Scientific African 10 (2020) e00553

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

An East African perspective of the Anthropocene

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ARTICLE INFO

Article history:
Received 5 June 2020
Revised 5 September 2020
Accepted 10 September 2020

Keywords:
East Africa Anthropocene
Holocene
People, climate and environment
Natural and human impacts
Ecological changes

ABSTRACT

The advent of anthropogenic global warming and widespread modification of the climate, landscape and environment has brought humans to the fore as a formidable force of nature. The terrestrial and aquatic environment of the East African region is sensitive to a variety of global, regional and local stresses. The geological materials along East Africa coasts, lakes and peats are excellent archives of environmental and climatic changes. The study of their sedimentary records has contributed to our understanding of global environmental and ecosystem changes induced by anthropogenic activities associated with the "Anthropocene", the proposed new geological epoch in Earth history. Humans have occupied East Africa for thousands of years, but until about 300 years ago, their impact on the environment was localized and transitory. The impacts intensified during the 19th century due to rapid population growth and extension and intensification of agriculture that was largely driven by colonists; during this period, the overprinting of natural environmental changes by humans is clear, marked by significant changes in sedimentation, sediment properties, and lake water quality as a consequence of land and water degradation and overexploitation of terrestrial and aquatic ecosystem goods and services. Related impacts include changes in terrestrial and aquatic ecosystems and associated biodiversity losses. There have been temporal and spatial lags in the changes, depending on locality, but there is a widespread convergence of these effects from the mid-1900s, support the Anthropocene Working Group's proposed date of 1950 as the start of the Anthropocene.

Introduction

The expansion of humans has impacted on the Earth and its resources. The recognition that humans were becoming a formidable geological agent was recognized early by very few scientists who published books on humans as agents of landscape alteration in 1865 (George Perkins Marsh) and 1922 (Robert Lionel Sherlock) [22]. During the past three centuries the human population increased tenfold to (currently) 7.6 billion, accompanied by a growth in cattle population to 1400 million [42,54,136], while about 30–50% of the land surface has been transformed by human action [46,153]. As a result, the imprint of humans on the globe has now become so large that it rivals some of nature's forces on its impact on Earth System functions [129]. For example, the development of diverse products such as antibiotics and pesticides [53,112], as well

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https://doi.org/10.1016/j.sciaf.2020.e00553

as nitrogen and phosphate cycle alteration due to the development of synthetic ammonia and phosphate fertilizer, carbon increase in the atmosphere increasing global temperatures, and depletion of the ozone layer due to increase in human-made chlorofluorocarbons in the atmosphere [21,23] can alter evolutionary outcomes through loss of species and species diversity by extirpation.

Scholars agree that drastic changes have occurred since the 1800s [128] and there is ongoing debate on whether to introduce a new geological epoch, the "Anthropocene", due to the global impact of humans on the environment [29]. This has gained wide recognition: some authors have argued against it [52], and others for it, and various dates have been proposed for its beginning, e.g. 1610, 1800, 1950 or 1964 [10,29,30,81,155]. The year 1610 is linked to the Orbis spike, which is marked by transoceanic movement of species to the New World and a brief dip in CO_2 levels attributed to abandonment of native farms across the Americas following the deaths of millions of indigenous people in the aftermath of European colonization [81]. 1800 marks the beginning of the Industrial Revolution where accelerated fossil fuel use and rapid societal changes accompanied by introduction of significant amounts of CO_2 in the atmosphere led to progressive warming of the Earth [29,155]. From the 1950s onwards is the "Great Acceleration" in the Earth System indicators (specified in [130]), while 1964 is the peak of the atomic 'bomb spike' [81], relating to the onset of global fallout of artificial radionuclides due to atmospheric detonations of nuclear devices [40,58,154,162]. The Anthropocene Working Group [10] proposed the mid-20th century as the beginning of the Anthropocene, laying out a host of supporting phenomena such as significant increase in erosion and sediment transport related to urbanization and agriculture, human perturbations of biogeochemical cycles and their consequences, global warming, and rapid biospheric changes due to human activities, amongst others.

Most of the studies carried out provide a review of impacts and activities in the Northern Hemisphere, and while the ice cores from the polar regions provide pictures of global environmental changes mediated through the atmosphere, there are no systematic reviews of evidences of Anthropocene markers in Africa. East Africa, which is regarded as the cradle of humankind has a long history of human occupation, is also an important place to study the extensive changes caused by accelerated human activities. As humans proceed into the 21st century, we explore the changes that have occurred in an attempt to clearly identify the beginning of the Anthropocene in East Africa.

The climate and environmental context: early Holocene to present

East Africa's terrain is characterized by highly variable topography, ranging from highly mountainous areas to extensive plains, changing within short distances, and resulting in marked climatic and ecological zones [94]. This is a result of ongoing tectonic and surface processes initiated around 40 Ma, associated with the development of the East African Rift System [138,159]. East Africa has numerous lakes, varying in size from a few hundreds of square meters to several thousands of km^2 (Lake Victoria, 69,000 km^2) and from shallow to deep (Lake Tanganyika, 1470 m) with varying physicochemical characteristics ranging from fresh to saline [7,32,36,124,125,163]. Many of these lacustrine systems, along with peat deposits, contain excellent archives for understanding climatic and environmental changes over the years [48,66,89,100,107,147,161]. Some of the East African lakes are known as amplifier lakes because they respond dramatically to even small climatic changes [107,133,134,141].

Environmental reconstructions of East Africa's past have shown changes from arid to humid conditions, and vice-versa, of various magnitude and scale throughout the Quaternary Period [64,73,108,137], and natural earth-extrinsic and intrinsic processes were the main agents driving the changes. The early to mid-Holocene in East Africa was generally humid, and the late Holocene was drier [50,67,93,134]. Multi-decadal and centennial-scale wet episodes and droughts accompanied with changes in vegetation composition and fire incidences are superimposed on the Late Holocene drying trend, particularly after 2000 yr BP [11,19,35,74,77,79,118,119,126,127,149]. More recently, over the last 150 years, the rate of climate and environmental change has been more rapid than before, and this accelerated change is linked to human activities [44,71,72,132]. The sevenfold increase in the population of Eastern Africa, from 66 million in 1950 to about 435 million today [143]; partly accounts for the extensive and intensive impact of human activities on the environment in recent decades. Prolonged droughts have had devastating effects and are linked to migrations and environmental degradation including loss of biodiversity [13,27,45].

Humans in East Africa: from the early Holocene to present

The peopling of East Africa

The present population distribution of East Africa by race, ethnicity and culture is a result of large population movements, influenced in part by climate, wars and diseases over the past 2000 years [62], or even as far back as 5600 years ago [14,37,82,140] when the climate transitioned from a more humid to a drier phase [104]. At this time, there was a notable expansion of pastoral communities and the introduction of domesticated livestock [85]. Prior to this, little information exists on the impact of humans on the environment due to the low population [5]. However, globally, such impacts are noted to have been largely localized and transitory, not exceeding the natural variability of the environment [128] though there are examples of alteration of spatially restricted land areas in the east Africa region due to permanent settlement and agriculture, e.g. in the Pare mountains since the 7th century AD [60]. More generally, over longer geological timescales it is recognized that high levels of environmental variability enabled hominids to occupy different ecological niches [15]. Over

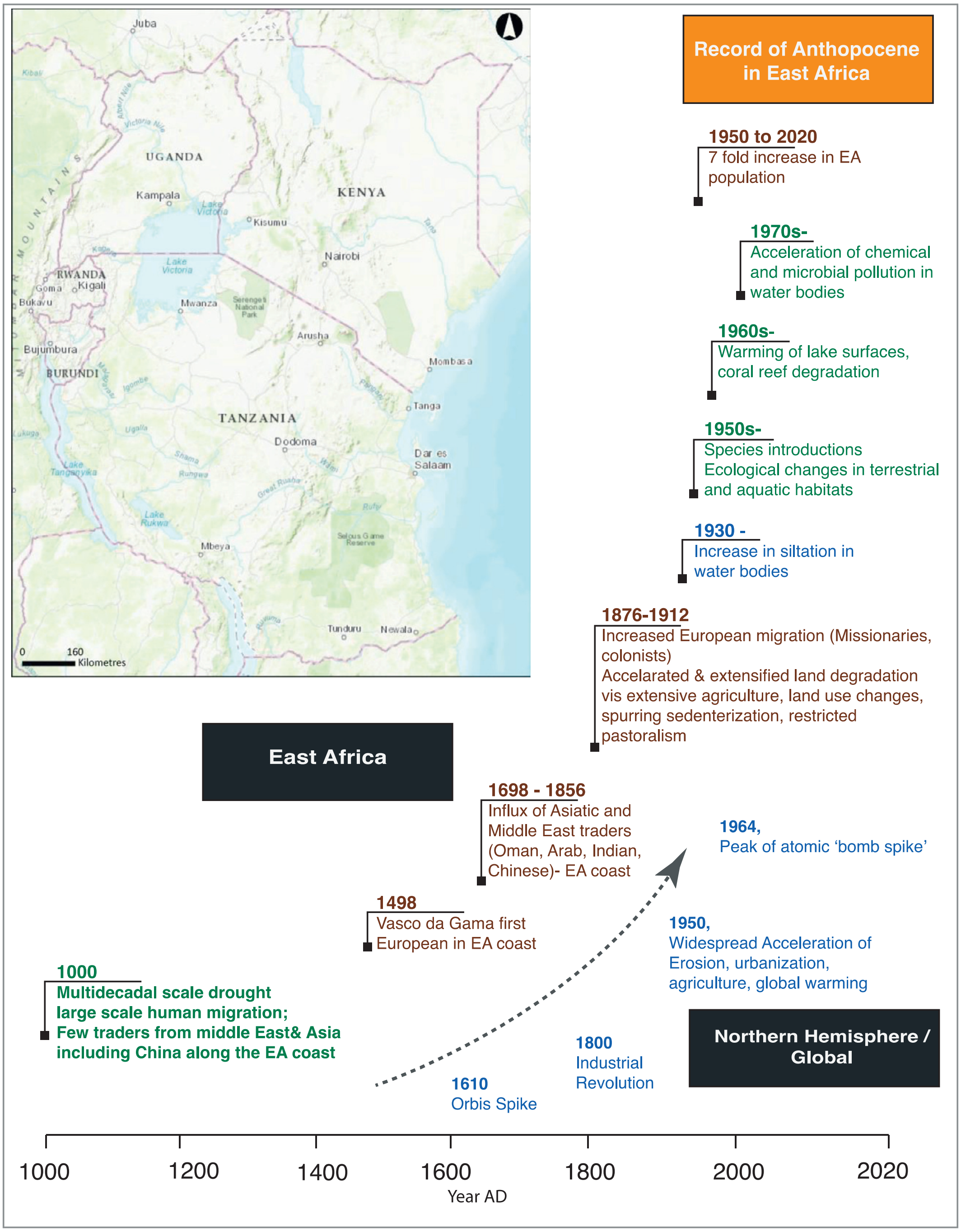

Fig. 1. Schematic chronology of significant regional and global anthropogenic and environmental events and their impacts in East Africa from 1000 AD to present. Data for the GIS map of East Africa was compiled from the following sources: ESRI, HERE, GARMIN Intermap, Increment P Corp., GEBCO, USGS, FAO, NPS NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (HongKong), © OpenStreetMap contributors, and the GIS community.

the past one thousand years, large-scale human migrations in the region have been coincident with prolonged droughts [149], similar to findings in the Sahara [75] (Fig. 1).

Three main groups currently occupy the area, the Bantu (majority), Nilotic and Cushitic groups. The Nilotic communities migrated southwards along the Nile through Sudan within the past 3000 years [39]. The Bantu started migrating south-eastwards into East Africa from the Congo Forest-Cameroonian hills about 1000 years ago, and reached southern Africa in the late 16th Century [33,43,95]. As they moved they introduced cultivation agriculture and new tools. Historians are divided on the cause of their migration; reasons that have been proposed include conflicts, search for food and resources for their

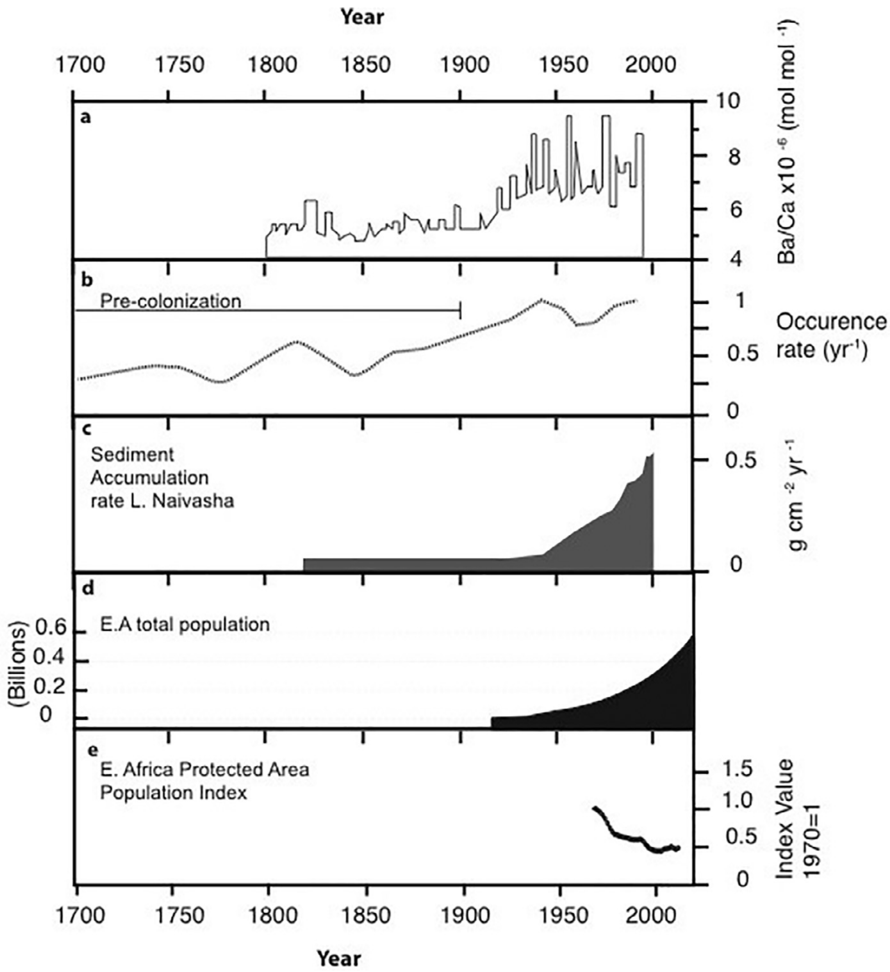

Fig. 2. (a) Ba/Ca profiles exhibit a distinct long-term pattern of sediment flux into Malindi reef (from [44]) (b) Occurrence rate of extreme sediment flux events to Malindi from [44]), (c) Sediment accumulation rate in Lake Naivasha [132], (d) Changes in population of East Africa, since 1920 [6,142,143] (e) Population index of megafauna in protected areas in East Africa (from Craigie et al. [168]).

tribes and animals, diseases and overpopulation in their native land [37]. Early accounts of interaction with non-Africans are first documented along the East African coast around the first millennium BCE [165]. Later, it has been documented that the region was frequently visited by Arabs from about 700 AD for trade in tortoise shell, rhinoceros horn, ivory and coconut oil [86], then the Portuguese in Mombasa (1498–1698), and the Omani, Arabs, Indian and Chinese (1698–1856), mainly for trade in spices and slaves [12,59,114]. European migration into East Africa is linked to the arrival of missionaries and colonists between 1876 and 1912. Over the past century, the population of East Africa has grown from 6–12 million in the 1920s [6,142] (Fig. 2d) to 173 million in 2017 [143]; some impacts of the growth include urban sprawl and loss of forests [166].

Expansion of Agriculture

Agricultural practice in East Africa is linked with the Bantu migrating and settling there, having invented iron tools. Early human impact on the environment linked to intensive agriculture includes records of irrigation in Engaruka, Tanzania around 1300 CE [38,76,135]. Analysis of many sediment core and archaeological records from across East Africa show that during the past millennium, there were palaeoenvironmental changes in some areas that could be attributed to human rather than natural causes. These changes were associated with crop agriculture, livestock husbandry, pastoralism, or a combination of these among other activities such as iron working, depending on the region (e.g. [16,80,85]). Presently, agricultural production relies heavily on chemical fertilizers and agrochemicals which have detrimental effects on ecosystems. Intensive commercial farming has altered species assemblages, reduced plant biodiversity and some native shrubs that had medicinal benefits have disappeared in some areas [84]. For example, studies by Pomeroy et al. [113] and Maitima [83], have also shown that in Uganda and Kenya the number of bird species is much lower in plantations of tea, sugarcane and cotton than in mixed farming systems. Increased erosion rates from the early 1900s, in part related to agricultural expansion, have been observed in various parts of East Africa [44,68,139] (Fig. 1).

Impacts on land

The rugged topography of East Africa, together with its rock, soil and vegetation characteristics, predisposes certain regions to high erosion rates during land conversion. Lake and peat records from the East African region clearly document the impacts of human activities on land. Human-related enhanced erosion from the central Kenya highlands is documented from 1900 AD, based on Ba/Ca records from *Porites* corals off the Indian Ocean coast of Kenya. Near-surface sediments in a paleoecological record from Lake Solai, Kenya, indicate increasing anthropogenic impact through pastoralism [55]. From 1950 onwards, a sediment core record from Lake Naivasha reflects overprinting of the previously natural climate variation by the effects of increasingly intensive commercial farming of coffee, tea, flowers, and other horticultural crops within Lake Naivasha catchment [132]. Within the central Kenya rift, reduction of the extent of Loboi wetland by about 60% since 1969 has been attributed to anthropogenic impacts from land-use change [8] (Fig. 2a–c). Lake Massoko, Tanzania, shows clear impact from human activities (agriculture, forest clearing, road construction) from 1940 [49].

The acquisition of colonies by Europeans, driven by the need for food and raw materials, increased resource exploitation of the land. Furthermore, colonialization in East Africa precipitated sedentarisation of many communities, and reduction of range for pastoralist groups such as the Maasai and Samburu. This, in a way, led to land use extensification, intensification and changes in the traditional land management; for example, many of the highlands areas that were used as dry-season pasturing ground by pastoralists were sealed off by the colonial governments thus confining too many animals in delicate wooded grasslands [111], enhancing land degradation. Denudation rates within the region differ depending on the land use, and estimates are between 0.13 mm/yr and 0.08 mm/yr [1]. The high erosion rates in the region, driven by cropland expansion and high livestock densities, also reduce productivity [34,55,71,78], and are exacerbated by the high erosivity of rainfall [17].

Impacts on water

High erosion rates on land increase sedimentation, siltation and eutrophication in water bodies, and enhances flooding [44,71,72,106,132]. In the African Great Lakes, sediment influx rates began to rapidly increase from about 1970, and modified some of the littoral environments to such an extent that habitat changes have been observed [106,144]. Increased turbidity in water bodies is visible from satellite images from as early as the late 1970s in places such as the Nyanza Gulf of Lake Victoria [157], Lake Turkana [57], the Sabaki and Tana rivers which drain into the Indian Ocean [18], and the Rufiji River [87]. Some reservoirs/dams are operating at below capacity in power production due to high silt levels, such as Sondu Miriu, Turkwel dam and Masinga dam in Kenya. Chemical and microbiological pollutants from land and water-based activities are increasing threats to all the large and many of the small lakes since 1960 [144]. Moreover, the growth of cities and informal settlements in East Africa can be correlated with increase in eutrophication of fresh inland surface waters [96]. At present, less than 30% of the total sewage produced is treated in sewage treatment plants, while the remainder is disposed of via on-site sanitation systems, which eventually infiltrate into surface and ground water reservoirs.

Natural and human impacts on terrestrial and aquatic ecosystems

Floristic transformations

Numerous palynological studies have been undertaken in the East Africa region to reconstruct the Holocene vegetation history (summarized in [85,104,105]). They broadly indicate that there was a transition at about 5500 cal. yr BP from wet to dry forest in the highlands, and expansion of savanna woodlands and grasslands in the lowlands, marking the onset of variable but drier conditions than the early Holocene, which persisted until present. As described earlier, the multi-decadal to centennial-scale variability in climate, with centennial-scale vegetation responses (e.g. [28]), was sometimes asynchronous or out of phase between the western and eastern parts of East Africa [117,120]. Early but localized and transitory human impacts on vegetation are inferred from around 2600 cal yr BP (e.g. [31,150,151]), though it is recognized that sometimes it is not possible to distinguish between a climatic or anthropogenic signal in the palaeoenvironmental record [85,91]. In addition to climate, and despite the nucleated and permanent human settlements that developed during the past 1000 years [91], humans appear to have started to significantly shape the environment from 300 yr BP, and with highly intensified impact from the start of the colonial period about 150 years ago [85]. A third of the tropical African flora is potentially threatened with extinction [131]. Since 1900 East African forests have experienced the highest deforestation in the continent estimated at 93% [2]. Additionally, about 164 invasive alien species in 110 genera and 47 families have been introduced in the region and some of the species have the greatest impacts in terms of transforming natural ecosystems [167].

Megafaunal declines

Large mammal extinctions in continental Africa during the late Pleistocene or Holocene primarily affected grazers or species that prefer grasslands [41]. The extinctions are associated with changes in the availability, productivity, or structure of grassland habitats, suggesting that environmental changes played a decisive role in the losses though there is no strong evidence for or against the possible role of humans with respect to the extinctions [41,63]. However, in the recent past, megafaunal declines have intensified; Craigie et al. [168] estimate an up to 59% decline between 1970 and 2005 (Fig. 2e). Large mammals are lost as cultivation expands, but bird species, small mammals and plants may increase where land is under moderate use [84]. Bush meat and timber harvesting, and ecosystem modification by changed land uses is threatening terrestrial species [90]. Poaching, targeting mainly rhinos and elephants, intensified during the 20th century; black rhino populations declined by more than twenty-fold until the mid-1990s, when intensive protection led to a population recovery to just over 5000 individuals by 2014 [92]. The poaching effect was exacerbated by expansion of livestock and human habitats, with estimates of decline in wildlife of between 72–88% from 1977 to 2016 [101,102]. In addition to rhinos and elephants, the animals that are threatened include warthog, lesser kudu, Thomson's gazelle, eland, oryx, topi, hartebeest, impala, grevy's zebra and waterbuck in Kenya's rangelands [65,102]. A succinct discussion on the ecological function of Africa's megafauna and the interplay between them, climate and humans is provided by Hoag and Svenning [63].

Aquatic transformations

In western Uganda, a large influx of catchment sediments attributed to climate and human impacts and with impact on freshwater aquatic ecosystems is observed in two crater lakes from AD 1800 [91]. Changes to the benthic species composition of Lake Tanganyika due to increased sediment influx are related to watershed deforestation since 1880, and in Lake Malawi starting between 1930 based on increased accumulation rates of retene [25] and 1940 [110]. Since the beginning of the 20th Century, the African Great Lakes have lost at least 500 cichlid fish species due to introduction of carnivorous species by the colonial powers, increase in siltation in the rivers, and lakes, and over-harvesting [103]. The introduction of exotic fish species in Lake Victoria in the 1950s and ecological changes in the lake [56] threaten or have led to the extinction of more than 200 species of haplochromine cichlids in Lake Victoria [88,158]. Species introductions leading to changes in fish communities, and habitat changes due to sedimentation, particularly in the littoral zone where lake biodiversity is concentrated, has affected food webs and reduced species diversity [4,69,97,98,144,156].

Global warming has raised the surface temperatures of the African Great Lakes, particularly since 1960, with impacts on lake productivity [20,61,109,121,123,146]. Chemical and microbiological pollution are adversely impacting the aquatic ecosystems. Phytoplankton production in Lake Victoria increased from the 1930s onwards, in parallel with human–population growth and agricultural activity in the Lake Victoria catchment [148], and in recent decades increased frequency of algal blooms and related fish kills, reflect the ongoing deterioration of aquatic water quality [99]. Nutrient inputs from land-derived sediments and the atmosphere due to widespread biomass burning in the region exacerbates eutrophication of the African Great Lakes [3,24]. In the coastal Indian Ocean, north of Malindi town, increased sediments and nutrient influx into the ocean has spurred coral-reef degradation [44,145]. Aquatic system transformations are being accelerated by recent and on-going construction of large, multipurpose dams across many of the major rivers in the region, including, for example, the Gibe Dam series on River Omo that is hydrologically coupled to the expansive Lake Turkana in northwestern Kenya. These large and many other smaller dams also create new aquatic ecosystems at the expense of the terrestrial ecosystems.

Discussion

As reflected in this review, numerous researchers indicate that, over geological timescales, there has been a harmonic cadence between hominids and the environment, with the latter dictating the actions of the former in terms of which areas they occupy, the duration of occupation, and migration, among others. In recent centuries, however, this relationship has, in some aspects, been flipped over by modern humans through the advent of the industrial revolution and rapid large-scale globalization and their consequences such as global warming and modification of the climate and related systems, and extensive transformation of the landscape and socio-ecological systems. The changes mentioned in this paper have influenced the communities in eastern Africa in various ways that have been complexly overprinted by rapid population increase, differentiated economic growth rates in locally disparate areas in part related to geographical setting (humid to arid) and vulnerability to climate extremes (droughts and floods), and policies that have favored flow of financial resources to agriculturally potential areas over those that are not, among others. Land degradation, which has in some areas been attributed to unsustainable agricultural practices [122,139], is linked to poverty [70] because it erodes the natural resource-base that supports the livelihoods of the majority of the region's inhabitants. Several studies referenced above also show that anthropogenic pollution and siltation have led to aquatic ecosystem changes which have had adverse impacts on aquatic resource-based livelihoods.

The International Commission on Stratigraphy is mandated to "promote international agreement on principles of stratigraphic classification and to develop an internationally acceptable stratigraphic terminology and rules of stratigraphic procedure-all in the interest of improved accuracy and precision in international communication, coordination, and understanding" (https://stratigraphy.org/guide/intr). Stratotypes are geological units that serve as reference standards for either a stratigraphic unit or boundary. Of particular interest in our discussion is the Boundary-Stratotype "the specified sequence of strata that contains the specific point that defines a boundary between two stratigraphic units" (https://stratigraphy.org/guide/intr). The present debate, elaborated upon in the introduction of this review, is to define the proposed Anthropocene with reference to an accepted stratigraphic boundary that may serve as a global marker. The debate which ensued with respect to the position, status, and representative time interval of the 'Quaternary' and the 'Pleistocene' [51] is not unlike the present one concerning the Anthropocene, but it has its own peculiarities. For example, the present geological timescale and its sub-divisions have been delineated from the beneficial aspect of being able to "hindcast", looking into the geological record of the past to determine globally significant and characteristically differentiated events and periods. Ruddiman [116] notes that the existing formal chronostratigraphic rules do not recognize, *a priori*, these early occurring changes. Today, we are literally standing on the surface that we wish to define, and this is a departure from the norm. Several viewpoints have been proposed and critically analyzed (e.g. [26,47,152]) and here we highlight just a few from the very rich debate that has been ongoing over the past two decades.

When Crutzen and Stoermer [30] proposed the Anthropocene with a start date in the latter half of the 18th century to recognize "the central role of mankind in geology and ecology", they also recognized that the start date was somewhat arbitrary and that others may want to include the entire Holocene. Indeed, Ruddiman [115] proposed a date of 8000 yr BP based on changes in atmospheric CO_2 and CH_4 that could be attributed to forest clearance and later agriculture from 5000 yr BP in Eurasia. Zalasiewicz et al. [164] were of the view that the Anthropocene can be considered as a formal epoch since a global stratigraphic signature, quite distinct from that of the Holocene, has been etched into the earth since the start of the Industrial Revolution. Autin and Holbrook [9], however, state that the identification of a basal boundary is premature since Anthropocene strata are not yet fully developed and note that "a stratotype that records a continuous, preferably marine, sedimentation record and separates the Anthropocene from underlying units needs to be identified and correlated into the global time stratigraphy". There are, however, some examples of such potential stratotypes; Wolfe et al. [160] examined stable nitrogen isotopes in organic matter from remote arctic and alpine lake sediments and noted that they reflect anthropogenic influences on the global nitrogen cycle from 1850, which accelerated from 1950 onwards. Further, the wider scientific community, beyond geologists, and the public have adopted a broader definition of the Anthropocene. They consider it as incorporating awareness of the role of humans in environmental change and its social and cultural [9,63] contexts, as well as the legacies of colonialism, imperialism and capitalism [63]. In our view, therefore, this debate can potentially be resolved by expanding the markers currently used to define new boundary layers to include non-geological materials that have potential to be retained in the geological record and that are globally distributed, such as the extensive concrete and hewn stone rubble from cities and towns on land, and artificial, stable compounds that are deposited in marine and lacustrine sediments and in terrestrial soils. Hence, we support the view by Howard [169] to define new ansthrostratigraphic (ASU) and technostratigraphic (TSU) units to take into account artificially altered or manufactured objects. Looking back to today from a standpoint several thousands and millions of years in the future, these will be distinct and globally mappable stratigraphic units in the geological record.

Conclusions

The significant landscape and environmental changes that have taken place in the East African region have not been homogeneous nor temporally coincident; rather, they have been spread out over a 100-year period (1880-present) but with intensification noted in the mid-1900s, thus supporting the AWG (2019) proposed date of 1950 for the start of the Anthropocene. The most significant are increase in land degradation, deforestation, siltation of water bodies and extinction/disappearance of key terrestrial and aquatic species these are mostly linked to agricultural land expansion and extensive land degradation, over-exploitation of natural resources, and increase in human and livestock populations. The environmental changes during the Anthropocene seen here are not as pronounced as those witnessed in the Northern Hemisphere; however, the trends identified of extinction of species, poaching and environmental degradation need to be curtailed.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to thank the reviewers who have helped improve this manuscript. Specific appreciation to T.C. Johnson and C. Waters for reviewing the initial drafts.

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