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name) in the Indian Ocean, department of France, or Antarctica, are both considered as "countries." In order to increase the reliability of computer-based text mining (see Section Lexical information processing), adjectival forms of country names (e.g.,: Afghanistan -> Afghan; Angola -> Angolan) as well as demonyms (e.g.,: Sahraouian, Sahrawis, western Saharan, Sahraouis, Sahrawi, Sahrawian) were also collected. The list we use includes the names of 4,445 cities worldwide of more than 100,000 inhabitants (5,287 names when including their eventual Latinized dialectical name or their name in French in addition to their English name), the names of 262 countries (in the sense of GeoNames) and 452 additional adjectival forms or demonyms.

2.2. Lexical information processing

The automatic identification of the main issues addressed by scientific research on African cities and climate change, as well as the evaluation of their importance, requires prior processing of textual information. The 24,757 articles of the WoS provide 43,255 key expressions. These expressions are distinct in the sense that they derive from different standardized forms or lemmas. Lemmatization is performed with NLTK's lemmatizer (Manning et al., 2008) based on WordNet (Miller, 1995; Felbaum, 1998). We consider that the lemma of an expression composed of several words consists of the sequence of lemmas of each of these words, their order of occurrence being preserved.

Synonyms and acronyms present specific challenges. In fact, in order not to bias the text mining process and statistics, the numbers of occurrences of two synonymous words must be added and credited to only one of these words, then considered as an "entry" (as a dictionary entry) for this series of synonyms. But if there are indeed lists of synonymous words, the synonymy relationship between compound expressions is difficult to automate (a) because it can take a wide variety of orthographic or grammatical forms (e.g.,: waste water / waste-water / wastewater; biodiversity / biological diversity) or (b) because what is considered as synonyms depends on the ontology underlying the analysis (e.g., making a difference or not between "community-based adaptation" and "community-level adaptation"). Acronyms generally appear for the first time in the texts accompanied by their developed meaning and are then used in capital letters. A list of these acronyms must therefore be drawn up from an initial analysis of the corpus as a whole (looking for expressions in capitals), and then used in counting the number of occurrences of the expressions concerned.

For the assignment of WoS articles to one or more countries (resp. cities) derived adjectival forms and demonyms (resp. other names of cities) are considered synonyms. When two cities of two different countries are homonymous (e.g., Tripoli, respectively, in Libya and in Lebanon), the co-occurrence in the article of the country name is usually sufficient to remove the ambiguity (in our case, to exclude Tripoli from Lebanon, a non-African country according to the GeoNames classification). If no country name (or derived form) appears, the ambiguity is resolved by direct inspection (not by computer) of the article's metadata.

2.3. Issues as a taxonomy of keywords

Two types of information provide an overview of the content of the research work performed over 30 years on climate change and cities: (a) the scientific disciplines involved and (b) the keywords chosen by the authors of the publications. The first shows the kinds of scientific knowledge mobilized according to their structuring in the academic field, and how collaborations are organized between disciplines to respond to the issues linking cities and climate change. WoS metadata provides direct access to this type of disciplinary mapping.

The second type of information, the set of key expressions, constitutes a dense sampling of the thematic field delimited by the initial query used to constitute the textual corpus. To compensate for the extent of the pool of key expressions and its semantic dispersion, these expressions must be grouped into various classes whose labels evoke major socio-ecological or development issues. There are two options for constituting such taxonomy, i.e., for defining these classes and their respective lexical coverage. An automatic (unsupervised) clustering (Pérez-Suárez et al., 2019; Naouali et al., 2020; Ezugwu et al., 2021) based on the most frequent co-occurrences of key expressions in articles offers the possibility (with some parameterization of the algorithms used) to computationally define these classes and their content. However, we do not use this option here because on the one hand it often leads to classes having little meaning in the field of academic studies and their history, and on the other hand it deprives us of the possibility of giving orientations to the analyses. An example is illustrative of this gap: computational clustering will tend not to separate the grouping of expressions under the distinct labels of "mitigation" and "adaptation" to climate change. Nevertheless, this distinction deserves a rigorous structuring in two lexical classes because it makes full sense to the actors and decision-makers involved particularly in the design and implementation of measures to combat climate change in urban areas, in initiatives aimed at fulfilling certain sustainable development goals or in urban planning.

We have opted for a definition of classes based on the collective expertise of the co-authors of this study, co-authors whose academic profiles are well differentiated (urban planning, data science, geography, sociology, climatology). The control over the definition of the taxonomy allowed by this option has a counterpart: the cumbersome processing of each key expression for which it is necessary to agree on the attribution to a class. To reduce this burden, we have focused on the key expressions of the only articles in our corpus dealing with African cities. A prior sorting discards a number of expressions-most often those made up of a single word-which, out of context, are too general in use, without a specific link with the subject of this study (e.g.,: "diagnostics;" "functional diversity;" "lessons learned"), or too ambiguous to be attached to a class (e.g.,: "exposure;" "distribution categories;" "net benefits"). Finally, 3,275 have been retained and distributed into eighteen classes which we will use in the following sections. The class labels are: Adaptation; Agriculture and Food; City Variables; Energy; Coast; Flood;

TABLE 1 Fifteen most cited African countries.

	Country	#Occ.	#Col.	Col.
1	South Africa	156	41	USA (34); UK (17); Australia (11); Germany (9); Canada (8)
2	Egypt	98	33	USA (15); Germany (12); Italy (5); France (4); South Africa (4)
3	Nigeria	87	29	UK (11); USA (10); South Africa (8); Canada (4); China (3); Germany (3); Kenya (3); Malaysia (3)
4	Kenya	54	27	UK (12); USA (11); Germany (8); South Africa (6); Australia (5)
5	Algeria	52	16	France (6); Belgium (3); Latvia (3); Germany (2); Morocco (2); Tunisia (2)
6	Ghana	48	33	Germany (11); USA (8); UK (7); Australia (4); France (4); Netherlands (4)
7	Tanzania	48	23	USA (11); Germany (7); Italy (6); Kenya (6); Canada (3); New Zealand (3); South Africa (3); Sweden (3); Switzerland (3); Uganda (3)
8	Ethiopia	47	32	USA (14); Belgium (7); Italy (5); Germany (4); Netherlands (4); South Africa (4); Sweden (4); UK (4)
9	Morocco	42	17	France (5); Germany (5); Belgium (3); Spain (3); Italy (2); Netherlands (2); Portugal (2); USA (2); UK (2)
10	Senegal	30	21	France (8); USA (8); UK (4); Germany (3); Mauritania (2); Switzerland (2); Uganda (2); Ivory Coast (2)
11	Zimbabwe	29	18	South Africa (16); Sweden (3); USA (3); Botswana (2); Cyprus (2); Germany (2); Turkey (2); UK (2)
12	Uganda	26	18	South Africa (4); Kenya (3); USA (3); Belgium (2); Netherlands (2); Nigeria (2); Switzerland (2)
13	Sudan	23	22	Egypt (3); Germany (3); Netherlands (2) (etc.)
14	Cameroon	22	20	USA (5); France (4); India (3); UK (3); Germany (2); Italy (2)
15	Tunisia	18	8	France (4); UK (2); Algeria (1); Germany (1); Greece (1); Nigeria (1); Saudi Arabia (1); Spain (1)

#Occ., number of occurrences in WoS articles metadata; #Col, number of collaborating countries; Col., upper ranked collaborating countries (number of cosigned publications).

Governance; Health; Heat; Land; Migration; Mitigation; Pollution; Risk & Hazard; Social Stakes; Tools; Urban Territory; Water. An overview of the contours used to define the classes is given in the Appendix.

3. African city distribution and related issues

The first aim is to identify the cities that have been the most frequent subject of research in connection with climate change over the past thirty years. The GeoNames database lists 514 African cities with more than 100,000 inhabitants and 53 names of countries on the continent. These names, as well as their derivatives (various names of a city, adjectival forms of countries, demonyms), are systematically searched in the titles, key expressions and abstracts of more than twenty-four thousand articles extracted from the WoS database. After various checks, automatic (e.g., we assume that the co-occurrence of a city name and the name of the country in the same article certifies the occurrence of this city) or manual (checking the occurrences of homonymous city names without mention of country; the city of Man in Ivory Coast is never mentioned although the word "*Man*" appears about ten times for example in "*UNESCO's Man and the Biosphere Programme*"), the metadata of 1,101 articles are retained as mentioning at least one African city.[7]

7 Of course, the authors' affiliations are not considered in the analyses that follow.

TABLE 2 African city names and their namesakes worldwide.

African city name (country)	Countries of homonymous cities
Alexandria (Egypt)	USA
Newcastle (South Africa)	Australia, UK
Tripoli (Libya)	Libanon
Worcester (South Africa)	UK, USA

3.1. African countries and cities in article metadata

The text mining of the selected articles finds 1,296 occurrences of names of 48 countries (or derived forms attributable to countries). The fifteen most frequently cited countries are listed in Table 1.

The last two columns give the number of countries that have collaborated on articles whose field is the host country (2nd column) and the list of the highest-ranked collaborating countries (classified by number of co-signed publications). Many factors, that certainly do not have the same influence depending on the host country, are likely to explain these patterns of collaboration. Among those factors, scientific collaboration is one of the vehicles of soft power through mechanisms of official development assistance (e.g., positions of the USA or the UK among the collaborating countries). An emerging country can also strengthen its regional influence by this means (e.g., South Africa with regard to Zimbabwe or Uganda). Linguistic influence and sharing, a partial expression of the persistence of postcolonial links, also seems to play an important role in certain areas (e.g., France

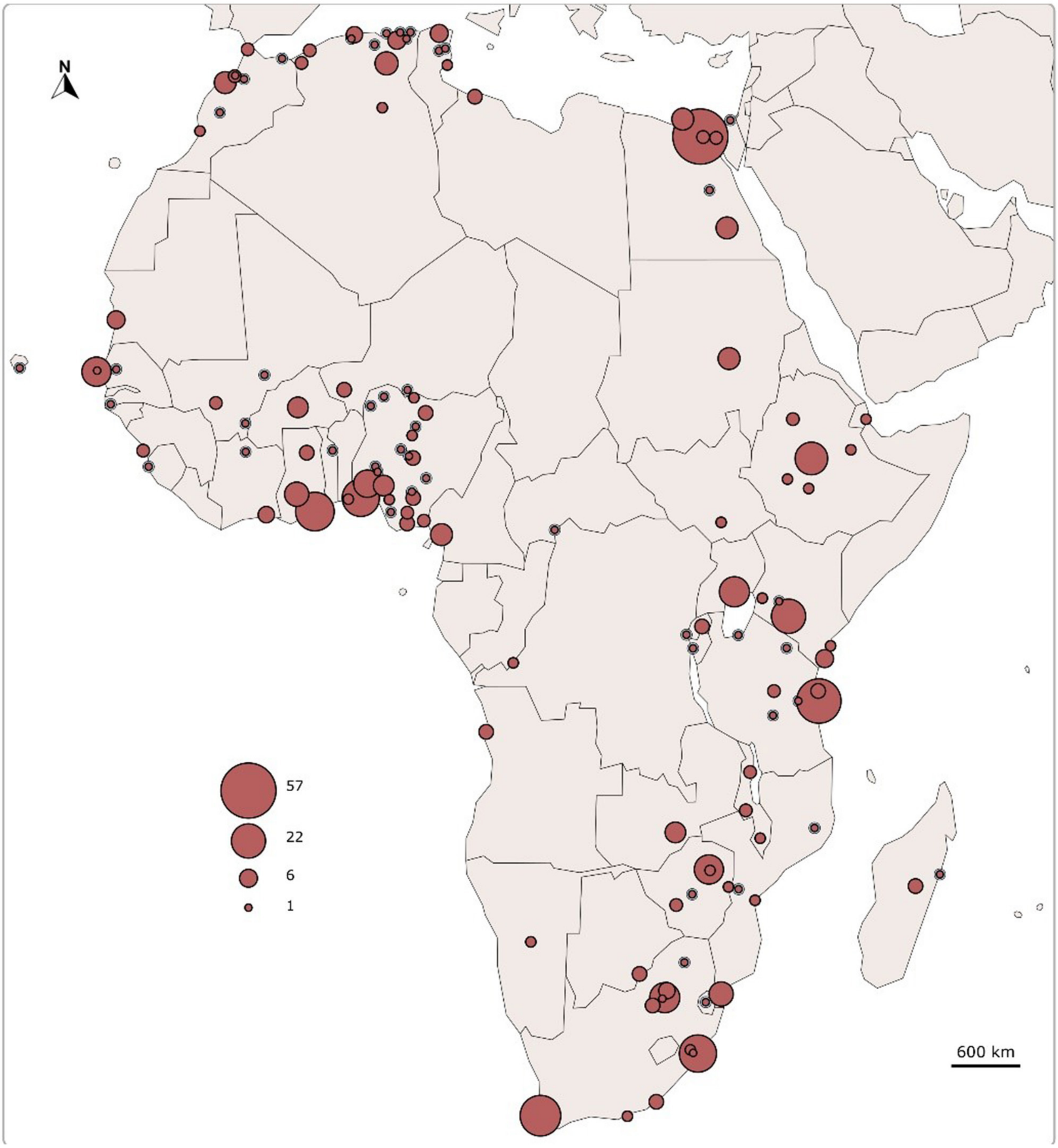

FIGURE 1
Geographical distribution of the cities named in the corpus (symbol size is proportional to the number of articles in which the corresponding city is cited; see the scale down-left).

and Algeria, Morocco, Senegal or Tunisia). Let us note the 59.7% of the articles have at least one of the authors' affiliation in Africa.

South Africa is the most cited country in the analyzed corpus, which reflects, among other things, the activity of a large scientific community and the existence of several research-intensive universities in the major cities of the country. This country belongs to the Southern sub-region of Africa which is very exposed to climate change effects, with a potential drought increase (WUP, 2019). Droughts period in this region will be longer and more severe. Moreover, other climate change hazards such as sea-level rise, cyclones and erosion are expected to increase (Rakgase and Norris, 2015).

Egypt, Algeria and Morocco are among the most cited countries in the analyzed corpus. The North African region is considered as a climate change hotspot (Diffenbaugh and Giorgi, 2012). Indeed, this region is highly exposed to many hazards such as a strong

TABLE 3 Ten most cited African city names and number of occurrences in WoS articles metadata (authors affiliations excluded).

Rank	City	#Occurrences
1	Cairo	57
2	Dar es Salaam	37
3	Cape Town	31
4	Accra	28
5	Lagos	26
6	Durban	26
7	Nairobi	22
8	Addis Ababa	20
9	Kampala	17
10	Johannesburg	17

variability of rainfall amounts, periods of very hard droughts and heat waves (Lelieveld et al., 2016). Cities situated in the African Horn are among the African cities most vulnerable to climate change (Moges and Gebregiorgis, 2013). These cities are suffering from recurrent water shortages and from extended and repeated drought periods (Ogola et al., 2012). It is estimated that between 2008 and 2010, these climate-related hazards have impacted thirteen million people in the region (Leal Filho et al., 2018) with a loss of human lives and a humanitarian crisis (Nganga et al., 2016).

The importance of the impacts of climate change is not the only factor explaining the volume of studies in the corpus attached to a given country. Indeed, for example Libya, also a Mediterranean country in North Africa, is mentioned very little in our corpus, a deficit that could reflect the political instability of recent years and the related insecurity. Research efforts are also partly explained by the high amount of climate change research funding focused on African countries from 1990 to 2020 (Overland et al., 2021) and its differential distribution between those countries. The percentage of climate change papers published on a given country that include at least one local institution (Pasgaard et al., 2015) also correlates with this distribution.

What map of occurrence frequencies do we obtain by searching for city names? We notice that four African cities with more than 100,000 inhabitants have namesakes in other countries located in North America, Europe or Oceania (see Table 2). The occurrence of these city names in the metadata without occurrence of the corresponding African country name, gives rise to a direct reading of the metadata in order to discard irrelevant detections (false positives; also see above the case of the city of Man). Names of African cities without namesakes are found in 520 occurrences with their respective country names, as well as in 221 occurrences without mention of the country. Thirteen occurrences of homonymous towns with their country were also found during text mining.

The geographical distribution of the 134 cities named in the corpus is represented in Figure 1. Many factors probably contribute, more or less independently, to this distribution: the number of inhabitants of cities; their economic dynamism and relative wealth; the rate of urban development; the presence of local universities and their attractiveness to encourage international collaborations on urban climate change; the ability of the organizations concerned to attract funding to conduct this kind of research; the willingness of local public authorities to take into account the proven or expected impacts of climate change; the existence of local skills allowing the development of services (health, access to essential resources, urban planning), etc. Assigning a local weighting to these various factors–the list of which is not exhaustive–would require the availability of numerous other local or national data and information. But it is certain that the pressure undergone by climate change on the populations and on the local governments is neither the only explanatory factor of this distribution (so to speak all the cities of Africa have to face, sometimes in the emergency, to one or more climate impacts), or even the necessarily dominant factor.[8]

The ten most cited African cities are listed in Table 3. It's noticed that the majority of the top ten cited cities are capital cities. Only Lagos, Durban and Johannesburg are not. That shows the interest of scientific research for the big cities and the centralized nature of this activity. It must be mentioned that Cairo, Lagos (with Kinshasa) are the only megacities in Africa in 2018 and that Dar es Salaam (Tanzania) is one of the fastest-growing cities in sub-Saharan Africa (WUP, 2019).

A lack of scientific production on climate change and urban areas clearly appears in the Sahel region.

Policymakers in Sahel are facing a high number of issues such as poverty, transnational crime, weak institutions and population displacement (Bøås and Strazzari, 2020). This makes climate change to be perceived as a non-priority issue. In addition, the largest cities of the African continent donot belong to this region. Indeed, except Dakar which benefits from a coastal location and high-level services, the capital cities in the Sahel region like Bamako, Niamey, Nouakchott, Ouagadougou and N'Djamena are secondary cities (Boyer and Lessault, 2017) in the sense that they have an economic influence limited to their national space.

In Western Africa, there is a high concentration of population in coastal megacities such as Abidjan, Accra, Lagos, and Douala. For instance, in Ghana, Benin, Togo and Nigeria, most economic activities are located in the coastal cities. These cities are vulnerable to sea level rise which is the most important climate hazard for these urban areas (Almar et al., 2022). Cities in Ghana such as Accra, Sekondi-Takoradi and Kumasi are facing uncontrolled growth, unplanned urbanization, overuse of water resources and the increase of energy demand (Korah and Cobbinah, 2017). These features make Ghanaian cities of importance for climate change studies (Cobbinah, 2021).

It can be seen on Figure 1 that countries situated in the North-South corridor which extends from Libya to Namibia through

8 For the same reasons, this map does not offer any element of an answer to the question of which cities would most need the implementation of actions to combat climate change, whether through adaptation or mitigation. The prioritization of such needs is above all a political matter and would depend on the evaluation criteria highlighted (e.g., social, economic, environmental, health-related), which could not only lead to very different choices but also to conflicting decisions.

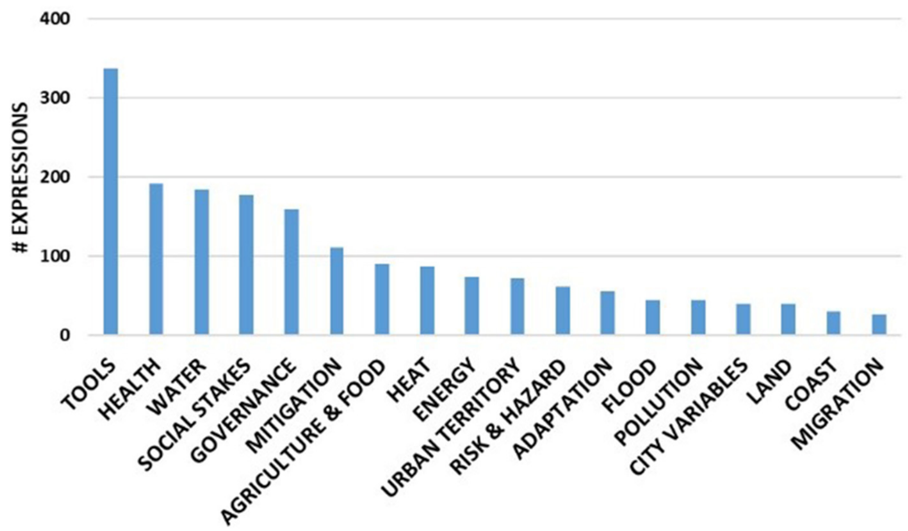

FIGURE 2
Ranking the number of expressions' occurrences (y-axis) aggregated per issue (x-axis).

Chad have almost no climate change studies focusing on cities. Amegavi et al. (2021) have shown that Libya, Chad, Central African Republic, Democratic Republic of Congo and Congo are classed as countries with low adaptation readiness. The adaptation readiness index has three dimensions, social, economic, and governance. The social dimension is based on social conditions, such as education, Information Communication Technology infrastructure (Chen et al., 2015) and the capacity of reducing inequality which hinders the ability of poor populations to adapt to climate change effects (Adger, 2006; Wang et al., 2020). Indeed, the countries cited above present a poor infrastructural development, a problem of governance and a low economic development which are important factors for adaptation capacity of territories at all scales (Adger, 2006; Fidelman et al., 2017).

3.2. Distribution of issues

Climate change affects all ecosystem compartments, all renewable natural resources (among which we include water here, even if this is a shortcut with regard to, for example, fossil groundwater in the Saharan zone). Equally rare are productive human activities or environmental living conditions that are not affected. A kind of hierarchy of issues emerges through the analysis of the frequencies of occurrence of key expressions grouped by theme. The distribution of key expressions subsumed under each issue of the taxonomy is shown in Figure 2 (see also the Appendix).

The first rank item in the histogram is the "tool" category. This testifies to the large number of articles paying a marked attention to the methodological and technical aspects of the observation and scientific study of climate change in African cities. The authors consider the designation of these tools sufficiently important and discriminating to mention it among the key expressions they choose.

Health is the second item–but first "issue"–most studied in scientific articles on African cities and climate change. Climate change already impacts the health of tens of millions of Africans. But mortality rate is known to increase with further global warming, putting additional pressure on health challenge (Romanello et al., 2021). The impact on human health is especially pronounced in African cities generally marked by massive poverty, high population growth as well as rapid and informal urbanization (Chersich et al., 2018; Brousse et al., 2019). These features make these cities more vulnerable to climate change mainly in the absence of access to basic health services for all. Vulnerability, especially health vulnerability (Zerbo et al., 2020), is highest for specific social groups or communities such as pregnant women, the elderly, the poor and people with poor living conditions, immune-compromised people and young children.[9] Thus, the major challenge for African cities is to manage the direct effects of climate change on human health. These are, among others, the increased burden of water-borne diseases (especially after floods) or vector-borne diseases such as dengue fever or malaria, more frequent exposure to heat waves and to higher heat stresses, the higher incidence of respiratory and cardiovascular diseases favored by chronic air pollution mainly in megacities such as Cairo or Lagos (Frumkin et al., 2008; Hathaway and Maibach, 2018).

Water appears as the third most studied issue in our scientific corpus. Globally, half of the people drinking water from unsafe sources live in Africa. For instance, in Sub-Saharan Africa, only 24% of the population have access to safe drinking water (Behind, 2019).

9 This enumeration is partly a generic, a priori, designation of vulnerable groups such as can be found in texts with a global vocation, one of the most emblematic among these being the 2030 Agenda (UNGA, 2015). Thus the SDG11 (on cities) associates "women, children, persons with disabilities and older persons" to "those in vulnerable situation." They are associated to "the poor" in SDG 1 (on poverty), "infants" in SDG2 (on hunger and nutrition), "women and girls" in SDG6 (on water and sanitation).

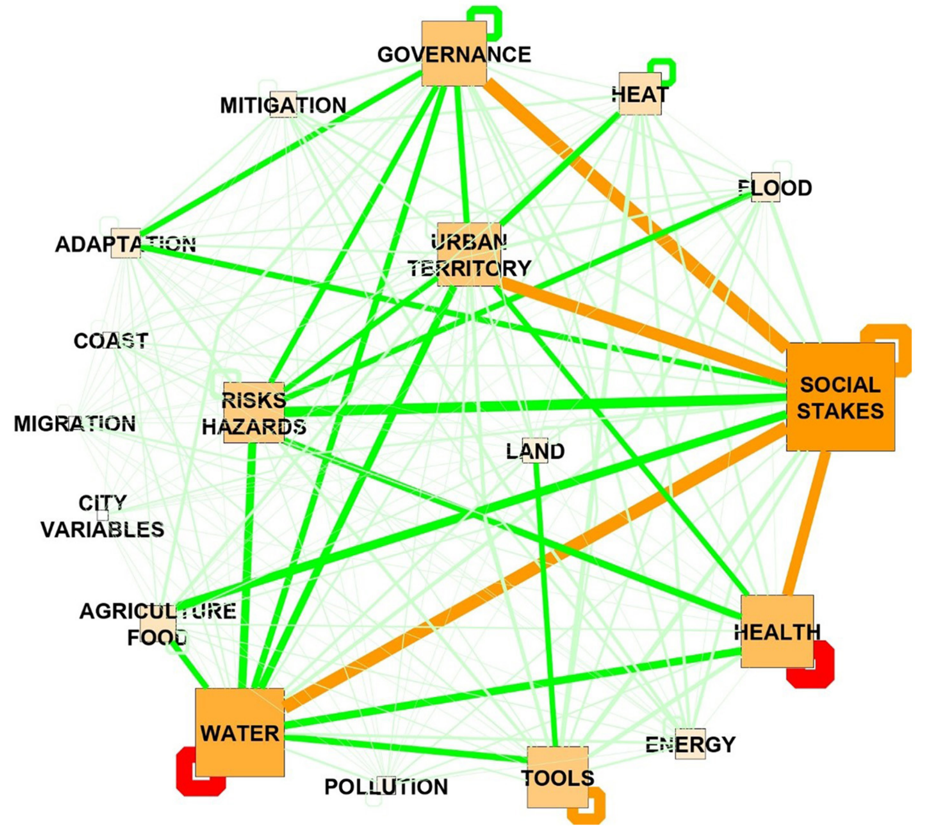

FIGURE 3
Network of Issues (classes of key expressions). Issues are linked to each other via the co-occurrences of their key expressions in the articles' meta-data. The size of each vertex is proportional to the sum of the weights of its links (red: $w > 600$; orange: $600 \geq w > 400$; green: $400 \geq w > 200$; light blue: $200 \geq w$).

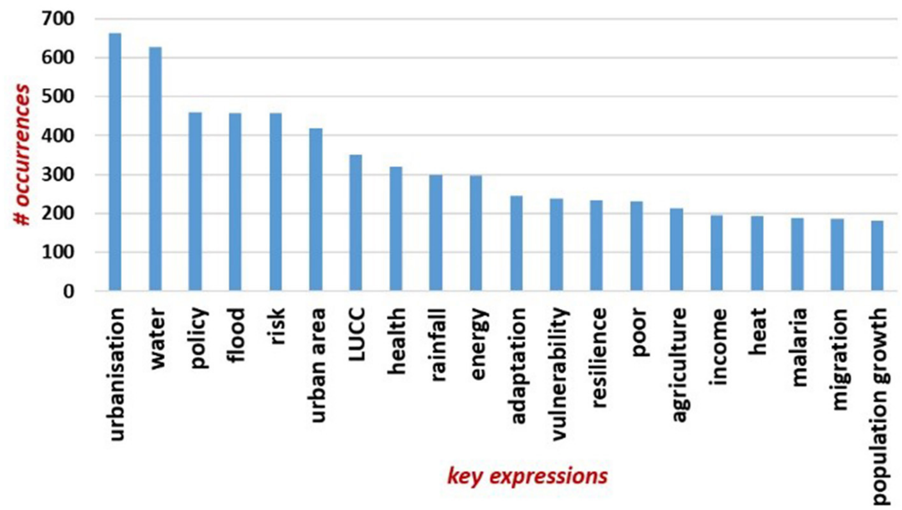

FIGURE 4
Ranking keyword expressions by the number of their occurrences in pair with other keywords.

Climate change have a huge impact on water in this continent because of increasing temperatures, changes in rainfall volumes and spatiotemporal patterns, increased seasonal and inter-annual variability and droughts in some regions. Correlatively, African cities are facing scarcity of the water resource under climate change (Grasham et al., 2019). The water resource is a dominant

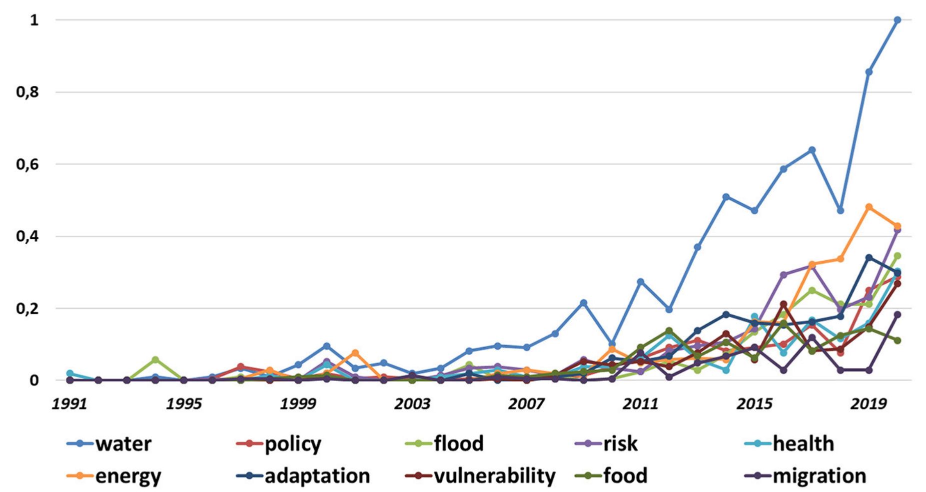

FIGURE 5
Normalized time series of occurrences of some key-words aver the 1991–2020 period.

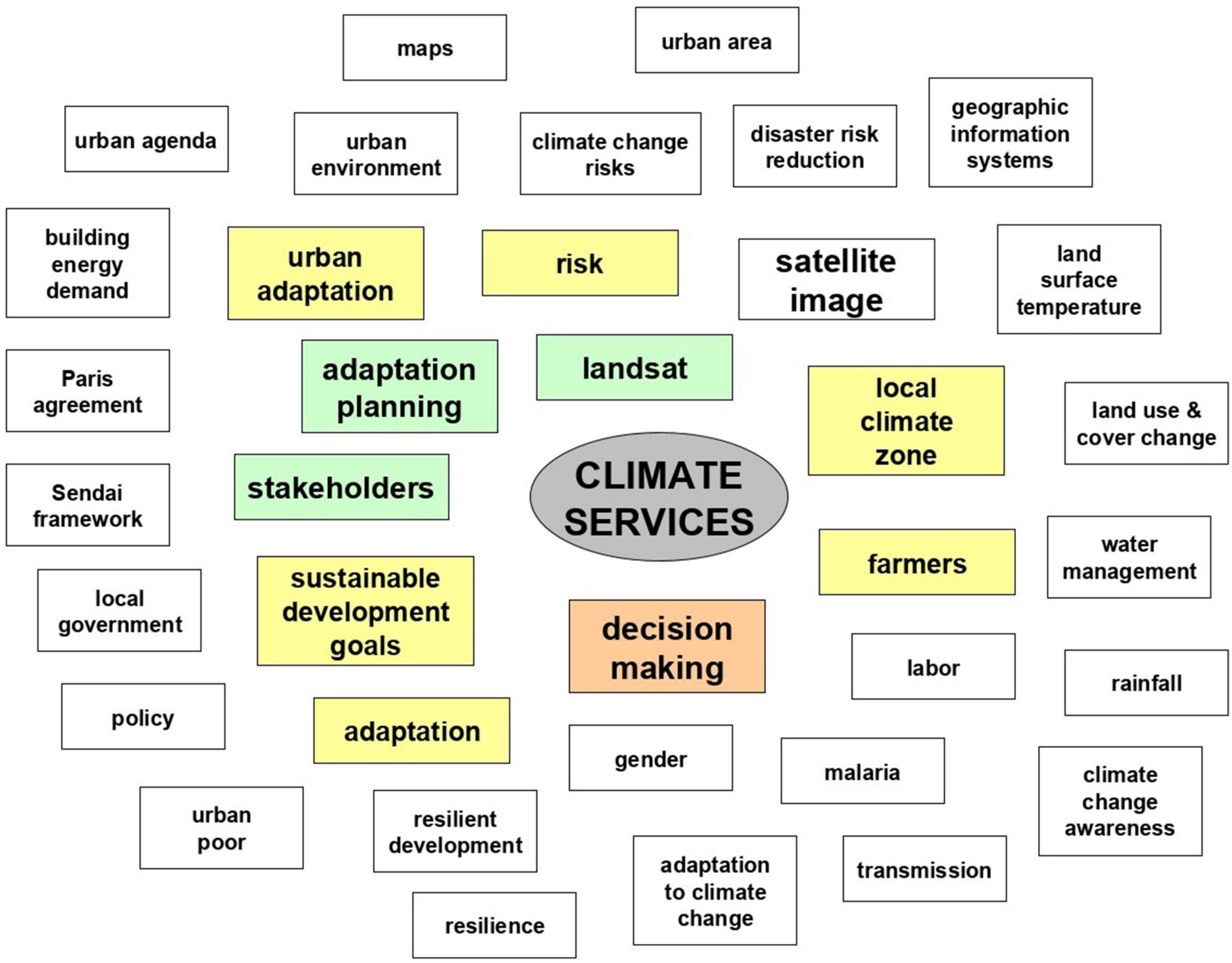

FIGURE 6
Key expressions neighboring the "climate services" in metadata of WoS articles on African cities and climate change (vertices' colors indicate the weight of each link: red = 6; green = 3; yellow = 2; white = 1).

issue for water management because the required volumes are not affordable and the water is often of bad quality. Moreover, increasing population and changing water use patterns establish a huge demand in this resource in African cities. Governments are not able to satisfy this demand, so right to water is hugely affected negatively.

Key expressions relative to social stakes are well represented in this corpus. Indeed, climate change is strongly affecting the economic growth and livelihood of African cities because of the socio-economic feature of these urban territory such as uncontrolled urbanization, poverty, unemployment and low quality of education (Sono et al., 2021). Added to their serious exposure, these factors make African cities more vulnerable to climate change. For instance, Africa has the largest population living in extreme poverty that are exposed to high flood risk (Rentschler and Salhab, 2020). Poverty is a significant factor of flood-induced impacts. In South Sudan, the severe flooding which took place in 2019 for about 6 months affected more than 900,000 inhabitants and caused a major humanitarian crisis (IFRC, 2022). Another likely manifestation of multifaceted climate change, the tropical cyclone Idai that hit Mozambique in march 2019 caused a socio-economic crisis. More than 270,000 people were affected, and over 340 deaths were recorded (Charrua et al., 2021).

Governance is likewise an important issue for African cities because of the slow policy implementation progress on climatic issues (Taylor, 2016). This slow-pace policy implementation is due to the scarcity or lack of support mechanisms and to the dependency on international partners' funding (Leck and Roberts, 2015). Moreover, the lack of systematic approaches marked by uncoordinated and non-territorialized sectoral policies (Mhedhbi, 2021), the hierarchical and intricated state bureaucracy (Meissner and Jacobs, 2016), the lack of coordination between stakeholders at all levels and limited local participatory approaches (Odemerho, 2015) hinders the setting of the agenda of climate change in national and urban policies in Africa. Added to these barriers, there is a lack of empirical studies that examine how local climate actions arise in political systems of developing and emerging economies (Adekola et al., 2020).

As the histogram shows, the semantics of attenuation is more present in this corpus than that of adaptation. This observation is an important clue that should be understood. At the first international events on climate change, attention was more directly focused on mitigation. Adaptation emerged rather lately on the international scene. It was during the Cancun (Mexico) summit (16th Conference of the Parties of the United Nations Framework Convention on Climate Change[10]), which took place in 2010, that an action plan for adaptation (the Cancun Adaptation Framework) was adopted. In addition to the greater importance given to mitigation over adaptation, international climate policies at their beginning did not consider the local scale as a relevant scale of action. Another reason is that so far, more than half of the climate-related financial aid for Africa was for mitigation (61%). Only 33% of this financial commitment was dedicated to adaptation and 6% supported both mitigation and adaptation (Savvidou et al., 2021). Indeed, only 19 African countries out of 55 received more than 50% of their climate-related finance for the implementation of adaptation-oriented measures (among this countries Angola, Botswana, Chad and Djibouti, etc.; Savvidou et al., 2021).

Even if agriculture and food is among the most important problem related to climate change in Africa, this category is less represented in the analyzed corpus. This is due to the fact that the search for articles was focused on urban areas. Heat issue is not very well-represented, as shown in Figure 2. Generally, limited urban climate studies have been carried out in developing countries. Among the 1,101 analyzed articles only 134 articles are dealing with Urban Heat Island (UHI) and thermal comfort.

Africa has witnessed rapid urbanization over the past few decades, which is likely to continue into the future (WUP, 2019). Cities in this region will undergo enormous change in urban infrastructure and population, leading to increases in UHI intensity, with implications for heat stress, public health, and cooling energy consumption (Kumar et al., 2017), particularly under projected climate changes. Various studies have documented the UHI effect in selected cities in Africa (e.g., Dar es Salaam: Gombe et al., 2017; for Tunis: Mhedhbi, 2021; or Nairobi: Matsaba, 2021) but knowledge gaps remain.

Energy issues is an emerging issue in our textual corpus. African continent presently contributes very little to energy consumption. However, energy demand is rising rapidly for this continent due to the fast-rising urbanization. African countries' economic development is also dependent on energy consumption. This is making this continent in a growing reliance on fossil fuels and affordable biomass like fuelwood. For instance, up to 2010, wood fuel accounted for 70% of energy consumption in Sub-Saharan African countries, followed by petroleum, with most industrial activities utilizing some form of wood fuel (Kebede et al., 2010).

Important knowledge gaps on climate change in African cities have been noticed (Vincent and Cundill, 2022), in particular concerning aspects of urban territory as shown on Figure 2. This may be because any urban stakeholders in Africa remain largely unaware of the seriousness of the climatic issue and that the global-level scientific reports and debates are sometimes considered like unintelligible or consider the climate change like psychologically distant (Mhedhbi, 2021). Besides, urban data and supporting information, which should inform urban action, are rarely available (Simon, 2010; Mhedhbi et al., 2019). From the point of view of funding, climate-related research cities have received significantly less funding than food, ecosystems, freshwater and health studies (Overland et al., 2021). Nevertheless, understanding the relationship between climate change risks and urbanization is still an urgent priority (Güneralp et al., 2017; Colenbrander et al., 2019).

4. Network of African cities and climate change issues

4.1. Networking the issues

In order to visualize the way in which the scientific articles address the various issues identified previously and link them in

10 See https://unfccc.int/process-and-meetings/conferences/past-conferences/cancun-climate-change-conference-november-2010/cop-16 (accessed April 25, 2022).

the analyses they propose, a graph is built whose vertices are the eighteen issues or themes (Figure 3). A link of weight w = n is drawn between two vertices if key expressions of each of the corresponding issues appear in the metadata of n articles. A self-loop of weight w = n on a vertex represents the cases where only expressions of the corresponding issue appear in the metadata of n articles. In Figure 3, the size of a vertex is proportional to the sum of the weights of its links. The graph obtained organizes the information contained in the metadata corpus and derives directly from the rule for linking classes of key expressions, these classes designating major issues of urban climate change (see Appendix). Some of the useful-to-know characteristics of the graph-such as the centralities-are estimated with the NetworkX library (Hagberg et al., 2020) and the plotting uses the general-purpose diagramming program yEd (yWorks GmbH, 2020).

"Social stakes" category has the highest degree centrality when taking links' weights into account. Indeed, social stakes form a central issue for all kinds of impacts and risks related to climate change. The literature repeatedly notes that in large African cities this theme is determined by the levels of poverty, inequality, unemployment, access to basic amenities such as drinking water and sanitation (see the link with the "water" issue on Figure 3), food security and by various institutional factors.

The analyzed corpus strongly links the social stakes with human health. Some features of African cities or of their population such as the lowness of income, the lack of accessibility to health systems mainly for poor or socially excluded people, or the limited coverage of sanitation infrastructures, increase the vulnerability of these cities (Costello et al., 2009). These situations in turn exacerbate health inequalities caused by climate change. Health vulnerabilities also reflect gender inequality, with a relative increase in women's infection rates, but also a relative decline in their income (Marphatia and Moussié, 2013).

These deficiencies generate an increasing potential range of people affected by climate hazards. The most affected are those concentrated in slums or informal settlements with low living standards and poor or non-existent basic services. The "urban territory" category is also strongly tied to "social stakes." Currently the climate and rapid formal and irregular urbanization consequences are widely regarded as being the most pressing challenges of African cities. In the studied corpus a link is noticed between the negative effect of urbanization with the social impact of climate change. The study of social vulnerability gives insight into the characteristics of different urban communities, emphasizing the differentiated burdens of climate change impacts.

A few other explicit linkages of themes by the network deserve special attention. The issues network shows an important link between the water and tools categories. This results from the methodological and technical nature of a large number of analyzed articles dedicated to urban waters. This kind of technical bias accounts for the fact that this theme often appears as the only theme of many of these articles[11] (see the high weight of the self-loop in red on Figure 3).

11 The technicality of most scientific approaches to health would explain in the same way the high frequency of the "health" issue as the only theme of articles.

Many papers jointly study heat and thermal comfort in urban areas (one instance of our "urban territory" category). Urbanization results in the artificialisation of surfaces, which has a strong influence on living conditions, particularly in terms of thermal degradation of urban spaces. Accordingly, land-use modifications, urban roughness, and anthropogenic activities in cities modify the local climate, generating an urban microclimate (Oke and Aigbavboa, 2017) contrasting with the climatic conditions of the surrounding areas. These urban heat islands enhance the negative impacts of heat waves in urban areas (Li and Bou-Zeid, 2013).

Climate change has already impacted economic growth, water security and human health in multiple African countries (Diffenbaugh and Burke, 2019). These impacts increase the need for adaptation strategies (an instance of the "adaptation" class) cross multiple sectors and social stakes. Adaptation also directly concerns urban territories, as the articles highlight. For African cities it is sometimes difficult to make adaptation a priority in urban planning, given the multitude of traditional urban challenges being faced by these cities, including massive poverty and high population growth. The consideration of climate adaptation in urban practices is further hampered by the rapid and informal growth of such cities, as well as the lack of climatic expertise within urban planning services. This is primarily due to a notable lack of urban and climatic data in these regions and the inadequacy of the available financial and human resources (Emmanuel, 2005). This makes adaptation to climate change a new challenge for these cities regardless of their location or size.

A theme also plays an important role of intermediary–that is to say, strengthens the links between two other issues or groups of issues which, without it, would be little linked or even separated from each other. The betweenness centrality (see e.g., Freeman, 1977) that is estimated from the previous graph provides this information. According to this criterion, it is the class of "city variables" that plays this role with the most intensity (despite the weakness of their weighted links) followed by the themes of "pollution" and "migration" (then come the "flood" and "coast" issues). City variables are used to link characteristics of the city, territories and related societal and environmental issues. For its part, the notion of pollution is quite polysemic and complex since it can refer to substances spread in an environment, or to the involved processes; it concerns various environments or resources, has a multitude of impacts and represents a risk. Migrations involve actors as well as resources and territories, and governance-related measures (legal frameworks, public policies, programs, etc.). The properties of these three concepts and the fields concerned in their semantic neighborhood probably explain their high betweenness among themes.

4.2. Most noticeable keywords

The previous sub-section and Figure 3 analyzes the graph of issues (classes of keywords) while the occurrences of the most frequently used key expressions or concepts (given by the authors of the articles in the corpus) are analyzed here. Indeed, conceived in our analysis as classes of expressions, the issues presented so far are of particular interest to the political and governance perspective focused on the links between climate change and African cities. The instances of these classes, that is to say the key expressions most used in the articles, directly show the objects and concepts solicited in the scientific analyzes at work in this field and as such, deserve special attention. In Figure 4, the most salient keywords are ranked by decreasing order of their respective number of occurrences.

As mentioned previously, "urb*" being one of the filtering regular expressions used to create the analyzed corpus, it is no surprise that the histogram shows "urbanization" as the most used key word in the analyzed articles (note also that "urban area" is in the sixth rank).

The second most used word, "water," refers in particular to water-related issues that affect all sectors of African cities, such as resource management and policies, the availability of this resource essential for life, the water quality and risks related to infectious diseases and human health (Anthonj, 2021).

The "energy" key word refers to the issues of energy transition and the necessary diversification of energy sources to satisfy the growing needs of African cities. Indeed, the challenge for African cities is to adopt a low-carbon development and increase energy access for poor citizens (Ambole et al., 2021).

Several of the analyzed key expressions or key words such as "vulnerability" "resilience," "poor," "income" and "migration" refer directly to social vulnerability and resilience issues. This priority given to social aspects in the analyzed articles shows the predominance of economic and social problems in African cities. Among these obstacles to sustainable development and consequently to adaptation to climate change, low incomes, unemployment, informal urbanization, limited resources, must be mentioned. Such factors exacerbate the social and urban vulnerability of these cities and reduce their adaptive capacity to climate related-risks (Leal Filho et al., 2018).

The 1991–2020[12] time series of the occurrences of some central terms are shown in Figure 5. The trend of strong growth in wholesale occurrences from 2010 follows the temporal pattern generally observed with the number of publications concerning numerous research topics. However, these evolutions turn out to be different when we look at particular notions. Thus, on the scale of the African continent, because it is both a vital resource that cannot be substituted, the environment of other resources and a source of energy and risks (floods, droughts), water clearly has the highest growth rate of use in research. With a rapidly growing demand, energy tends to become another major challenge for the development of large cities in Africa in a context of still strong dependence on fossil fuels and of opportunities offered by a transition to a higher share of renewable energies (C40 Cities and Sustainable Energy Africa, 2020). In connection with the urban impacts of climate change, the risks are also increasingly highlighted (the term "flood" presenting a similar progression). The term 'food' in Figure 5 presents the same temporal pattern as "agriculture" (one of the most frequent words in Figure 4), i.e., a decrease in frequency relative to the other major themes.

Do these empirical observations make it possible to predict the relative importance given to the various challenges of the development of African cities in relation to climate change? Caution is in order. The "COVID-19 years," as well as the recurrent emergence of epidemics coming from the continent or imported from other regions, could reinforce the growing importance of health-related themes which themselves depend in part on the evolution of the climate (Romanello et al., 2021), and more particularly of the urban climate. The increase in the frequency and intensity of the direct impacts of climate change toward pessimistic scenarios could give more importance to research devoted to the prevention and management of risks. Finally, with the war in Ukraine, the recent difficulties in supplying several African countries with cereals are likely to update the theme of food and nutrition in urban areas.

Other documents and information must be collected to refine these analyses at the local level and highlight the specificities of each city and their own social, political and climatic environment, as well as vulnerability and adaptive capacity status (Leal Filho et al., 2018). But certainly the issues relating to water and energy resources are shared by many of these large African cities.

4.3. Climate services in African cities

Do or could dedicated services take over these problems in order to deal with them in a coherent and integrated way over the long term? A Global Framework for Climate Services[13] (GFCS) was established by the World Climate Conference in 2009. In 2016, the World Meteorological Organization published a report titled "Climate Services for Supporting Climate Change Adaptation"[14] defending the importance of the integration of climate change adaptation initiatives into new and existing policies, programs and activities, in particular in development planning processes and strategies, within all relevant sectors and at different levels.

A subset of articles mentioning the "climate services" is drawn from the previous 1,101 articles. In order to map the concepts and notions related to these services in the scientific literature, a graph is established as follows. Each key expression of these articles is represented as a vertex in Figure 6. A link of weight $w = 1$ is created with the "climate services" vertex each time the metadata of an article mention the expression (weight unit per article). Thirty-six key expressions are thus linked to "climate services," "decision-making" presenting the most frequent link ($w = 6$) followed by "adaptation planning," "stakeholders" and "Landsat" ($w = 3$ for each of these vertices).

This network of expressions fairly faithfully reflects the list of the most used expressions in the corpus of the 1,101 initial articles (cf. Figure 4), but through the lens of "climate services": presence of adaptation, resilience or terms related to resources and their use (water, land use, energy, agriculture), urban territorial organization, or some major social issues (including health through malaria, gender, urban poverty). Basically, the GFCS aims to help decision makers to better manage the risks related to climate change. For this purpose, climate services built a connection between scientists, who

12 The year 2021 not being complete on the WoS database during the analysis, it is not included in the time series.

13 See https://gfcs.wmo.int/ (accessed April 4, 2022).

14 See https://gfcs.wmo.int/ClimateChangeAdaptation (accessed April 4, 2022).

are usually providers of these services, and a range of stakeholders (McNie, 2012). This accounts for the repeated connection shown in the network between climate service and decision making, and with stakeholders. It is also remarkable that various lexical forms related to adaptation to climate change, and, more marginally to resilience, appear repeatedly in the semantic environment of climate services. This observation is all the more striking since "mitigation" does not appear in this corpus centered on African cities.

Climate services contribute directly to the eleventh ("sustainable cities and communities") and thirteenth ("climate action") Sustainable Development Goals through the collection of climate data, the generation and provision of information and the development of products to improve the understanding of regional to local climate change and its impacts on natural and human systems. However, most often African cities lack data necessary to climate studies. Even when such data exist, they are scattered among different administrations and difficult to access (Mhedhbi, 2021). In such contexts, satellite remote sensing provides a mass of raw information useful for climate urban studies. In particular Landsat data[15] are widely used due to the depth of the time series, the ease of access to the data, and the availability of processing tools. Aiming to describe the neighborhoods of the city using remote sensing methodology, the Local Climate Zones (Stewart and Oke, 2012) also appears in the semantic field of the climate services.

5. Discussion and conclusion

The analysis of a corpus of metadata from more than a thousand articles extracted from the Web of Science database gives a fairly precise picture of the work published from 1991 to 2020 on the theme of climate change in African cities. Text mining of the corpus shows that while cities of the Northern, Western coastal, Eastern and Southern African sub-regions are the subject of research, cities with more than 100,000 inhabitants in the central Sahel strip and a north-south corridor (extending from Libya to Namibia through Chad) are omitted. Too numerous and intertwined, the explanatory factors of this distribution remain beyond the scope of the analysis of such corpus but are probably linked to one form or another of attractiveness (existence of renowned local universities, availability of funding, historical links between countries, linguistic affinities, etc.) of the host countries favorable to scientific collaboration, particularly international. Thus, the analysis of affiliations shows that authors from 41, 33, and 29 countries participated in the studies of the cities of South Africa, Egypt and Nigeria, respectively, host countries bringing the highest number of publications.

The semantic fields that are grouped under the labels "water," "health," "governance" and "urban territory," respectively, are almost systematically attached to "social stakes,"[16] the most central semantic field of all of this research bulk. The areas concerning the "tools" used in research, "risks and hazards," and everything related to "heat" or "floods," also trace a network of secondary interdependencies whose importance is modulated by the socio-economic context and environment specific to each city.

By reducing the semantic granularity, moving from issues (classes of concepts) to elementary concepts or objects, we observe that if the impacts of climate change are different from one country to another, water, energy and health stand out strongly at the scale of the African continent (and probably beyond). When the interest focuses on a given city, more information should be collected to fully understand the local socio-political specificities of the context and consider urban governance, territorial vulnerability, socio-spatial inequalities and local communities for action (United Nations Climate Change Secretariat, 2018). The corpus should be completed with documents produced by national actors such as sectoral adaptation strategies or planning and urban development documents.

The ubiquity of social issues testifies to the significant socio-economic vulnerability of urban populations and the current limits of the adaptive capacity of African cities. Better management of water resources and water risks, the gradual transition to a greater share of renewable energy resources, a broader approach to public health, are addressed by a rapidly growing number of studies. These are opportunities for sustainable development for the benefit of the populations concerned. However, other problems are likely to emerge and thwart the efforts made, in particular the intensification of health risks specifically linked to climate change, or the risk of food supply shortage and nutrition of the most vulnerable populations.

Faced with the intricacy of issues related to urban climate change, climate services as currently designed reflect more of an institutional project than the deployment of skills, tools and solutions to respond in a concrete way to the needs already identified and scientifically assessed. Climate services could actively participate in the socio-ecological transition and adaptation to climate change in African cities, in particular by including socio-ecological dimensions as well as governance and urban planning as key components within the scope of their expertise. They could thus be called upon to become an instrument allowing the local specificities of the territory to be taken into account, thus basing the decision-making processes on broader, reliable and relevant information.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: Publicly available datasets were analyzed in this study. The data include the abstracts of articles available on Web of Science (https://www.webofscience.com/wos/woscc/basic-search).

Author contributions

PM and ZM initially conceived the study, but the research was designed jointly by all authors. MG created and organized the database. Methodology and computer codes were designed

15 See https://landsat.gsfc.nasa.gov/ (accessed 25th April, 2022).

16 This domain brings together expressions implying, among other things, behavior, exclusion, gender, household, housing, income, inequality, justice, labor, lifestyle, population, poverty, settlement, tourism, transport; see also Appendix.

and developed by PM. ZM and PM wrote the first draft of the manuscript and data analysis and visualization was predominantly carried out. All authors worked on the taxonomy of the corpus, contributed to manuscript revision, read, and approved the submitted version.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

Appendix: overview of taxonomy structure

The taxonomy used in this study forms a partition of a set of key expressions. A label representing an issue is assigned to each part (subset). 1,101 articles metadata of the WoS extraction mention a country or city in Africa with more than 100,000 inhabitants. These articles offer 1,829 distinct and relevant keywords (overly generic expressions being discarded) that we distribute in 18 classes that constitute the taxonomy. The choice of classes as well as their labels emerged by discussing the distribution of each of the key expressions, forming classes of relatively similar sizes. The classes are presented below with: their rank in descending order of the number of elements; the number of expressions in the class; a brief description of the content followed by three examples of class expressions (in square brackets).

1. Tools 338: this class includes expressions related to modeling, indicators, observation and data production systems [ex.: "earth observation;" "multi-index dataset;" "simulation methods"].
2. Health 192: a large range of health-related expressions, including some climate change related diseases, pathogens and vectors [ex.: "disease burden;" "health services;" "urban malaria"].
3. Water 184: water resources and bodies, access to, treatment and management of these resources at different scales (from basin-wide to the tap) [ex.: "desalination;" "right to water;" "urban water system"].
4. Social Stakes 177: ways in which the diversity of social and societal issues are expressed in this corpus [ex.: "green jobs;" "livelihood diversification;" "poverty"].
5. Governance 159: identifies the institutions, frameworks for action, capacities and programs dedicated or linked to combat climate change [ex.: "civil society;" "climate financing;" "governance and public policy"].
6. Mitigation 111: expressions mainly referring to sources of GHGs and technical devices aimed at reducing their emission or the greenhouse effect [ex.: "carbon emission;" "green technologies;" "renewable energy sources"].
7. Agriculture and Food 90: urban and peri-urban agriculture, food production and supply in cities in relation to climate change [ex.: "agricultural practices;" "suburban agriculture;" "urban food security"].
8. Heat 87: expressions referring to the thermal effects (hot or cool) of the cities, streets and dwellings [ex.: "anthropogenic heat flux;" "cool roofs;" "urban heat island"].
9. Energy 74: energy sources, management and services in the context of climate change [ex.: "biomass fuel;" "renewable energy;" "urban energy use"].
10. Urban Territory 72: the city as a physical, social and policy territory [ex.: "informal urbanization;" "territorial planning;" "urban growth"].
11. Risks and Hazards 62: hazards, risks and related prevention tools and policies [ex.: "climate change risks;" "disaster vulnerability;" "threat perception"].
12. Adaptation 56: brings together expressions related to all the devices (technical, social) or possible behaviors relating to adaptation to climate change and resilience [ex.: "adaptation strategies;" "community-based adaptation;" "resilient cities"].
13. Flood 45: effects, prevention and fight against the various types of floods and the risks specific to them [ex.: "extreme rainfall;" "flood management;" "urban flood risk"].
14. Pollution 45: various kinds of pollutions and pollution sources [ex.: "air quality;" "groundwater pollution;" "waste disposal"].
15. City Variables 40: variables used to represent physical or morphological features of cities [ex.: "albedo;" "city design;" "urban canyon"].
16. Land 40: land, land use, land cover and changes [ex.: "land reform;" "land-use planning;" "urban landscape pattern"].
17. Coast 30: processes specifically affecting coastal cities or their resources [ex.: "beach tourism;" "coastal cities;" "sea level rise"].
18. Migration 27: some lexical entry to the issue of climate change related migration and city development [ex.: "environmental migration;" "refugees;" "rural-urban migration"].