5-10-2019

A 23 Kyrs Record Of Environmental Change From Cherangani Hills, Kenya

Vicky Cheruiyot

A 23 KYRS RECORD OF ENVIRONMENTAL CHANGE FROM CHERANGANI HILLS, KENYA

by

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Under supervision of Lawrence Kiage, PhD.

ABSTRACT

The sensitivity of East Africa's environment to anthropogenic and natural climatic changes is poorly understood. Therefore, there is need to incorporate continuous high-resolution records to provide insights into the timings of climatic signals to reconstruct East Africa's paleoenvironment. This study presents sediment core data (KAP-01) from Kapkanyar Swamp, Cherangani Hills, based on fungal spores, Loss-On-Ignition (LOI) and microscopic charcoal analyses. The climate during the Last Glacial Maximum (LGM) was generally cold and dry with intermittent presence of moist environmental conditions evidenced by the minimal presence of *coprophilous* taxa, a well-known taxon used to signify presence herbivores, representing diminished fauna. Presence of charcoal in the LGM reflects probable natural fires suggesting dry environmental conditions. The deglaciation period, on the other hand, was relatively colder and drier compared to any other period in the last ~23 Kyrs with scanty preservation fungal spores. The Holocene period is characterized by increased fungal assemblages, indicative of a moist environment punctuated by drought episodes evidenced by fires and fungal spores such as *Tetraploa*, *Meliola,* and *Glomus*. In the Late Holocene, fires are more frequent and with potential fire breaks suggesting anthropogenic controlled fires. Our results depict anthropogenic imprints in the environment in the Late Holocene period, ~4 Kyrs to the present.

INDEX WORDS: East Africa, Late Glacial Maximum, Holocene, Fungal spores, Charcoal, Fires, Anthropogenic imprints.

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science in the

College of Arts and Sciences

Georgia State University

2019

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May 2019

DEDICATION

This research thesis is dedicated to my parents, Mr. David Cheruiyot and Mrs. Grace Cheruiyot, for their incredible support and encouraging me to pursue my masters. They have played a key role in motivating me to push to greater heights, my success is their success.

ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge the National Science Foundation (NSF) for funding this project under the award number 1502971.

I would like to thank my advisor, Dr. Larry Kiage for his expertise, guidance and patience throughout the process of writing my thesis. Many thanks to my committee, Dr. Gebregiorgis, Dr. Deocampo and Dr. Meyer for their support and suggestions to furnish this material.

I extend my sincere gratitude to the Department of Geosciences and my colleagues that I have earned the pleasure of interacting with and motivating each other during my time as a graduate student.

Special thanks to family & friends who have encouraged and contributed their ideas towards this project. I extend my appreciation to Benjamin Opiyo whom I worked with tirelessly in the Palynology Lab.

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LIST OF ABBREVIATIONS

AHP - African Humid Period

CAB - Congo Air Boundary

EAM - East African Monsoon

ITCZ - Intertropical Convergence Zone

LGM - Late Glacial Maximum

LOI - Loss-On-Ignition

SST - Sea Surface Temperature

XRF – X-Ray Fluorescence

1 INTRODUCTION

Fungal spores have not been widely applied in palynological contexts aimed at paleoenvironmental reconstructions (Miao et al., 2017; van Geel et al., 2007). Most paleoecological studies tend to overlook fungal spores that are often well-preserved in lakes, wetland sediments, and soils, yet they provide valuable information for paleoenvironmental and paleoclimate reconstructions (Albert et al., 2016; Soka & Ritchie, 2018). Fungal spores offer essential perspectives on temporal paleoenvironment variations and are valuable paleoecological indicators of existing and abundance of megafauna, and microflora while highlighting anthropogenic imprints in the paleoenvironment (Van Geel et al., 2011; Raczka et al.,2016; Szymanski, 2017; van Geel et al., 2003). Fungal taxa provide valuable information on the paleoenvironmental reconstructions complementing other palynological data such as pollen or diatoms thereby enabling a comprehensive understanding of environmental conditions. Identification of high-resolution fungal taxa in the paleo records will contribute to interpretations of East Africa's paleoenvironment and highlight marks of human disturbance. Insufficient paleoenvironmental data from East Africa has implications on understanding the climate nature and the onset of anthropogenic impacts on the environment that is widely regarded as the cradle of mankind (Molinaro & Pagani, 2018; Potts, 2013). The nature of climate affects the development and fruition of specific fungi (Tchouatcha et al., 2016) and the abundance or lack of fungi is highly reciprocal of paleoclimate or signatures of anthropogenic influences on the paleoenvironment. Some studies (Kiage & Liu, 2009; Miao et al., 2017) have demonstrated the importance of fungal spore data for providing information regarding anthropogenic impacts on the paleoenvironment and point to probable timings of events and implications for paleoenvironmental change.

Disturbed environments tend to be associated with significant and diverse fungal assemblages as opposed to pristine landscapes (Gelorini et al., 2011; van Geel et al., 2011). Some of the fungal spores preservation environments include lakes and generally open landscapes that favor the growth of fungi on decomposing materials (Gelorini et al., 2011; Kiage & Liu, 2009; Miras et al., 2015; Raczka et al., 2016; van Geel et al., 2003). The sporangial nature of spores allows them to be transported for long distances (of up to ~100 m) either by wind, animals and in most cases humans (Heitman et al., 2017) evidencing regional paleoclimate as opposed to local effects. Cultivated lands are suitable habitats for the development and fruition of resultant diverse fungi (Oehl et al., 2017).

The transition from the Last Glacial Maximum (LGM) to the Holocene climate resulted in a significant change in presence and diversity of fungal spores. Studies focusing on fungal spore assemblages to improve understanding of past climates, environment and anthropogenic activities have applied globally (Filipova-Marinova et al., 2016; Miras et al., 2015; Tripathi et al., 2014) and in Africa (Gelorini et al., 2011; Kiage & Liu, 2009; van Geel, Fisher, et al., 2011). Despite the potential of fungal spores' data to provide valuable and new insights on paleoenvironments, they have been largely underutilized in East Africa's paleoenvironment. Obligatory or facultative fungal spores are used to infer ecological, climatic and environmental variations due to natural or anthropogenic impacts shaping the environment (Revelles et al., 2016).

Anthropogenic impacts tend to modify landscapes (Luelmo-Lautenschlaeger et al., 2018; Russo Ermolli et al., 2018). Fungal spores can reveal crucial information on paleoenvironmental changes, anthropogenic impacts, and the presence of fauna in the paleoenvironment (van Geel, Fisher, et al., 2011). Therefore, there's a need to enhance paleoenvironmental data in the tropics, East Africa, to determine the probable timing of environmental and climatic events (Garcin et al., 2012). Few studies from East Africa have focused on the use of fungal spores as a proxy for paleoenvironmental change. Therefore, this study employs fungal spore data from Cherangani Hills to elucidate paleoclimate shifts and resultant changes in the paleoenvironment from the Last Glacial Maximum (LGM) to the Holocene epoch.

This study also presents a record of both local and regional fires through the analysis of microscopic charcoal. Microscopic charcoal analyses have effectively used across many environments for reconstructing changes in paleoclimates and to assess human impacts on the environment (Marlon et al., 2013; Norström et al., 2014; Whitlock, Moreno, & Bartlein, 2007). Use of macroscopic and microscopic charcoal as a proxy for both local and regional allowed us to understand the nature of paleo fires (Brncic et al., 2009; Power et al., 2008; Wooller et al., 2003). In particular, the last ~4 Kyrs is a critical period in history where agriculture and technology development could have significantly modified the natural landscapes in East Africa (Grillo et al., 2018).

1.1 Research Questions

Although the use of fungal taxa has proven useful for paleoenvironmental reconstruction, their potential remains untapped mainly in tropical Africa. This study is designed to investigate paleoenvironmental changes in tropical East Africa through the examination of multi-proxy data, the primary being fungal spores, from Kapkanyar Swamp, Cherangani Hills, Kenya. The location of Cherangani Hills in the fragmented mountains region makes it a potential site for investigating climate variability. Studies of fungi provide insights on environmental changes in tropical eastern Africa due to natural and anthropogenic impacts since the Late Pleistocene to the present. This study aims aimed to provide new information on past environmental change and pinpoint traces of anthropogenic effects on the environment from ~4 Kyrs. Specifically, this study seeks to address the following questions:

a) Is there any evidence of anthropogenic impacts on East Africa's paleoenvironment after ~4 Kyrs?

b) What is the response of East Africa's paleoenvironment and paleoclimate to either natural or anthropogenic climate changes?

1.2 Study area

The Cherangani Hills (1.25° N, 35.45° E), (Figure 1), are part of a vast system of East Rift-Valley in Kenya that formed by tectonic activities during the Miocene. The tectonic activity also resulted in the creation of lakes and troughs that have since favored the development of wetlands. Wetlands are good geo-archival sites reflecting both anthropogenic and natural changes (Owen et al., 2018; Tryon et al., 2016). To understand paleoenvironmental changes, it is necessary to increase the number of continuous paleoclimatic records in tropical Africa (Liu et al., 2017).

The high elevation of Cherangani (Figure 1), 3000 m above sea level, offers a good site (Picture 1) for palynological studies because of climatic conditions that ensure that pollen and fungal spores preserved, and tectonic disturbances can be ruled out (Owen et al., 2018; Tryon et al., 2016), Coetzee, 1967). The Cherangani Hills are characterized by altitudinal zonation of diverse vegetation such as conifers, juniper, acacia, East African rosewood, ferns and other flowering plants, and grasslands. However, the high levels of human disturbance define these Hills to the extent that only fragments of former vegetation now exist. These Hills form an essential water catchment area for Rivers Nzoia, Kerio, and are located between Lakes Turkana and Victoria which have in the past been useful in illustrating temporal climatic variability (Owen et al., 2018; Tryon et al., 2016). The biodiversity at Cherangani Hills is composed of extensive and unique flora and fauna.

Cherangani Hills is characterized by a tropical wet climate with precipitation of approximately 1200 mm in the east and at least 1600 mm in the west influenced by prevailing winds from Lake Victoria. Seasonal precipitation in the region is controlled by changes in Sea Surface Temperature (SST) in the Indian Ocean, shifts in the Inter-Tropical Convergence Zone (ITCZ) with short rains occurring in March to May and in October to December (Coetzee, 1967).

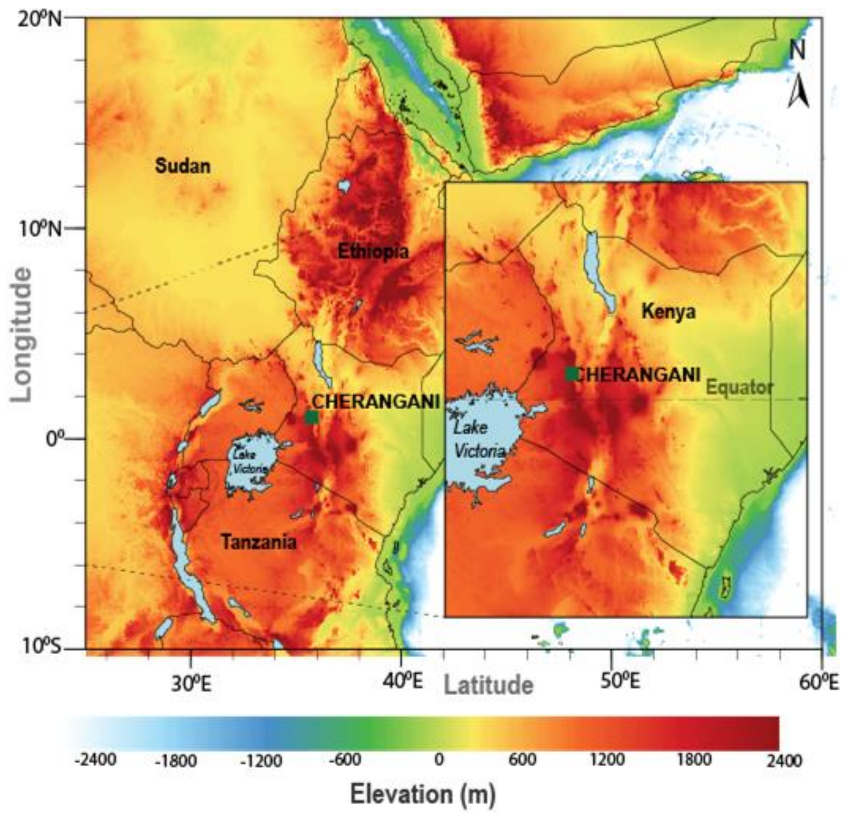


Figure 1. Eastern Africa map showing the approximate location of Cherangani Hills in Kenya and topographical elevation ranging from -2400 to 2400 m.

Picture 1. A picture showing core retrieval from Kapkanyar Swamp located in the Cherangani Hills.

2 METHODS

2.1 Coring, lithostratigraphy, and chronology

Sediment cores were retrieved from Kapkanyar Swamp (01° 17’ 38” N, 35° 17’ 38” E), Cherangani Hills, in the summer of 2016 using a modified Livingstone corer, a type of piston corer, following the standard procedures described by (Chambers & Cameron, 2001). The composite sequences were preserved in sealed clear polyvinyl chloride (PVC) tubes to retain moisture and transported to the Palynology Lab at Georgia State University. The longest core, KAP-01 (Picture 2) with a total of length of 3.47 m, was chosen for detailed Loss on Ignition (LOI), X-Ray Fluorescence (XRF), palynological, and charcoal analyses.

KAP-01 was longitudinally split into two halves: one half was designated as the working core and subjected to analyses while the other half (which we labeled “archive core”) was archived for future reference and review. Seven organic samples (plant microfossils) were dated to establish the chronology of Kapkanyar composite sediments using Accelerator Mass Spectrometer (AMS). The AMS radiocarbon dating was performed by Direct-AMS laboratory in Seattle, Washington. The raw ^{14}C dates were calibrated using CALIB program (Stuiver & Reimer, 1993), then the Bayesian Accumulation (BACON) program was used to reconstruct the age model (Blaauw et al., 2011).

Picture 2. One of the core segments of KAP-01 ready for splitting into two halves; one half as working core and the other archived for reference.

2.2 LOI and elemental geochemistry analyses

A total of 347 samples were sampled for LOI analyses following standard procedures (Luczak et al., 1997; Santisteban et al., 2004). 1 cm^3 sample at ~1 cm interval generated high-resolution data of total organic matter, carbonates and water content. LOI involved measuring weight loss of the samples after drying them overnight at 105˚C, followed by establishing weight loss after combustion at 550˚C and 1000˚C for an hour respectively to determine water, organics, and carbonates content.

High-resolution data of both high and low atomic number geochemical elements were measured at intervals of 1 cm for a period of 180 using a handheld XRF analyzer. The output was recorded in parts per million (ppm) to evaluate the sediment composition and enhance interpretation of geochemical results based on environmental variations either due to natural or anthropogenic processes.

2.3 Fungal Spores and Microscopic Charcoal Analyses

A total of 24 samples were retrieved from KAP-01 for charcoal and fungi taxa analysis. Sampling intervals were done at varying intervals while paying acute attention to core sediments that displayed significant changes in sediment composition based on LOI data. Each sample vial was spiked with two tablets of Lycopodium spores before the chemical treatment to determine the accuracy and variability of the fungal spore results (Meng, 1994). All samples were prepared and treated with KOH, HF, HCl, acetolysis, sieved for fine concentrations, and suspended in silicon oil following the standard method of pollen processing (Faegri, Kaland, & Krzywinski, 1989). Fungal spores samples were then mounted on slides for identification and counting. Identification of fungal spores and microscopic charcoal was performed using Olympus BX 43 microscope at 60X magnification.

Counting of fungi was done in multiple slides for each sample to ensure the accuracy of presence because their abundances were minimal throughout the core. Identification of fungal spores was based on descriptions and illustrations previously published from East Africa (Gelorini et al., 2011; van Geel et al., 2003). Fungal spores were expressed as percentages relative to charcoal counts that were presented in terms of presence and both plotted using TILIA software. The fungal spores data were defined using the stratigraphically constrained sum of squares cluster analysis (CONISS) for all the taxa encountered. Charred (grass) cuticles and charred wood were grouped into two categories depending on the length of the longest axis; ≤ 150 μm (microscopic charcoal) and ≥ 150 μm ("macroscopic" charcoal) following conventional descriptions (Abel-Schaad & López-Sáez, 2013; Higuera et al 2014; Metwally et al., 2014). Grass and tree microscopic charcoal counts were expressed in terms of presence to show evidence of direct local and regional fires.

3 RESULTS

3.1 Core description

The sediments of Kapkanyar swamp were classified into five stratigraphic horizons. The basal part of the core from 347 to 272 cm is composed of thick clayey black mud which transitions to gray clayey mud rich in plant microfossils at depth 272 to 232 cm. This was followed by a sharp transition to brown-yellow sandy clays between 232 to 222 cm. From depth 222 to 214 cm the deposit sharply transitions to brown micaceous clay. Between 214 to 40 cm the sediment is characteristic of lake mud with no visible organic matter and capped by dark clay from 40 cm to the top of the core characterized by extensive fibrous rootlets.

3.2 Chronology (Age depth model)

The AMS radiocarbon chronology based on AMS ^{14}C-dated plant microfossils from KAP -01 is summarized in Table 1 below. Seven conventional radiocarbon dates deduced from core KAP-01 and calibrated using IntCal13 to yield the probable ages of the Kapkanyar sediments. Five ages from 178 onwards were used to develop an age model using BACON version 2.2, Figure 2, showing the chronology for the last ~23 Kyrs. The chronological sequence of KAP-01 was obtained using a linear extrapolation between dates 0 to 178 cm. Except for the date at (228 cm), the other dates show a continuous sequence following the law of superposition, no signs of disturbance, with probable inconsistent rates of sedimentation in the record. The sedimentation rates in the Late Holocene can be described as intense and rapid, while in the mid-Holocene to the Late Pleistocene the rates are relatively constant. All Calibrated dates are presented in Appendix 1.

Table 1: Chronology of KAP-01 from Cherangani Hills. ^{14}C Radiocarbon dates, Cal yrs considered the most probable age.

Sample Depth	Material dated	^{14}C age (yrs BP)	Cal yrs (BP)	Modeled ages (yrs BP) 2 **σ** age ranges
90	Leaf fragment	Modern		
110	Leaf fragment	Modern		
178	Leaf fragment	4565 ± 35	5272	4982 to 5532
228 (Outlier)	Leaf fragment	5287 ± 52	12964	10240 to 15166
254	Leaf fragment	14320 ± 62	17256	16498 to 17726
300	Leaf fragment	17543 ± 71	21169	20394 to 21649
345	Leaf fragment	19597 ± 166	23657	22976 to 24226

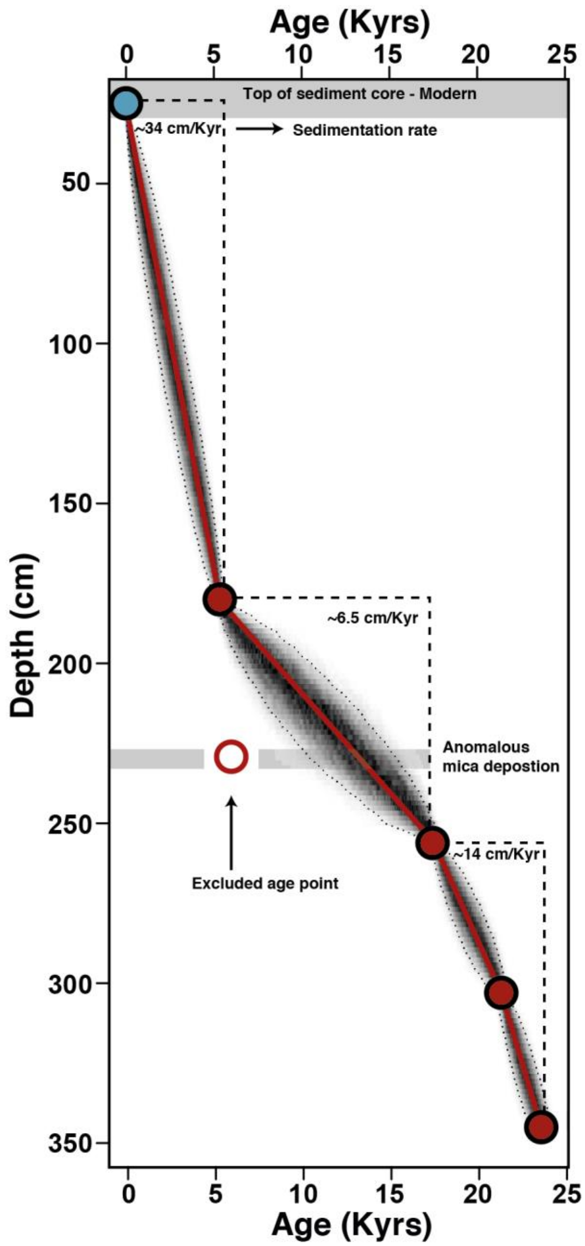


Figure 2. Age model of KAP-01 generated using BACON version 2.2 model showing rapid sedimentation rates to ~5 Kyrs. The age @228 cm was considered an outlier thus excluded when generating the age model.

3.3 LOI

CONISS, a multivariate method for quantitative definition of stratigraphic zones, was used to delineate KAP-01 into five zones based on LOI analysis (Figure 3). LOI data showed elevated levels of organics at the base of the core. Fluctuating levels of organics are notable between 305 to 248 cm (21.5 – 16.3 Kyrs) with a significant drop at 200 cm (8.2 Kyrs) mark. There’s a decline in organic levels in the subsequent zones to values as low as ~12% recorded at 120 cm (3.2 Kyrs) after which there is a slight increase of ~15% to the top of the core. Between 0 to 25 cm the organics display a substantial increase of approximately ~35%. Water percentages show a similar pattern to that of organics. Carbonate contents are as low as ~3% throughout the core with an exception at 300 cm mark (~21.1 Kyrs) where there’s a peak of approximately ~25%. This sudden and only elevated percentage in the record suggests the possibility of a sampled gastropod carbonate shell.

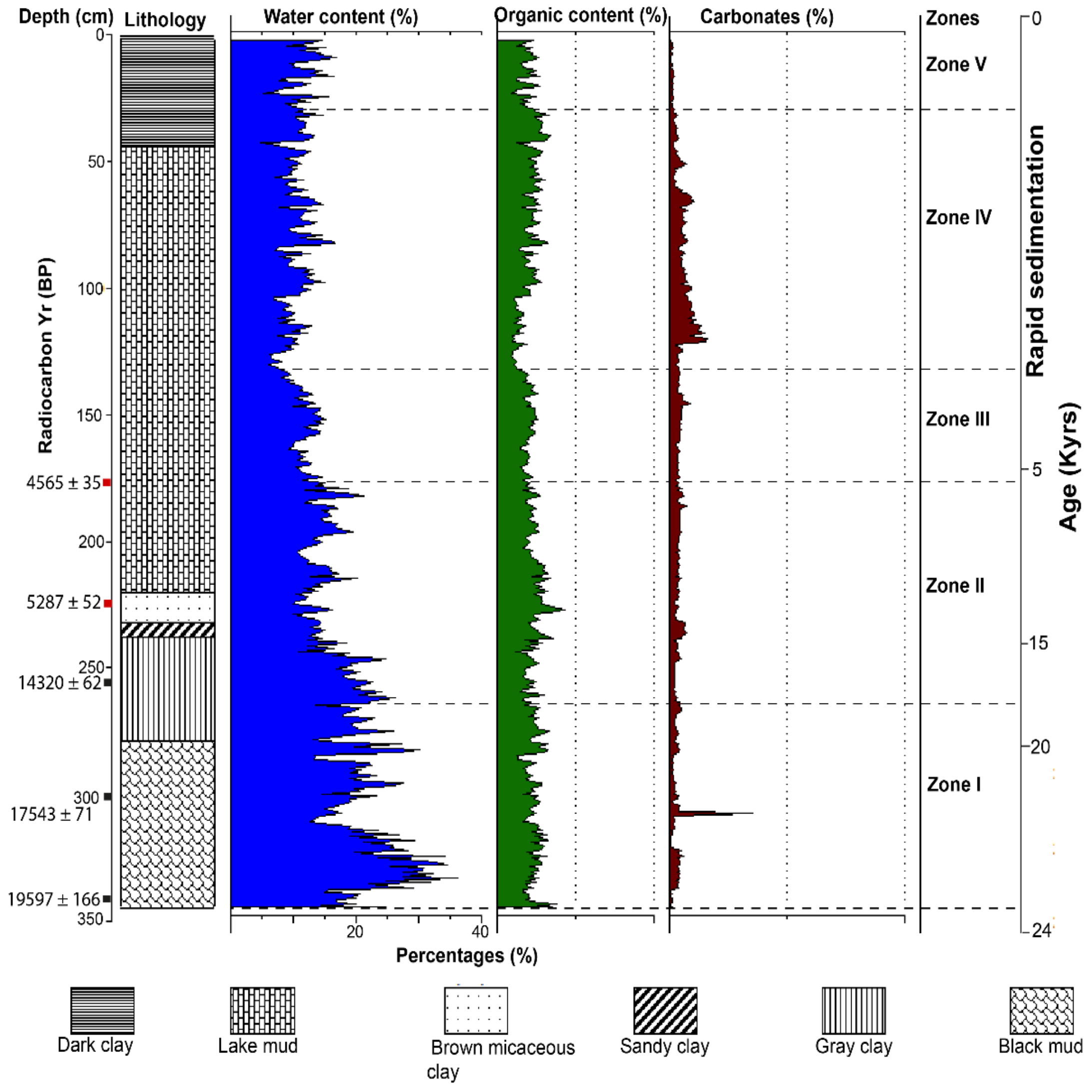


Figure 3. Physical properties, water, organics, and carbonate content percentages of KAP-01 core.

3.4 Palynological (Fungi), Charcoal and XRF data

Figure 4 shows the percentages of dominant fungal spores in KAP–01 which are essential for interpreting potential paleoclimatic and paleoenvironment changes. CONISS stratigraphic zonation of fungal spores in core KAP-01 shows five significant fungal assemblage zones (Figure 4). A total of 19 distinct fungal spore types including unknown types (clustered in indeterminates/others category), were identified from the 24 sediment samples analyzed at multiple levels as one level did not show enough counts of fungal spores necessary for interpretation. The indeterminate fungal spores were not categorized like the known types due to lack of proper references necessary for reliable identification.

The general trend shown by Kapkanyar fungal spores taxon is in order of increasing abundance from the bottom to the top of the core. These fungal spores are described in Table 2 below. The dominant fungal spores in the coprophilous taxa are *Sordaria, Cercophora, Podospora,* and *Sporormiella*. Other fungi represented are *Glomus, Coniochaeta, Gelanispora, Gelanispora, Diporotheca, Chaetomium* and *Meliola.* Low frequencies of *Glomus* also characterize KAP–01 and were presented in presence to clearly highlight distinct environmental processes and because of their sporadic occurrences. The assemblages also comprised of single and double-celled spores with few of multi-celled spores such *Conidia*. Microscopic and macroscopic charcoal counts showing paleo-fire incidences over the last ~23 Kyrs to present varied significantly (Figure 5). The elemental concentrations are shown in Figure 6 below. Details of charcoal, fungi and elemental data as per the five CONISS zones are as follows:

3.4.1 Zone I (347 to 274 cm), ~23 to 19 Kyrs

The pattern in this zone is one of low count of spores' types except for the coprophilous fungal taxa are represented by *Cercophora*, *Coniochaeta*, *Sordaria, Delitschia*, *Chaetomium*. Two *Glomus-type* are also present. All the other fungal spores were classified in the indeterminate/others category. Microscopic charcoal counts are very insignificant in this zone and the elemental data shows decreased levels of Ca, Ti, Fe, Cl, and K.

3.4.2 Zone II (274 to 174 cm), ~19 to 5.1 Kyrs

Fungal spores in this zone are poorly represented and impoverished. Zone II is devoid of most of the coprophilous taxa except for *Cercophora*. Significant counts of *Chaetomium* are also present. The impoverishment of fungal spores in this zone could be a factor of corrosion or null preservation in the sandy micaceous sequence as observed in the sediment. Microscopic charcoal counts are purely insignificant in this zone. Just at the onset of this period, Cl levels peak as Fe, Ti, K levels drop, and they vary dependently.

3.4.3 Zone III (174 to 128 cm), ~5.1 to 3.5 Kyrs

There was a recovery of the coprophilous taxa such as S*ordaria, Coniochaeta, Gelanispora, Sporormiella, Chaetomium* and indeterminates/others. Microscopic charcoal counts are slightly high at ~10.5 Kyrs characterized by elevated levels of tree charcoal. Elemental composition in this zone portrays elevated levels of Ca, Ti, K, Fe concurrent with decrease in Cl levels and vice versa. At ~3 Kyrs, the record shows slightly elevated levels of K, Ti, and Fe accompanied by drops of Cl.

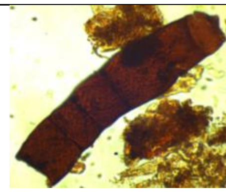
3.4.4 Zone IV (128 to 86 cm), ~3.5 to 2 Kyrs

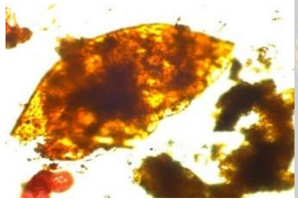
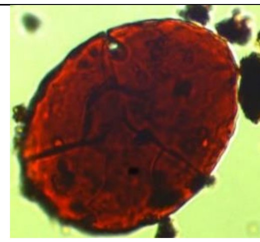
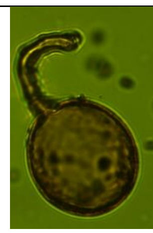
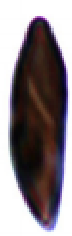
This zone was characterized by increased percentages and diverse fungal spore morphologies. Spores of *Sordaria, Sporormiella*, *Podospora, Cercophora, Coniochaeta* are dominant. *Glomus* is also present in this zone. In this zone there is a general upward, and significant increase of major fungal taxa from this zone to zone V. Grass and tree charcoal counts are significant with potential fire breaks. At ~ 2 Kyrs, the elemental concentration of Ca, K, Fe and Ti are decreased, accompanied by an increase of Cl. Thereafter, small peaks of K, Ca, Ti, Fe are recorded accompanied by decreased levels of Cl.

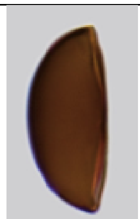
3.4.5 Zone V (86 to 0 cm), ~ 2 Kyrs to present

There was a resurgence of the coprophilous taxa, *Conidia*, *Glomus* and emergence of new taxa such as *Tricholdelitschia*, *Tetraploa*, and *Epicoccum* fungi. Microscopic counts declined to as low as ~10% compared to zone IV. This period is also characterized by slight variations of all the elements with no significant changes.

Table 2. Descriptions and image references of fungal spores types identified in KAP-01 as described by Gelorini et al., 2011, Van Geel et al., 2011 and Schlütz & Shumilovskikh, 2017.

Fungal Spores name	Fungal spore image	Description of fungal spore
Cercophora		One celled wall, smooth, dark brown with a tapering end, 23x 12 µm. Belongs to the coprophilous taxa.
Chaetomium		Ascospores that are lemon shaped with apical pore at the end, 9 x 7 µm.
Conidia		5 or 7 more celled wall, pale brown to dark brown in color, narrow and oblong in shape, 45 x 10 µm and thick walled.
Coniochaeta		Like Sordaria but narrow, 20-24 x 18-24 µm, one cell walled and dark brown. Belongs to the coprophilous taxa
Delitschia		Elliptical spores that are dark-brown, two cells walled, smooth and in fusiform, 30x 15 µm.
Diporotheca		One celled, dark brown in color and anastomosing in shape with an octagonal shape, 38 x 27 µm.

Epiccocum	 	Globose, greenish yellow, multiple septa with an irregular base, 15-28 µm in diameter.
Gelanispora		Dark brown to light brown ascospore with a hyaline appearance, 37 x 25 µm.
Glomus		One celled, smooth, 55 x 50 µm with a short hypha like attachment.
Meliola		Oblong, curved in shape fungi that is dark brown and 4 celled walls and of about 53 x 16 µm.
Podospora		One celled, smooth dark brown, one sided basal end with a tapering end, 56 x 26 µm. Belongs to the coprophilous taxa
Rosellinia		25 x 6 µm fusiform ascospore with a long germ slit and is light brown in color

Sordaria		Oval ascospore that is one celled, brown to dark brown, smooth, 20 x 11µm with two visible pores at the tips. Classified as a coprophilous type.
Sporoschisma		Dark brown conidia of about 50-61 x 12-14 µm with flattened ends that is smooth and thick walled
Tetraploa		Brownish yellow in color with 3-4 cells, with 3 medium appendages, 38 x 22µm.
Trichodelitschia		Light brown to dark brown in color and appears like two attached spores at their basal ends. Attached hypha like at the ends.
Xylariaceae		Dark brown ascospores with one flattened side and 22 x 9µm.

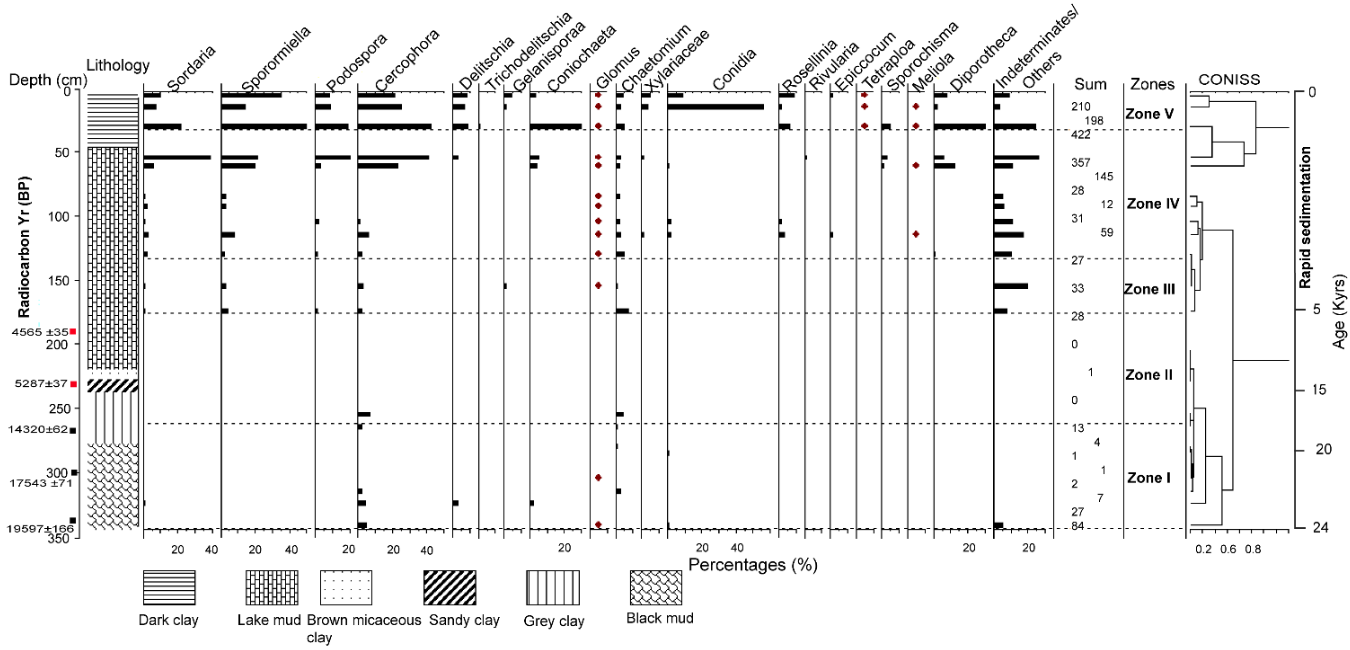


Figure 4. Diverse fungi percentages of KAP-01 from zone I through V. The various zones suggest different environmental and climatic conditions.

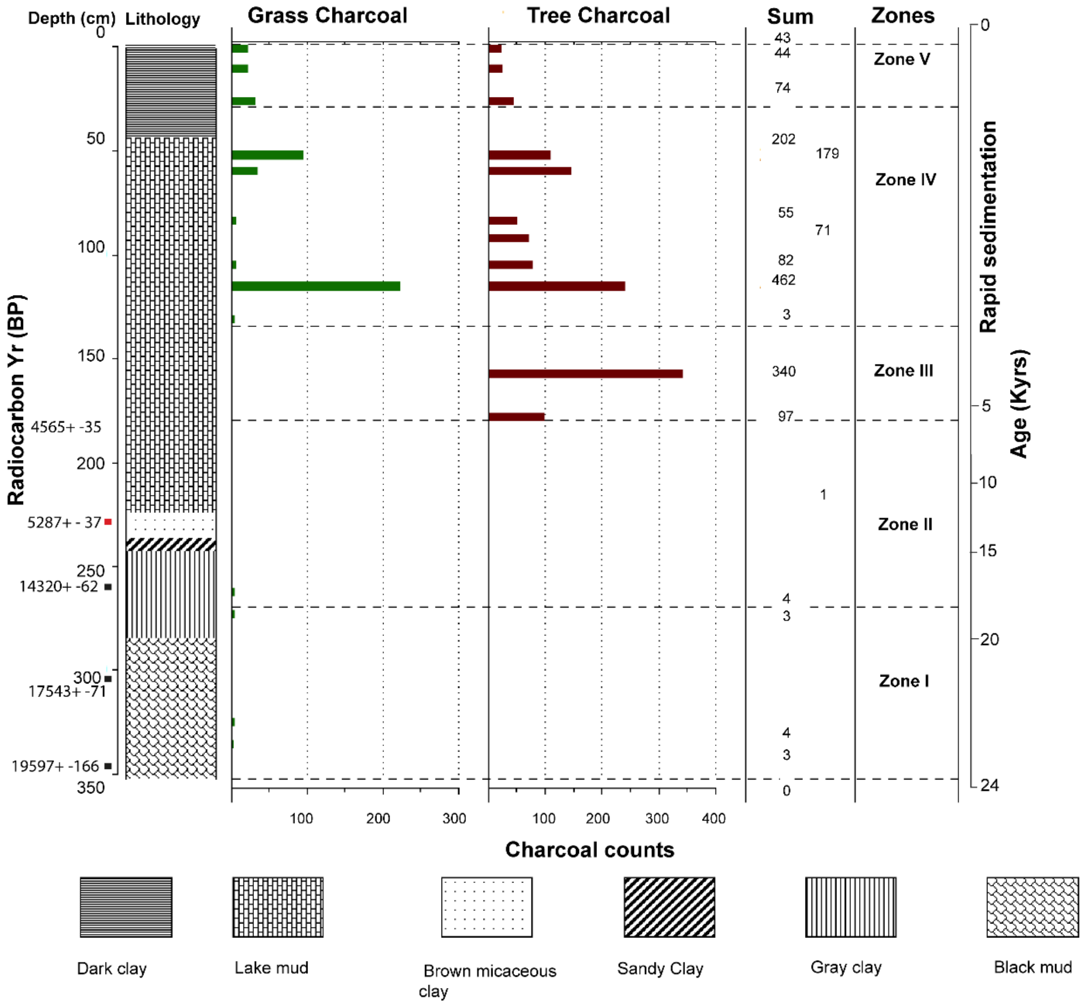


Figure 5. Microscopic (<150μm) grass and tree charcoal counts of KAP-01 from zone I through V.

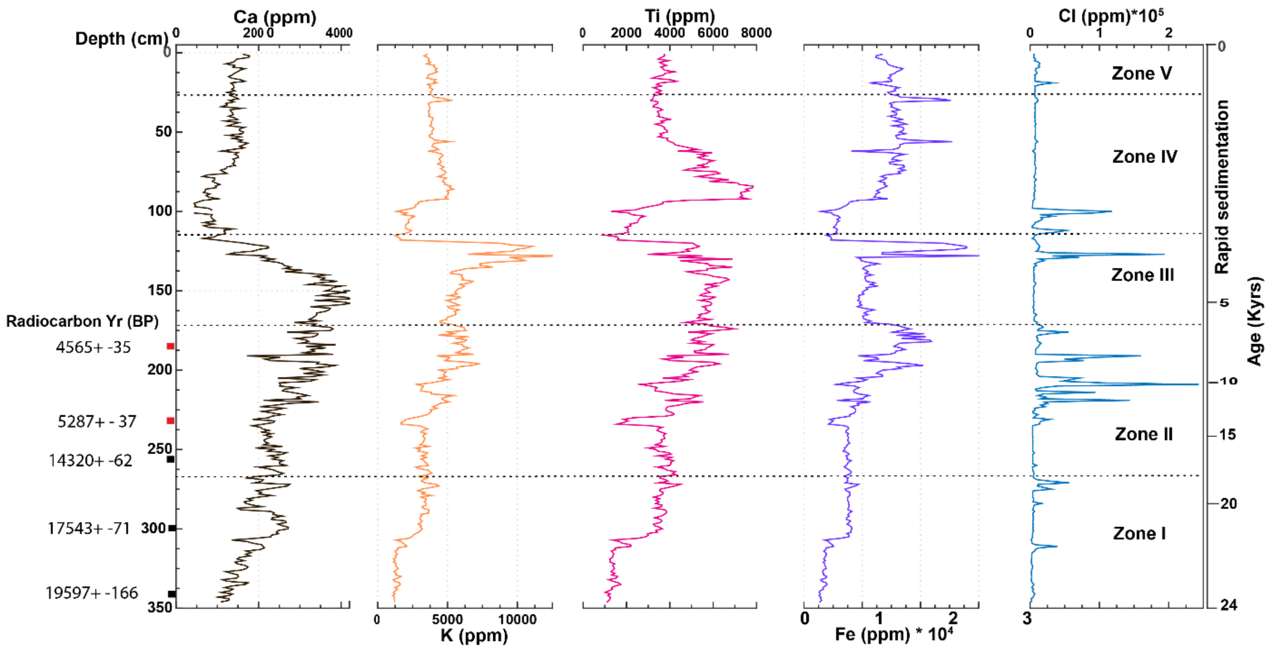


Figure 6. Ca, K, Ti, Fe & Cl geochemical data of KAP-01 plotted in ppm from zones I through V.

4 DISCUSSION

4.1 Paleoclimatic and paleoenvironmental interpretations

This study employs fungal spores along with LOI, XRF and charcoal data to highlight environmental changes in the vicinity of Cherangani Hills during the following periods; Late glacial maximum, deglaciation, late Pleistocene to Early Holocene, Holocene and more recent past. The chronological control and high resolution of the sediment data provide reliable interpretations of the paleoenvironment of Cherangani Hills while highlighting any anthropogenic impacts on the environment. The diverse fungal taxa in the record suggest different environmental and climatic conditions. All the taxa were presented as percentages except for *Glomus* and *Tetraploa* due to their sporadic occurrences which is a factor of specific environmental conditions conducive for their development and sporulation.

Paleoenvironmental changes are interpreted based on the relative abundances of fungal spores complemented by LOI, elemental geochemistry, and microscopic charcoal data in the five significant zones. Fungal spores are highly sensitive to changes in climate, moisture variability, and each taxon is unique to its niche. The diversity of fungi taxa is highly dependent on the nature of the environment and subsequent environmental impacts due to climate variability. One major limitation of using the fungal spores as a paleoenvironmental proxy is that some morphologies are difficult to identify exclusively due to corrosion while processing or inability to classify them accordingly. Also lack of reliable information about each taxon made it arduous to identify some fungi. It is important to note that there is no vast knowledge on the ecology and diversity of tropical African fungi. Despite these challenges, we consider results from fungi, LOI and XRF analyses as signals of prevailing environmental conditions at the different sediment levels encompassing various periods discussed below.

4.2 Late Glacial Maximum (~23 to 18 Kyrs)

The LGM period is likely to have played a significant role in control of the climate influencing the abundance of fungal assemblages overtime. Total fungal spores fluxes and their diversity in zone 1 are diminished, impoverished, and majorly of coprophilous taxa such as *Cercophora*, *Coniochaeta*, and *Sordaria*, compared to the Late Holocene period where they tend to occur in higher densities. Chaetomium type found in this is like the kind found at Lake Challa, Kenya which is a fungus that thrives on animal dung and decaying plant matter (van Geel, Gelorini, et al., 2011). The impoverished representation of fungal spores is probably due to unfavorable paleoenvironmental conditions inhibiting proper fruition and preservation of spores.

Presence of ascospores of coprophilous fungi is usually associated with grazing activities in an environment (Musotto et al., 2017). Therefore, the minimal presence of coprophilous fungi in the record suggests the probable existence of diminishing herbivores in the vicinity of the Cherangani Hills in the LGM. The impoverished presence of *Sordaria and Cercophora* is likely an indicator of remains of Late Pleistocene fauna after extinction (Ecker, Brink, Horwitz, Scott, & Lee-Thorp, 2018). Fungi records from southeastern Kenya show diminished *Coniochaeta sp.* during the LGM (van Geel et al., 2011), like the trend observed in this record. Reduced abundances of *Coniochaeta* also implies the diminishing presence of fauna in the surroundings. Therefore, the LGM played a major role in influencing East Africa's paleoenvironment and paleoclimate. Temperature extremes and moisture variations can be detrimental to the preservation and existence of fungal assemblages (Boddy et al., 2014).

The few fungal taxa observed in this zone point to intermittent moist Cherangani that allowed fruition of the observed taxa in the cold and dry LGM. *Glomus* is an indicator of soil erosion (Loughlin et al., 2018). The presence of *Glomus* type suggests the probable existence of open landscapes that were susceptible to erosion. The erosional processes may have been due to glaciers dominant in the LGM. The high water and organics content from the LOI analysis also point towards a probable moist environment in Cherangani in the prominent cold and dry climatic period.

Charcoal fluxes are also very low suggesting minimal fire activity. The limited fire activities indicate that the fire environment was not right for fire ignition. It is likely that most of the environmental changes during this time is a factor of natural climate variability, fires and herbivores and not humans as suggested by (Ivory & Russell, 2016). Between ~23 to 19 Kyrs fire regimes have significantly varied due to climate variability. In East Africa, LGM fires were frequent and propagated by abundant C-4 grasses (Nelson et al., 2012), but this does not appear to have been the case in the vicinity of the Cherangani Hills site. Paleoecological analyses of the Late Holocene records from the tropics show increased fires and droughts (Brncic et al., 2009). The elemental concentrations of Fe, Cl, Ti, Ca, and K show insignificant variations, and this could have been due to the general prevalence of cold and dry environmental conditions.

A previous pollen reconstruction record from this same site suggests wetter climatic conditions (Opiyo et al., in review) which is consistent with findings in the fungi record. Previous studies from the region affirm the observations from this study which shows a prolonged dry climate punctuated by wet environmental conditions. Pollen records from Mt. Kenya, to the east of the Cherangani study site suggest predominance of dry and cold ecological conditions during the LGM (Montade et al., 2018). There is a need to increase high-resolution records and perform extensive studies in East Africa during the LGM period to exclusively describe the nature of the environment and climate. This is so because East Africa’s climate is highly variable and influenced by topography (Funk et al., 2015; Olaka et al., 2010).

The LGM has been considered a major cause of global aridity (Cutler et al., 2003; Huybrechts, 2002; Pope & Terrell, 2007). The regional cold and dry climate in the LGM coincides with environmental interpretations from our record. In the tropics, this period is of profound aridity (Cohen et al., 2007; Faith et al., 2015; Felton et al., 2007). However, the environmental conditions of the Cherangani Hills could have favored fungal preservation evident in the record due to probable intermittent cases of moist environmental conditions.

4.3 Deglaciation (~18 to 12 Kyrs)

Zone II marks the transition from the maximum glacial period to a cooler period, and to the termination of the Late Pleistocene climatic period. This cool period marking the post-glacial environment is characterized by impoverished and diminished counts of fungi such as *Chaetomium* and *Cercophora*. *Cercophora* are not obligate dung-fungi and could have survived on non-dung substrates (Johnson et al., 2002) as opposed to other dung fungi. It is possible that already diminishing fauna present in the LGM barely survived into the post glacial period marking an environment characterized by few fauna or none. Presence of *Chaetomium* in low counts could be due to favorable cooler and episodes of moist conditions after the LGM. The overall diminished counts during the deglaciation indicates the prevalence of cool and drier environment inhibiting preservation of fungi and sporulation of fungi. The absence of both tree or grass charcoal in this zone is indicative of suppressed fire activity both locally and regional while reducing levels of organic and water contents suggest a drier climate in the region, more so at ~17 Kyrs. The fungi and LOI data point to a cool, drier environment while the charcoal proxy suggests a period of minimal fire activity in the region probably due to inappropriate fire conditions. The concentrations of Ti, K, Fe and Cl during this period do not exclusively highlight the nature of climate.

The drier environmental observations can be correlated with other findings from East Africa such as paleosols geochemical record from Lake Victoria, located to the southwest of the Cherangani Hills, paleohydrology record from Lake Turkana (north of the Cherangani) Hills and a sedimentary facies record from the Kenyan coast, all of which suggest the climate as dry at ~17 Kyrs (Accordi & Carbone, 2016; Beverly et al., 2017; Morrissey & Scholz, 2014). Hydroclimatic variability from the Nile River showed prevailing arid conditions in the same period (Castañeda et al., 2016).

4.4 The Holocene (~12 Kyrs to present)

There was a minor recovery of fungal spores in this chronozone as opposed to the Late Pleistocene and deglacial periods. The diverse representation fungal taxa and increase of indeterminate spores category point to favorable moist environmental conditions favoring sporulation and fruition of fungi in the Late Pleistocene progressing to Early Holocene. *Sordaria* and *Sporormiella* are obligate dung fungi, showing the probable presence of grazing activities in the environment.

This moist paleoenvironmental conditions coincide with the African Humid Period (AHP) (Tierney et al., 2011). The onset of the Holocene period is humid in Equatorial Africa (Tierney, Lewis et al., 2011, Russell et al., 2003). This period has been referred to as AHP which has been associated with variable Sea Surface Temperature (SST), Congo Air Boundary (CAB), shifting of ITCZ, and expansion of montane forests. However, xeric environmental conditions punctuate the wet environmental conditions at approximately 10.5 Kyrs. Generally, the Early Holocene period is characterized by major climatic transitions in eastern Africa (Olago, 2001).

Charcoal size can be used to determine the source area of the fire. Large charcoal particles indicate local fire events because they are less likely to be transported far from the source (Tinner et al., 2006). The spike in both grass and tree charcoal in this zone point towards a significant fire event in the vicinity of Cherangani. Fires modify the vegetation and environments at large. These fires could be contemporaneous with large natural fires at ~11.5 Kyrs recorded at Lake Kifuruka, Uganda (Kiage et al., 2017) which affirms the prevalence of a regional desiccation event. The fluctuating levels of organics and elevated levels of carbonates support the fungi record interpretations, all pointing towards a drier climate. This is further evidenced by the presence of *Glomus* suggesting existence of landscapes that are more susceptible to erosion. Also, the possibility of low wetland levels contributing to the anomalous deposition of sandy sediments at 228 cm (~12 Kyrs) could be a resultant of drier conditions. This is the reason the radiocarbon age at this point was considered an outlier when reconstructing the age model

. The stabilized nature of Ca, dips of Ti, Fe, and K with increase in the concentration of Cl also suggest common drier environmental conditions at ~ 10 Kyrs. Fe concentrations in Kapkanyar wetland are dependent of Ti & K often known as erosion indicators (Lomas-Clarke & Barber, 2007). The decrease in Ti and K infers less erosion and existence of a drier environment. The elemental concentrations also support similar interpretations of drier environmental conditions at the onset of this period indicated by increased levels of Cl and reduced Fe. Fe is used as a proxy for redox reactions is preserved in sediments and other external factors control its concentration. In this study its concentration appears dependent of erosion indicators (Ti and K) (Żarczyński et al., 2019). Less Fe in the anoxic environment infers changes in redox reactions and the wetland was probably less oxygenated hence less accumulation of pyrite. Chlorine has been used to infer levels of salinity (Herbert et al., 2015); hence its use in this study to determine wetland water levels and climatic conditions. Its increase in this zone infers relatively low water levels and ultimately drier climatic conditions.

At ~9 Kyrs there is a resurgence of the coprophilous fungi such as *Sporormiella, Podospora, Delitschia, Coniochaeta,* and *Cercophora* indicative of significant grazing activities in the vicinity of Cherangani Hills. The heightened diversity of fungi is an implication of diverse and increased environmental activities from mid-Holocene to Late Holocene. Presence of these fungi suggest prevalence of moist environmental conditions and potentially increased number of herbivores in the vicinity of Cherangani especially in the Late Holocene. The high levels of Ca in this period suggests relatively moist conditions in the wetland supporting our findings from fungi as Ca has been used as an indicator of water levels (Korponai et al., 2010). A *Sporormiella* record from Lake Tanganyika, located to the south of the Cherangani Hills, reveals an increase in large herbivore populations in the early Holocene (Ivory & Russell, 2016). The presence of increased herbivores in the paleoenvironment could have brought about ecological balance; thus, fires became less frequent and probably leading to development of lush paleoenvironment. The pollen record from the site (Opiyo et al., in review) also provides evidence of flourishing forests in the Holocene period, a likelihood of favorable climate.

The increase of macro charcoal frequencies between 7.8 to 4 Kyrs document significant local fires and lesser regional fires. This points to a drier climate counts at 7.8 Kyrs can be interpreted as a dry period in the wet environmental conditions that created a conducive fire climate. Fluctuating water and organic levels accompanied by increased carbonates suggest that environmental conditions continued to be warmer and drier at this time. Our record points towards a moist early Holocene paleoenvironment by paleoclimatic conditions punctuated by prominent drought episodes. The elevated levels of Ca at ~5 Kyrs in the record suggests point towards high eutrophic levels in the wetland and this could be due to favorable wetter climate in the Holocene. The drier climate recorded at ~4 Kyrs could be part of the extensive desiccation period that has been recorded in an adjacent site, Lake Baringo (Kiage et al., 2017). Geochemical data shows evidences of drier conditions at ~4 Kyrs indicated by significant increase of Cl countered by decrease of Fe. Cl has been used as a measure of salinity. This period is exclusively followed by probable wet climatic conditions indicated by increase of Fe and low concentrations of Cl. Paleoclimatic records show that the early to the mid-Holocene climate in Africa is a pluvial period (Castañeda et al., 2009; Neumann et al., 2008). Increased precipitation in East Africa is stimulated by increase in Northern Hemisphere insolation which in turn increased sea surface temperature (SST) creating a climatic cycle (Kutzbach & Liu, 1997; Stager, Cumming, & Meeker, 2003) that enhanced the East African Monsoon, EAM, (Tierney et al., 2011). The EAM systems are propagated by shifts in ITCZ due to change in ocean mass thermodynamics and weak Tropical Easterly jet streams (Sultan & Janicot, 2003).

Increased microscopic charcoal counts indicate the heightened number of fire events, some of which could be linked to human activities. Increased human disturbances in the late Holocene appears coeval with the period of iron use technology at ~2.5 Kyrs (Marchant et al., 2018). The increase of coprophilous taxa and diversity of fungi in the late Holocene point to enhanced grazing in the environment and probable pastoralism practices in the Cherangani region. This is coincidental with subsistence practices at the onset of the Holocene period in Turkana Region, Kenya, believed to be the first in East Africa (Ashley et al., 2004). The fire activities at approximately 2 Kyrs suggests drought episodes prevalent in the environment. These fires appear to be frequent yet of low intensity suggestive of anthropogenic controlled fires. Previous studies from East Africa have also suggested drought episodes at approximately this period. A multi-proxy record from Kyambangunguru, Tanzania showed transition from lake to a peatland as a result of drier and warmer conditions (Coffinet et al., 2018), and lacustrine sediments from Lake Edward and Lake Nabugabo in Uganda inferred low lake levels (Russell et al., 2003; Stager et al., 2005).

The record also signifies predominant drought periods in the recent past around 0.5 Kyrs. The dry periods are indicated by the presence of fungi taxa such as *Tetraploa* and *Meliola* which are known to sporulate in xeric and warmer conditions. respectively. Presence of *Tetraploa* could be marking a major climate variability in the record because it is known to occur in very distinct climatic conditions. The microscopic charcoal record document frequents local and regional fires likely to be controlled by humans in the recent past and reflective of increased levels of human disturbance in the environment. Increase of Ti & K concentrations could be as a result of increased human activities and farming practices in the vicinity of Cherangani. Ti has been used as indicator of human disturbance (Hormes, 2005). Increased levels of environmental disturbance in the region play a great role in modifying future landscapes and even a greater impact on climate. Generally, the wet Holocene climate in Cherangani is punctuated by desiccation periods.

4.5 Summary of environmental conditions in Cherangani Hills from KAP-01

Table 3. Summary of environmental conditions in Cherangani Hills and other previous records from East Africa, modified from Opiyo et al., in review. The darker regions represent continued prevalent conditions.

Radiocarbon Age (^{14}C Yr BP)	Previous records from East Africa	Cherangani Hills (Kapkanyar mire)
1000	Warm & Dry	Increased grazing activities/Fires
2000		
3000		
4000		
5000		
6000	Warm & Moist	
7000		
8000		
9000		
10000	Low lake levels	Drought episode
11000		
12000	Low lake levels	Sandy sediment deposits
13000		
14000		
15000	Low lake levels (15-17 Kyrs)	
16000		Drier conditions with little moisture
17000	Cool & Dry	
18000		Cool & Dry with intermittent moist conditions
19000		
20000		
21000		
22000		
23000		

Table 4. Comparison of Cherangani Hills anthropogenic activities and environmental conditions with other previous records from East Africa over the past 5 Kyrs. The darker regions represent continued prevalent conditions.

Radiocarbon Age (^{14}C Yr BP)	Lake Naivasha	Chew Bahir Basin, Ethiopia	Amboseli	Lake Kifuruka	Lake Victoria	Cherangani Hills (Kapkanyar mire)
			Anthropogenic activities at 300 cal Yr BP Increased herbivores /Increased local fires at 400 cal Yr BP)			Evidence of increased anthropogenic activities/Drier conditions
500				Evidence of fires (600 cal Yr BP)		
1000					Evidence of drought/anthropogenic impact on the lake (2500-650 cal Yr BP)	Evidence of drought/grazing activities
1500	Evidence of farming (1650 AD)					Increased fires
2000		Evidence of human settlement (hunting & gathering)			Anthropogenic impact on the lake (2000 cal Yr BP)	Increased grazing activities/Increased local fires/Anthropogenic activities
3000						
						Increased regional fires/ Desiccation period
4000				Drought (4300 cal Yr BP)		
5000		Wet environment	Semi-Arid			Evidence of increasing herbivores

5 Summary of Findings, and Suggestions for further investigation

This study presents ~23 Kyrs paleoenvironmental record from well preserved, undisturbed core sediments from Kapkanyar Swamp, Cherangani Hills. The fungal spores, microscopic charcoal, elemental geochemistry, and LOI data provide insights into timings of climate variability from the LGM to the present. The fungal assemblages represent taxa from the single cell to double cell to multi-cell wall fungal spores. This diversity has been associated with paleoenvironmental and paleoclimatic variability in the region. These indicators of the paleoenvironmental change suggest a landscape modified largely by natural climatic regimes in the LGM to Mid-Holocene and both natural and anthropogenic impacts in the late Holocene. The variability in abundance and diversity of fungi from the LGM to the Holocene period suggests a transition from dry to mesic environmental conditions and increased anthropogenic influence.

The LGM aridity is followed by a more humid Holocene period to the present, however, frequented by droughts. The paleoenvironmental conditions in the LGM are a factor of natural climatic regimes while in the Holocene it's a factor of both natural and anthropogenic impacts. The record also shows progressive occurrence and increase in fire frequency from the LGM to the present. Increased coprophilous fungal spores, diversity of spores and fires from ~4 Kyrs could have been established due to a more heterogeneous landscape as a result of increased anthropogenic impacts. Drier conditions become more prominent in the past ~2 Kyrs to the present succeeded by mesic paleoclimatic conditions. Evidences of increased human activities in the last 2 Kyrs have peaked and greatly modified the paleoenvironment. Due to this the paleoclimatic conditions have tended towards drier periods and this has in turn impacted Cherangani Hills present environment.

Although this study generated a high-resolution reconstruction of the paleoenvironment it was limited by few factors such as corrosion of some fungi during preparation which made identification to be an arduous task. There is need for more high-temporal resolution data from the region to affirm the findings of this study. A good candidate for such study is the nearby Saiwa swamp that has already been cored. The cores from Saiwa Swamp are relatively short and will yield a better control and understanding of how anthropogenic activities have modified East African landscapes during the late Holocene period. High-resolution data with reliable dates should be applied in developing and understanding how both natural and anthropogenic processes modify landscapes. Acquisition of archaeological or paleontological data from the East African region would corroborate the anthropogenic imprints over the last 4 Kyrs.

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APPENDIX

Depth (cm)	Min (Yrs)	Max (Yrs)	Median (Yrs)	Mean (Yrs)
30	14.2	255.6	89.8	109.5
31	32.7	307.2	124.3	143.3
32	43.2	377	156	177.1
33	50	463.3	187	210.3
34	55.4	551	218.6	243.1
35	59.3	645.4	247	276.1
36	85.9	685.9	283.5	310.6
37	101.6	734.6	320.9	345.1
38	113.5	786.4	354.2	379.8
39	123.4	844.4	387.3	414.3
40	130.6	913.9	419.9	448.5
41	161.5	951.8	452.9	483.1
42	183.1	998.3	486.1	517.6
43	201.5	1041.7	519.5	552.2
44	215.8	1101.4	552.5	586.7
45	225.2	1165.7	583.3	621.1
46	257.6	1198.2	620.7	655.6
47	280.3	1239.2	658.9	689.8
48	297.3	1289.4	693.7	723.8
49	312.8	1341.9	727.4	758.1
50	323.3	1394	759.3	791.3
51	363.1	1427.2	796.5	827.1
52	386.4	1468.9	834.6	863
53	405.1	1519.6	869.9	898.8
54	422.9	1566.4	905.6	934.7
55	440.1	1618.8	941.3	970.5
56	470.3	1648	976.1	1004.1
57	498	1680.1	1011.5	1037.6
58	521.7	1722.5	1044.9	1071.3
59	541.4	1768.7	1079	1104.6
60	555.9	1812.5	1111.1	1138.1
61	587.1	1844.3	1146.7	1173.7
62	616.4	1878.7	1186	1208.8
63	643	1916.4	1221.1	1244.4
64	665	1971.1	1259.1	1280
65	684.4	2024.1	1294.1	1315.4
66	724.7	2051.9	1331.2	1349.1
67	753	2085.7	1365.1	1383.3
68	781	2130.3	1399.7	1417.1

69	800.2	2176.3	1432.3	1451
70	819.1	2227.4	1465.5	1484.7
71	863	2250.4	1496.7	1520
72	892	2284.6	1531.2	1554.7
73	921.6	2320.5	1569.2	1589.5
74	945.6	2363.2	1604	1624.6
75	967.4	2407.1	1641	1659.5
76	1001.5	2440.1	1676.1	1694.5
77	1030.1	2469.1	1712	1729.7
78	1062.6	2506.5	1749.8	1765.3
79	1086.6	2563.4	1787.6	1800
80	1108.7	2610.2	1822.3	1835.2
81	1149.4	2642.1	1855.9	1868.6
82	1184	2670.9	1889.2	1902.6
83	1213.8	2696	1921.3	1935.9
84	1247.8	2735	1954.9	1969.8
85	1273.4	2781.2	1990.4	2003.2
86	1312.2	2809.5	2024.3	2038.9
87	1349.4	2838.3	2060.8	2074.4
88	1378.4	2873.9	2094.2	2109.6
89	1407.8	2912.8	2128.9	2145
90	1435.9	2958.1	2165.2	2180.9
91	1471	2985.9	2200.4	2216.2
92	1504.3	3015.3	2235.7	2251
93	1544.3	3041.8	2272.3	2285.9
94	1565.3	3087	2308.7	2320.7
95	1586.5	3137.8	2342.6	2355.6
96	1630.3	3162.7	2379	2390.5
97	1660.2	3195.8	2415.5	2424.8
98	1690.1	3233.5	2450.5	2459.7
99	1718.3	3268.3	2484.6	2494.3
100	1744.4	3298.8	2517.6	2528.2
101	1784.6	3330.1	2553.8	2562.5
102	1815.8	3357.9	2586.5	2597
103	1849.7	3391.3	2620.3	2630.8
104	1878.8	3435	2653.7	2665.3
105	1905.3	3476.2	2685.9	2698.7
106	1942.4	3497.5	2723.4	2734.1
107	1977.9	3532.6	2760.6	2769
108	2010.8	3567.5	2797.8	2804.1
109	2038.7	3603.7	2832.5	2839.1
110	2061.5	3638.3	2869.1	2873.9
111	2102.9	3670.8	2906.9	2910.1

112	2141.4	3701.7	2942	2945.9
113	2172.1	3736.8	2978	2981.3
114	2199.6	3781.1	3015.5	3017.6
115	2222.9	3818.5	3051.5	3053.9
116	2262.1	3842.7	3089.9	3089.3
117	2306.2	3876.4	3129.4	3125.2
118	2350	3908.2	3163.7	3160.6
119	2385.4	3946.4	3200.4	3196.4
120	2412	3985.1	3236.7	3231.9
121	2455.3	4008.6	3271.2	3268.1
122	2499.9	4035	3303.6	3303.7
123	2539.2	4063	3342.2	3338.4
124	2572.5	4105.6	3377.3	3374.9
125	2604.5	4143.1	3414.6	3410.3
126	2649.2	4172.4	3450.2	3446
127	2693.7	4200.5	3485.8	3481.3
128	2732.7	4233.4	3520.9	3516.1
129	2766.6	4265.5	3556	3551.5
130	2797.9	4308.3	3589.8	3586.1
131	2857.7	4328.1	3626.5	3622.6
132	2897.5	4353.5	3662	3657.5
133	2936	4380.3	3699.9	3692.6
134	2968.3	4412.7	3733.4	3727.7
135	2990.2	4442.9	3770	3762.5
136	3040.8	4464.1	3801.8	3797.2
137	3075.9	4491.2	3834.8	3832.1
138	3117.4	4523.1	3871.5	3867
139	3152.1	4553.5	3901.2	3900.8
140	3177.9	4591.1	3937.8	3935.5
141	3241.1	4613.3	3976.2	3971.8
142	3288	4639.1	4015.9	4008.3
143	3329.9	4670.3	4052.3	4044
144	3360.5	4706.6	4092	4080.9
145	3386.8	4744.4	4128.7	4116.2
146	3439.1	4770.7	4164.3	4152.5
147	3482.1	4790	4199.4	4188.1
148	3515.8	4821.1	4238.6	4224.1
149	3547.9	4857.4	4275.8	4260.4
150	3579.7	4893.2	4308.8	4296
151	3627.1	4912.5	4342.4	4330.2
152	3674.1	4933.7	4375.4	4364.4
153	3715.4	4959.4	4413.6	4398.6
154	3747.1	4981.5	4448.5	4431.8

155	3775.2	5016.8	4482.9	4465.8
156	3830.7	5038.1	4515.8	4499.4
157	3874.8	5059	4551	4534.8
158	3917.1	5083.8	4585.9	4570.1
159	3955.3	5112.7	4621.7	4605.4
160	3991.3	5150.7	4656.5	4640.8
161	4046.8	5170.5	4692.6	4675.9
162	4102.1	5188.2	4728.8	4711.4
163	4141.3	5211.5	4767.4	4746.9
164	4177.4	5238.3	4803.4	4782.5
165	4204.9	5271.9	4837.3	4817.2
166	4276.9	5286.1	4869.3	4851.2
167	4320.8	5302.8	4902.2	4885.2
168	4365.1	5324.1	4938.5	4919.3
169	4407.7	5350.5	4971.3	4953.4
170	4445	5380.4	5008	4987.9
171	4528.4	5396.7	5038.5	5023.5
172	4596.2	5411.5	5070.9	5059.3
173	4656.6	5429.4	5106.3	5095.2
174	4700	5452.9	5142.6	5131.1
175	4736.9	5480.8	5175.9	5166
176	4830.7	5492.6	5207.9	5200.9
177	4912.5	5509.4	5241.1	5235.9
178	4982.2	5532.6	5272.2	5270.2
179	5039.3	5563.1	5303.6	5305.4
180	5080.3	5603.3	5336.5	5341.2
181	5189.8	5751.2	5462.9	5467.8
182	5234	6062.4	5572.7	5593.9
183	5258.7	6411.2	5667.1	5716.9
184	5280.2	6756.1	5760.5	5839.5
185	5301	7124.7	5855.6	5961.8
186	5411.7	7304.6	6020.6	6122.9
187	5486.6	7547	6192.6	6283.9
188	5542.7	7818	6348.1	6443.4
189	5588	8165.4	6494.4	6603.6
190	5625.2	8552.1	6637.7	6763.2
191	5760.8	8648.8	6801.6	6922.1
192	5849.7	8808.4	6967.3	7078.9
193	5910.5	9030.6	7128.1	7235.3
194	5969	9278.4	7284.6	7392
195	6005.5	9605.2	7426.5	7548
196	6151.9	9741.3	7588.8	7704.3
197	6255.1	9887.2	7752.8	7860.2

198	6335.9	10080	7932.2	8017.5
199	6415.7	10338.9	8088.2	8174.2
200	6472.3	10573.8	8233.2	8327.4
201	6643.9	10706.7	8394.1	8484.9
202	6773.2	10865.2	8554	8640.4
203	6866.1	11087.9	8715.9	8797
204	6949.3	11291.5	8873.7	8951.4
205	7035.1	11500.7	9028.8	9107.6
206	7215.4	11608.8	9197.5	9275
207	7353.3	11760	9367.5	9443.2
208	7473.2	11988.8	9542.3	9613.1
209	7561.6	12234.2	9716.7	9781
210	7644.8	12482.6	9892	9947.6
211	7793.2	12588.9	10075.8	10115.1
212	7908.1	12761.7	10256.7	10282.9
213	8018.5	12943.6	10433.3	10449.9
214	8125.2	13118.2	10609.6	10615.8
215	8215.7	13329.6	10779.8	10779.5
216	8421.2	13447.7	10954.3	10939
217	8600.3	13537.5	11118.1	11099.8
218	8727.1	13660.1	11289.9	11264.2
219	8822.9	13807.3	11449	11428.9
220	8924	14035.4	11608	11591.1
221	9178.4	14138.9	11765.1	11753.2
222	9347.3	14272.7	11933.5	11913.6
223	9480.1	14430.2	12105.1	12075.6
224	9605.5	14607.1	12275.1	12239.7
225	9735.1	14815.4	12436.9	12399.7
226	9927.8	14909.2	12619.6	12569.2
227	10079.4	15013.6	12796.9	12739
228	10240.7	15166.2	12964.5	12907.3
229	10374	15305.9	13134.9	13077.5
230	10503.9	15483.4	13299.8	13245.9
231	10769.5	15569.9	13462.5	13412
232	10963.3	15668.9	13628.8	13577.9
233	11135.9	15801.3	13796	13747.8
234	11315.4	15968	13960	13916.5
235	11492.2	16141.2	14128.3	14083.9
236	11802.5	16226.8	14299.6	14258.6
237	12031.2	16321.7	14481.6	14432.7
238	12256.2	16417.8	14676	14606.2
239	12439.6	16515.1	14869.8	14777.6
240	12606.6	16696.1	15051.2	14950.4

241	12878.3	16752.4	15197.2	15107.3
242	13136.9	16821.8	15346.4	15265.1
243	13363.2	16906.5	15503.3	15423.8
244	13526.7	17023.3	15671.2	15583
245	13645.9	17168.8	15838.9	15742.5
246	13973.1	17219.2	15998.4	15903
247	14253.1	17267.9	16169.9	16066.4
248	14453.4	17338.3	16339.2	16230
249	14565.3	17419.1	16517.3	16394.3
250	14698.6	17556.1	16688.1	16557.8
251	15215.5	17585.2	16822.5	16723.1
252	15700.8	17616	16960.4	16888.1
253	16148	17664.2	17101.3	17053.5
254	16498	17726.3	17256.5	17225.5
255	16696.6	17842.6	17436.5	17398.3
256	16957.7	17881.2	17525.1	17504.1
257	17167.4	17938.2	17624.6	17611.1
258	17283.7	18036.1	17730.4	17719.4
259	17361.9	18258.3	17821.4	17828
260	17420.6	18550.8	17908.1	17936.7
261	17501.6	18618.1	17992.1	18017.3
262	17561.4	18712.9	18070.6	18097.7
263	17613.7	18847.5	18143	18176.9
264	17649.6	19002.7	18212.8	18254.8
265	17675.8	19171.9	18280	18331.1
266	17760.5	19231.1	18364.7	18409.8
267	17821.3	19317.9	18446.9	18488
268	17870.5	19414.8	18529.5	18566.8
269	17905.4	19527.4	18606.5	18646
270	17937.3	19662.4	18682.6	18725.1
271	18026.9	19719	18769.1	18807.5
272	18099.3	19796.7	18856	18890.4
273	18162.8	19881.8	18943.1	18971.8
274	18214.7	19998.2	19023.2	19053.2
275	18247.4	20132.8	19101	19135.3
276	18338.4	20184.2	19186.6	19215.5
277	18408.8	20237.9	19271.1	19296.2
278	18471.7	20306.9	19357.3	19376.2
279	18519.2	20388.5	19446.3	19457
280	18560.2	20495	19525.7	19537.1
281	18664.4	20547.5	19608.8	19616.7
282	18760.4	20603.9	19694	19697.1
283	18825.6	20680.3	19778.3	19777.5

284	18871.4	20767.3	19864.2	19858.4
285	18919.4	20872.6	19951	19938.6
286	19024.7	20916.8	20024.7	20017.3
287	19113.2	20963.2	20109.3	20095.5
288	19188.7	21020.4	20189.3	20173.4
289	19252.9	21088.5	20274.2	20252.1
290	19308.8	21175.1	20359.1	20330.9
291	19440.8	21205.7	20438.2	20409.9
292	19547.2	21244.1	20519.6	20490
293	19636.9	21292.7	20601	20570.5
294	19717.6	21352.1	20683.1	20650.8
295	19767.3	21428.5	20761.7	20730
296	19933.6	21450	20834.9	20808.7
297	20087.4	21479.4	20913.9	20890.5
298	20212.9	21524	20996.7	20972
299	20311.2	21567.2	21085.5	21054.2
300	20394.4	21649.4	21169.8	21135.8
301	20614.7	21671.9	21232.6	21214.2
302	20793.2	21703.4	21300.1	21293
303	20967.9	21743.7	21372.3	21372.7
304	21077.5	21804.9	21449.5	21452.8
305	21149.9	21894	21531	21533.4
306	21197.7	21946.2	21583	21586.5
307	21232.8	22014.5	21634.7	21639
308	21253.8	22111.8	21683.5	21692.3
309	21279.6	22234.1	21729	21744.1
310	21298.4	22355.9	21772.5	21796.1
311	21349.9	22401.8	21830.4	21850.8
312	21390.6	22460.5	21889.3	21904.6
313	21427.9	22536.4	21943.9	21958.8
314	21450.4	22623.6	21996.8	22012.5
315	21471.9	22727.7	22043.1	22063.5
316	21536.5	22771.6	22095.7	22116.8
317	21594.5	22808.7	22151.5	22170.4
318	21631.6	22862.3	22202	22222.7
319	21667.1	22934.3	22251.6	22274.8
320	21693	23023.7	22301.6	22326.8
321	21749.9	23065.4	22353.8	22379.2
322	21795.6	23110.9	22408.6	22432.4
323	21833.7	23162.3	22466.7	22485.5
324	21873	23227.6	22524.7	22540.2
325	21904.4	23308.1	22577.7	22593.8
326	21964.3	23340.2	22631.5	22646.2

327	22021.6	23384.7	22685.4	22699
328	22060.1	23438.4	22742.3	22752.2
329	22096.2	23509.1	22798.2	22805.3
330	22132	23583.7	22850.1	22858.5
331	22198.8	23615.2	22902.5	22909.2
332	22251.7	23649.5	22955.5	22960.2
333	22295.3	23695.5	23010.3	23011.6
334	22334.6	23748.6	23061.7	23063.3
335	22374.7	23810.3	23113.3	23114.9
336	22456.5	23842.8	23168.2	23168
337	22516.6	23878.3	23221.8	23221.4
338	22567.8	23916.5	23273.8	23274
339	22617.8	23970.2	23327.6	23327.2
340	22650	24035	23383.9	23380.4
341	22733	24065.7	23436.7	23434.5
342	22806.5	24089.2	23491.6	23488.1
343	22874.1	24125.6	23549	23541.7
344	22927.7	24171.7	23603.8	23595.3
345	22976.2	24226.5	23657.7	23649.6