



Influence of Indian Ocean Dipole on Drought Occurrence in Makueni County, Kenya

Jackob H. Ondiko, Amon M. Karanja, Humphreys W. Obulinji, Kennedy N. Ondimu

Department of Geography, Egerton University, Nakuru, Kenya

Email: ondikojackob2018@gmail.com

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Abstract

Increasing frequency, severity and duration of droughts in Arid and Semi-Arid Lands in Kenya in the past three decades is a major challenge to survival of agrarian livelihoods and food security in Makueni County. Increasing frequency and severity of droughts in the region are influenced by a number of factors. The Indian Ocean Dipole is the principal factor driving droughts in the lower Eastern region. The influence of the Indian Ocean Sea Surface Temperatures on occurrence of droughts in Makueni is exacerbated by a long coastal contact zone between East African coast and the Indian Ocean coastline. 80% of the Kenya landmass is under Arid and Semi-Arid zones. The study determined the influence of Indian Ocean Dipole on occurrence and nature of droughts in Makueni County, Kenya. The study adopted explanatory sequential mixed methods research design. Indian Ocean Sea Surface Temperature data and rainfall data were collected from the National Oceanic Atmospheric Administration website and Kenya Meteorological Department respectively. Linear regression model was used in data analysis. The study found that Indian Ocean Dipole has a significant influence on the occurrence of droughts in Makueni County. The study established that a reduction in the value of Indian Ocean Sea Surface Temperatures in Western Indian Ocean (10°S - 10°N, 50° - 70°E) and Eastern (tropical) Indian Ocean (10°S - 0°, 90° - 110°E) leads to a similar reduction in the amount of rainfall hence drought episodes in Makueni County. On the other hand, an increase in the value of Indian Ocean Sea Surface Temperatures leads to a similar increase in amount of rainfall in Makueni County. Variation in Indian Ocean Sea Surface Temperature resulted in erratic, unpredictable and fluctuating rainfall patterns accompanied by 5 mild and 20 near-normal drought episodes with multi-year droughts between 2003 and 2009. Increasing trend of seasonal droughts was also established due to declining March-April-May seasonal rainfall. An upward trend in October-November-December seasonal rainfall was also established. This study recommends studies on the influence

of anthropogenic forcing on drought occurrence in Arid and Semi-Arid Lands and other agroecological zones in Kenya.

Subject Areas

Natural Geography

Keywords

Indian Ocean Dipole, Sea Surface Temperature, Drought, ASALs

1. Introduction

Increased frequency, severity and duration of droughts have been recorded in different regions of the world [1]-[5]. Uncertain global drought trends accompanied by regional drought fluctuations led to 52 mega-droughts from 1951 to 2016 [6]. The droughts resulted in increased hectareage of arid lands and deserts. Droughts are a major concern globally where drought hotspots have been identified in Mid-West United States, a large part of the Eurasian belt which extends from Eastern Europe to Eastern Asia and equatorial Africa [7]. Increase in frequency, magnitude and duration of droughts is posing significant challenges to food production in Arid and Semi-Arid Lands (ASALs) globally.

Africa experienced increasing drought recurrence in the last century: 1910s, 1940s, 1960s, 1970s, 1980s, 1990s, 2000s and 2010s [8] [9]. Southern Africa recorded an increase in drought trend, frequency, and severity [10].

A number of severe droughts have been recorded in East Africa since the 1970s whereas Kenya recorded droughts in 1999/2000, 2005/2006, 2008/2009 2010, 2011, 2012 and 2016/2017 [11]-[14] reported that Kenya experienced a reduced drought return period from five to three years. Further, Assessment Capacities Project [15]-[20] established that droughts occurred in all the decades since 1900 with severe droughts being experienced in Kenya in the 1930s, 1940s, 1950s 1980s, 1990s and 2000s. The studies also indicated that the periodic droughts ranged from mild to severe; mostly affecting lowlands in North-eastern, Coast, Nyanza, and parts of North Rift Valley.

These droughts are linked to variations in Sea Surface Temperatures (SSTs) in the Indian Ocean [21]-[24] established that the Equatorial Western Indian Ocean (EWIO) heated up more rapidly than the rest of the tropical oceans in the 20th Century, hence a major factor in the rise of global SSTs mean. In addition, [25] reported rapid warming from the 1960s thereby increasing SSTs up to 1.2°C in the EWIO leading to several extreme phenomena including droughts and floods.

The location of Kenya along the equator and a long coastline of the Indian Ocean, vast low-altitude areas and widespread ASALs covering 80% of the surface area; make the country significantly vulnerable to frequent droughts. Even

though IOD was associated with droughts along the East African coast [26], there is limited information on the magnitude of association of IOD with frequent drought events in Makueni County. This study sought to establish the influence of IOD on the occurrence of drought which poses a significant challenge to agrarian livelihoods and food security in Makueni County. IOD is the principal driver of droughts around the Indian Ocean and the East African region [27].

[28] linked the Indian Ocean SSTs to droughts of 2000, 2009, and 2011 in East Africa. Meanwhile, the warming SSTs in the Indian Ocean decrease precipitation in East Africa [29]. The study also pointed out the spatial diversity and complexity in nature and characteristics of IOD as a result of varied internal processes in the Indian Ocean thereby making IOD modelling a major challenge.

The spatiotemporal rainfall distribution and patterns in Kenya are influenced by Indian Ocean SSTs where IOD is linked to droughts [29]. The study also attributed the SSTs variability along the coast of Kenya to the abundance of ocean water and topography. Moreover, [30] established that the Indian Ocean SSTs were associated with MAM and OND seasonal rainfall covariance in Kenya. Notably, variation in SSTs influences sea surface winds (circulations) and the thermocline temperatures which influence atmospheric temperatures of surrounding areas.

Variation in Indian Ocean SSTs influence wind patterns in East Africa where [31] [32] established that strong South-easterly winds originating from the South-western parts of the Indian Ocean or Western Indian Ocean (WIO) are significantly influenced by seasonal monsoon winds over the Indian Ocean. The winds are oceanic in nature and blow over the area resulting in the accumulation of water vapour in the atmosphere hence forming cumulous clouds. [32] also revealed that the winds had a continental trajectory and were arid in nature during the dry periods and years. On the other hand, a maritime trajectory was exhibited by winds during wet seasons and years. These maritime winds were characterized by high moisture content over land. Further, the study noted that Southeastern Kenya predominantly experiences cumulous clouds over the wet season in OND. The cumulous clouds are caused by strong South-easterly winds. The study also found that cumulonimbus clouds were common in the region during a typically wet season in OND. Variation in types of clouds and humidity levels are influenced by variation in SSTs in the Indian Ocean.

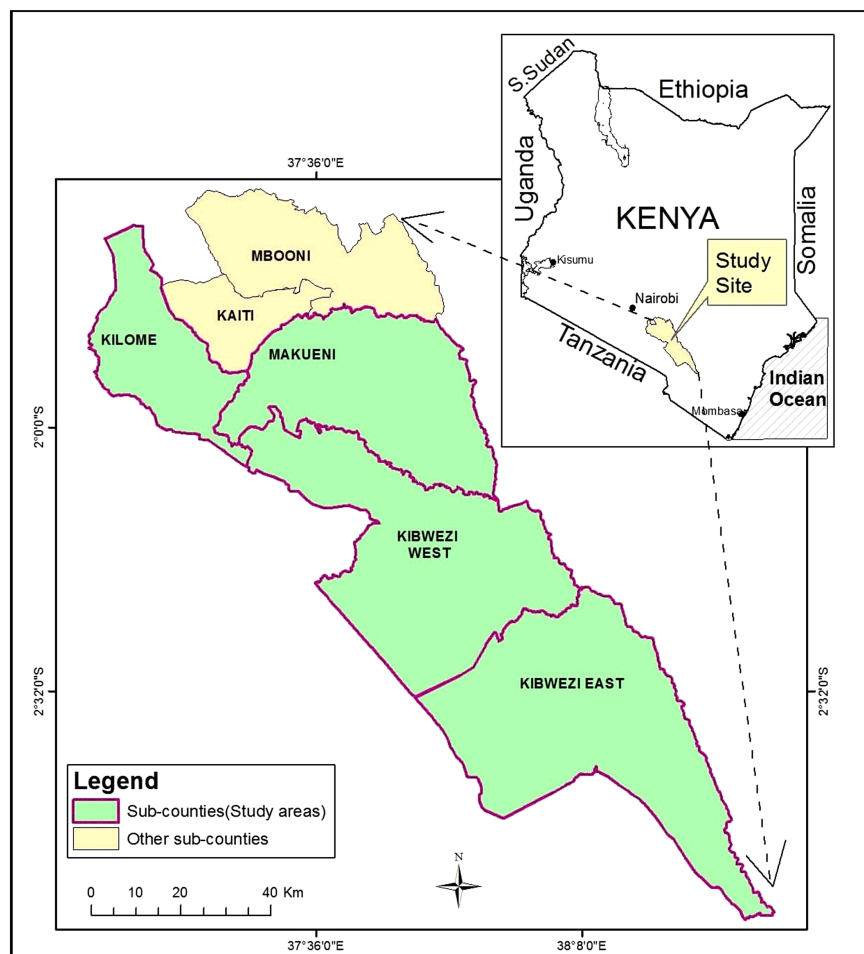
Even though the Government of Kenya (GoK) established the National Drought Management Authority (NDMA) [33], the National Climate Change Response Strategy (NCCRS), 2010 [34] and the Climate Change Act, 2016 [35], the influence of IOD on occurrence of the frequent droughts in the region was still inadequately addressed. Therefore, establishing the influence of IOD on occurrence of drought in Makueni County enables the achievement of the objectives of GoK on improving drought resilience and adaptive capacity to improve agrarian livelihoods, hence improvement in food security in the country. In addition, information and data

from this study can be used in drought adaptation policy formulation, data-driven decision-making, drought adaptive capacity building, and effective adaptation to drought to improve cereal yields hence food security in Kenya.

2. Materials and Methods

Study Area

This study was conducted in Makueni County, located 200 kilometres Southeast of Nairobi city, Kenya. The County is located between latitudes $1^{\circ}35'$ and $3^{\circ}00'S$ and between longitudes $37^{\circ}10'$ and $38^{\circ}30'E$ (**Figure 1**). The County is bordered by Machakos County to the North, Kitui County to the Northeast and East, Kajiado County to the West and Southwest, and Taita Taveta County to the South. Makueni County has a surface area of 8177 km^2 [36]. The County has six Sub-Counties namely: Mbooni, Kilome, Kaiti, Makueni, Kibwezi West, and Kibwezi East (County Government of Makueni [37]). The sample study sites were Kibwezi West sub-county, Kibwezi East sub-county, Makueni sub-county and Kilome sub-county. The various regions of Makueni County experience



Source: [42].

Figure 1. Map of the study area showing the study sites.

similar agroecological conditions [38]. The county experiences high temperatures with a mean of between 23°C (C) to 27°C [39]. Further, the lowlands experience higher temperatures of up to 35.8°C [40]. High temperatures in the lowlands of Makueni County result in hot climatic conditions and increased evaporation thereby increasing aridity while increasing water vapour in the atmosphere [41]. Indian Ocean SST data were obtained from the National Oceanic Atmospheric Administration (NOAA) Website for Western Indian Ocean (10°S - 10°N, 50° - 70°E), Block A and Eastern (tropical) Indian Ocean (10°S - 0°, 90° - 110°E), Block B. Annual rainfall data were collected from four Kenya Meteorological Department stations, including: Salama Meteorological Station in Kilome sub-County, Makindu Meteorological station in Kibwezi West sub-County, Makueni sub-County and Dwa Sisal Estate Meteorological Station in Kibwezi East sub-County. Regression analysis was done using the mean annual SSTs data from Blocks A and B in the Indian Ocean and mean annual rainfall data from Makueni County for the period 1990 to 2020.

3. Results and Discussion

3.1. Influence of Indian Ocean Dipole on Drought Occurrence in Makueni County

This study established that IOD SSTs have a significant influence on the occurrence of droughts in Makueni County. The results indicate that a reduction in the value of SSTs in Blocks A and B in the Indian Ocean leads to a similar reduction in the amount of rainfall received in Makueni County. On the other hand, an increase in the value of SSTs leads to a similar increase in amount of rainfall in Makueni County. Therefore, increasing SSTs in the Indian Ocean results in increased rainfall amounts and events while a reduction in the SSTs results in deficit or low amount of rainfall which may be accompanied by drought events in Makueni County. This study found that low SSTs resulted in droughts in 1996, 2000 and 2004 (**Figure 2**). On the other hand, high SSTs in the Indian Ocean resulted in higher-than-normal amounts of rainfalls in 1998 which was marked as an El Nino event. Further, higher than normal SSTs in the Indian Ocean resulted in higher rainfall amounts in 2010, 2015 and 2016.

The results of this study concur with those of studies conducted in East Africa and the Western Indian Ocean by [43] [44] which established that IOD is the principal driver of precipitation hence droughts and climate variability over the Indian Ocean and the East African region. [45] established IOD-related weak warming in the Western Indian Ocean during positive IOD events. There was a gradual development of IOD is caused by stochastic forcing such as weather noise, internal feedback processes and external drivers thereby resulting in warming conditions in the East African region [46]. Further, the results of this study agree with those of a study which was conducted by [47] which found that IOD influenced the frequency and trends of drought in the Indian Ocean and East Africa in the past few decades. In addition, it was established that 50% and

65% of MAM and OND seasonal rainfalls were linked to the variation in Indian Ocean SSTs [48]. [49] also argued that the short rains in the OND season are projected to experience more rainfall compared to the projected depressed rainfall conditions in MAM. The study also revealed that IOD significantly influences occurrence, magnitude and duration of rainfall hence droughts in East Africa.

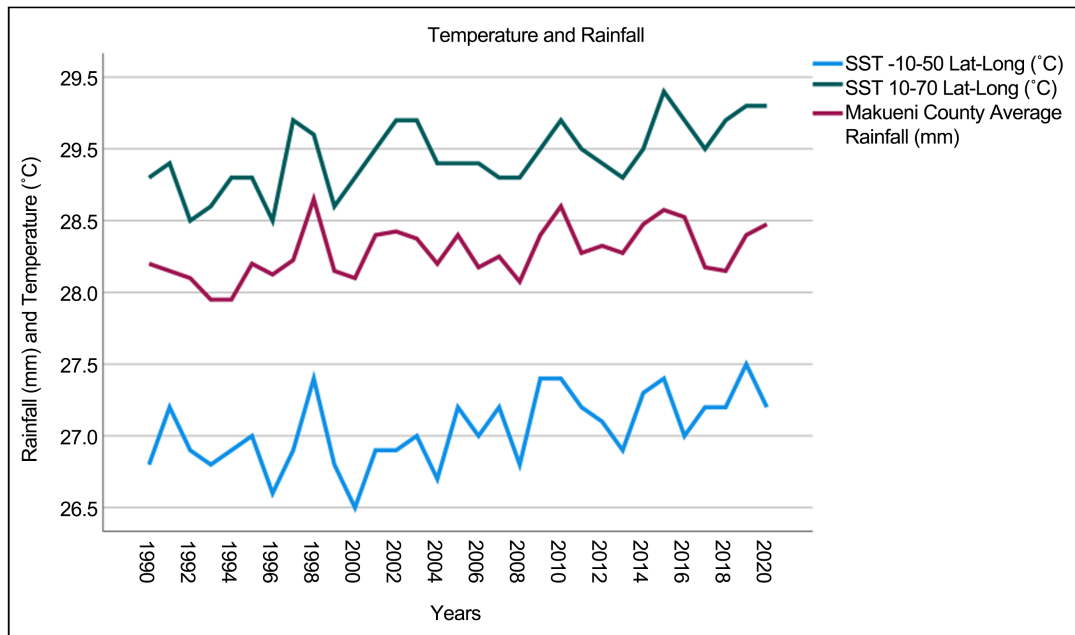


Figure 2. Influence of IOD on Drought occurrence in Makueni County.

3.2. Drought Trends in Makueni County

This study established 20 episodes of near-normal droughts (-0.99 to 0.99) while 5 mild droughts (-1.00 to -1.49) on the SPI, were experienced in Makueni County between 1990 and 2020. Mild droughts occurred in 1992, 1996, 2000, 2005 and 2012. Further, near-normal droughts occurred annually from 1992 to 1996, 1999 to 2002, 2007 to 2008, and 2011 to 2016. Furthermore, multi-year droughts occurred from 2003 to 2005 and from 2007 to 2009. This study revealed fluctuations in amount of rainfall from 1990 to 2000 whereby a significantly high amount of rainfall was recorded in 1998 indicated by high rainfall in both MAM and OND seasons which were associated with El Niño event. In addition, there were fluctuations in amount of rainfall received between 2008 and 2017. Rainfall amounts also indicate an increasing trend from 2018 to 2019 then a declining trend was experienced in 2020.

The results of this study mirror those of a study conducted by [50] which established that drought events were fewer in Southwest China before the 1930s. [51] also established that droughts accounted for 6% of total disasters globally where 7% of all economic losses were linked to the phenomenon. The study also established a high frequency of droughts in South Africa that were indicated by a

three to five-year return period between 1980 to 2007. The results of this study also agree with those of a study conducted in China by [52] which found that frequency of drought events increased after 1930 whereby severe droughts were experienced between 1936 to 1937. In addition, South Western China experienced more severe droughts in 1962, 1963, 1967, 1987, 2009 and 2010. The severity of the 2009 and 2010 droughts had not been felt in the 120 years under study. [53] also revealed that frequent and prolonged severe droughts were common in North Africa which caused significant socioeconomic impacts and changes in land use in the region where 70% of the land surface area is desert.

4. Conclusions and Recommendations

Indian Ocean Dipole has a significant influence on the occurrence of droughts in Makueni County. A reduction in the value of Indian Ocean Sea Surface Temperatures in both Western and Eastern Indian Ocean leads to a similar reduction in the amount of rainfall hence drought episodes in Makueni County. The positive IOD-drought relationship is a major concern to GoK due to increasing drought events which influence cereal production negatively despite the need for more cereal produce. On the other hand, an increase in the value of Indian Ocean Sea Surface Temperatures leads to a similar increase in amount of rainfall in Makueni County. Variation in Indian Ocean Sea Surface Temperatures resulted in erratic, unpredictable and fluctuating rainfall patterns accompanied by 5 mild and 20 near-normal drought episodes with multi-year droughts between 2003 and 2005 and 2007 and 2009. There was an increasing trend of seasonal droughts due to declining March-April-May seasonal rainfall signifying negative influence on cereal production conditions hence low yields and food insecurity. There was an upward trend in October-November-December seasonal rainfall signifying increased cereal production opportunity in the study area during the season. This study recommends a study on influence of anthropogenic forcing on drought occurrence in Kenya.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Han, X., Li, Y., Yu, W. and Feng, L. (2022) Attribution of the Extreme Drought in the Horn of Africa during Short-Rains of 2016 and Long-Rains of 2017. *Water*, **14**, Article 409. <https://doi.org/10.3390/w14030409>
- [2] Kew, S.F., Philip, S.Y., Hauser, M., Hobbins, M., Wanders, N., Van Oldenborgh, G.J., Van der Wiel, K., Veldkamp, T.I.E., Kimutai, J., Funk, C. and Otto, F.E.L. (2019) Impact of Precipitation and Increasing Temperatures on Drought in Eastern Africa. *Earth System Dynamics*, 1-29
- [3] Leeper, R.D., Bilotta, R., Petersen, B., Stiles, C.J., Heim, R., Fuchs, B., Prat, O.P., Pa-lecki, M. and Ansari, S. (2022) Characterizing U.S. Drought over the Past 20 Years Using the U.S. Drought Monitor. *International Journal of Climatology*, **42**,

- 6616-6630. <https://doi.org/10.1002/joc.7653>
- [4] Wahl, E.R., Zorita, E., Diaz, H.F. and Hoell, A. (2022) Southwestern United States Drought of the 21st Century Presages Drier Conditions into the Future. *Communications Earth & Environment*, **3**, Article No. 202. <https://doi.org/10.1038/s43247-022-00532-4>
- [5] Xue, Z.Y. and Ullrich, P.A. (2022). Changing Trends in Drought Patterns over the Northeastern United States Using Multiple Large Ensemble Datasets. *Journal of Climate*, **35**, 7413-7433. <https://doi.org/10.1175/JCLI-D-21-0810.1>
- [6] Spinoni, J., Barbore, P., Jager, A., McCormick, N., Naumann, G., Vogt, J.V., Magni, D., Masante, D. and Mazzeschi, M. (2019) A New Global Database of Meteorological Drought Events from 1951 to 2016. *Journal of Hydrology: Regional Studies*, **22**, Article 100593. <https://doi.org/10.1016/j.ejrh.2019.100593>
- [7] Reho, J., Trnka, M., Brázdil, R., Fischer, M., Balek, J., Van der Schrier, G. and Feng, S. (2024) Global Hotspots in Soil Moisture-based Drought Trends. *Environmental Research Letters*, **19**, Article 014021. <https://doi.org/10.1088/1748-9326/ad0f01>
- [8] Funk, C., Fink, A.H., Harrison, L., Segele, Z., Endris, H.S., Galu, G., Korecha, D. and Nicholson, S. (2023) Frequent but Predictable Droughts in East Africa Driven by a Walker Circulation Intensification. *Earth's Future*, **11**, e2022EF003454. <https://doi.org/10.1029/2022EF003454>
- [9] Gbegbelegbe, S., Chikoye, D., Alene, A., Kyei-Boahen, S. and Chigeza, G. (2024) Strategic Foresight Analysis of Droughts in Southern Africa and Implications for Food Security. *Frontiers in Sustainable Food Systems*, **7**, Article 1159901. <https://doi.org/10.3389/fsufs.2023.1159901>
- [10] Ruwanza, S., Thondhlana, G. and Falayi, M. (2022) Research Progress and Conceptual Insights on Drought Impacts and Responses among Smallholder Farmers in South Africa: A Review. *Land*, **11**, Article 159. <https://doi.org/10.3390/land11020159>
- [11] GoK (2018) National Climate Change Action Plan (Kenya) 2018-2022.
- [12] Haile, G., Tang, Q., Sun, S., Huang, Z., Zhang, X. and Liu, X. (2019) Droughts in East Africa: Causes, Impacts and Resilience. *Earth-Science Reviews*, **193**, 146-161. <https://doi.org/10.1016/j.earscirev.2019.04.015>
- [13] Nicholson, S.E. (2014) A Detailed look at the Recent Drought Situation in the Greater Horn of Africa. *Journal of Arid Environments*, **103**, 71-79. <https://doi.org/10.1016/j.jaridenv.2013.12.003>
- [14] Ondiko, J.H. and Karanja, A.M. (2021). Spatial and Temporal Occurrence and Effects of Droughts on Crop Yields in Kenya. *Open Access Library Journal*, **8**, e7354. <https://doi.org/10.4236/oalib.1107354>
- [15] ACAPS (2022) Impact of Drought on the Arid and Semi-Arid Regions: Kenya. Thematic Report.
- [16] Lam, R., Sanchez-Gonzalez, *et al.* (2023) Learning Skillful Medium-Range Global Projection. *Science*, **382**, 1416-1421. <https://doi.org/10.1126/science.adi2336>
- [17] Mutua, L.N., Omuterema, S. and Gweyi, J.O. (2016) Evaluation of the Nature of Drought Experienced in Makueni County, Kenya. *Research on Humanities and Social Sciences*, **6**, 2224-5766.
- [18] NEMA-Kenya (2019) Makueni Climate Resilience and Food Security Project.
- [19] Nyangena, J. (2020) Assessment of Meteorological Drought in Main Climatic Zones

of Kenya.

- [20] Venton, C. (2018) Economics of Resilience to Drought: Kenya Analysis.
- [21] Funk, C., Harrison, L., Shukla, S., Pomposi, C., Galu, G., Korecha, D., Husak, G., Magadzire, T., Davenport, F., Hillbruner, C., Eilerts, G., Zaitchik, B. and Verdin, J. (2018) Examining the Role of Unusually Warm Indo-Pacific Sea-Surface Temperatures in Recent African Droughts. *Advances in Remote Sensing of Rainfall and Snowfall. Quarterly Journal of the Royal Meteorological Society*, **144**, 360-383. <https://doi.org/10.1002/qj.3266>
- [22] McKenna, S., Santoso, A., Gupta, A.S., Taschetto, A.S. and Cali, W. (2020) Indian Ocean Dipole in CMIP5 and CIMP6: Characteristics, Biases and Links to ENSO. *Scientific Reports*, **10**, Article 11500. <https://doi.org/10.1038/s41598-020-68268-9>
- [23] Tierney, J.E., Abram, N.J., Anchukaitis, K.J., Evans, M.N., Giry, C., Kilbourne, K.H., Saenger, C.P., Wu, H.C. and Zinke, J. (2015) Tropical Sea Surface Temperatures for the Past Four Centuries Reconstructed from Coral Archives. *Paleoceanography*, **30**, 226-252. <https://doi.org/10.1002/2014PA002717>
- [24] Pfeiffer, M., Zinke, J., Dullo, W.-C., Garbe-Schönberg, D., Latif, M. and Weber, M.E. (2017) Indian Ocean Corals Reveal Crucial Role of World War II bias for Twentieth Century Warming Estimates. *Scientific Reports*, **7**, Article 14434. <https://doi.org/10.1038/s41598-017-14352-6>
- [25] Zinke, J., Reuning, L., Pfeiffer, M., Wassenburg, J.A., Hardman, E., Jhangeer-Khan, R., Davies, G.R., Curtise, K.C. and Kroon, D. (2016) A Sea Surface Temperature Reconstruction for the Southern Indian Ocean Trade Wind Belt from Corals in Rodrigues Island. (19°S, 63°E). *Biogeosciences*, **13**, 5827-5847. <https://doi.org/10.5194/bg-13-5827-2016>
- [26] Sagero, P.O., Shisanya, C.A. and Makokha, G.L. (2018) Investigation of Rainfall Variability over Kenya (1950-2012). *Journal of Environmental and Agricultural Sciences*, **14**, 1-15.
- [27] Ratna, S.B., Cherchi, A., Osborn, T.J., Joshi, M. and Uppara, U. (2021) The Extreme Positive Indian Ocean Dipole of 2019 and Associated Indian Summer Monsoon Rainfall Response. *Geophysical Research Letters*, **48**, e2020GL091497. <https://doi.org/10.1029/2020GL091497>
- [28] Funk, C., Hoell, A., Shukla, S., Bladé, I., Liebmann, B., Roberts, J.B., Robertson, F.R. and Husak, G. (2014) Predicting East African Spring Droughts Using Pacific and Indian Ocean Sea Surface Temperature Indices. *Hydrology and Earth System Sciences*, **18**, 4965-4978. <https://doi.org/10.5194/hess-18-4965-2014>
- [29] Uhe, P., Sjoukje, P., Kew, S., Kasturi, S., Kimutai, J., Mwangi, E., Oldenborgh, G., Singh, R., Arrighi, J., Jjemba, E., Cullend, H. and Otto, F. (2018) Attributing Drivers of the 2016 Kenyan Drought. *International Journal of Climatology*, **38**, e554-e568. <https://doi.org/10.1002/joc.5389>
- [30] Toreti, A., Bavera, D., *et al.* (2022) Drought in East Africa August 2022, Publications Office of the European Union, Luxembourg, 2022.
- [31] Ndiwa, N.J. (2012) Assessment of the Potential of Enhancing Rainfall through Weather Modification in Kenya. Master's Dissertation, University of Nairobi. <http://erepository.uonbi.ac.ke/handle/11295/7391>
- [32] Nying'uro, P., Kimutai, J., Kiptum, C., Ogutu, G., Kimani, S., Okelo, P., Gikungu, D., Thiong'o, K. and Adegü, D. (2022) State of the Climate: Kenya.
- [33] GoK (2020) National Drought Management Authority Act, 2016. Kenya Law.

- [34] GoK (2010) National Climate Change Response Strategy.
- [35] GoK (2017) The Climate Change Act, 2016.
- [36] KNBS (2019) 2019 Kenya Population and Housing Census.
- [37] CGoM (2023) Makueni County Integrated Development Plan (CIDP) 2023-2027. Theme: A Resilient Economy for Sustainable Development.
- [38] Kitinya, T.K., Onwonga, R.N., Onyango, C., Mbuvi, J.P. and Kironchi, G. (2012) Climate Change and Variability: Farmers' Perception, Experience and Adaptation Strategies in Makueni County, Kenya. *Asian Journal of Agriculture and Rural Development*, **2**, 411-421.
- [39] Amukono, C.L. (2016) Agroclimatic Characterization of Makueni County Using Rainfall Data. Bachelor's Degree, University of Nairobi.
<https://meteorology.uonbi.ac.ke/sites/default/files/cbps/sps/meteorology/Amukono.pdf>
- [40] GoK (2013) Makueni County First County Integrated Development Plan 2013-2017.
- [41] GoK (2014) Makueni County Annual Development Plan, 2013-2014.
- [42] Independent Electoral and Boundaries Commission (IEBC) (2013) Digitized Map from IEBC Shapefiles.
- [43] An, S., Park, H.-J., Kim, S.-K., Cai, W., Santoso, A., Kim, D. and Kug, J.-S. (2023) Main Drivers of Indian Ocean Dipole Asymmetry Revealed by a Simple IOD Model. *npj Climate and Atmospheric Science*, **6**, Article No. 93.
<https://doi.org/10.1038/s41612-023-00422-2>
- [44] Palmer, P.I., Wainwright, C.M., Dong, B., Maidment, R.I., Wheeler, K.G., Gedney, N., Hickman, J.E., Madani, N., Folwell, S.S., Abdo, G., Allan, R.P., Black, E.C.L., Feng, L., Gudoshava, M., Haines, K., Huntingford, C., Kilavi, M., Lunt, M.F., Shaaban, A. and Turner, A.G. (2023). Drivers and impacts of Eastern African Rainfall Variability. *Nature Reviews Earth & Environment*, **4**, 254-270.
<https://doi.org/10.1038/s43017-023-00397-x>
- [45] Liu, B., Yang, K., Liu, X., Huang, G. and Ng, B. (2023) Improved Indian Ocean Dipole Seasonal Prediction in the New Generation of CMA Prediction System. *Geoscience Letters*, **10**, Article No. 60.
<https://doi.org/10.1186/s40562-023-00315-5>
- [46] Stuecker, M.F., Timmermann, A., Jin, F.-F., Chikamoto, Y., Zhang, W., Wittenberg, A.T., Widiasih, E. and Zhao, S. (2017) Revisiting ENSO/Indian Ocean Dipole Phase Relationships. *Geophysical Research Letters*, **44**, 2481-2492.
<https://doi.org/10.1002/2016GL072308>
- [47] Koesuma, S., Andriani, R.D. and Legowo, B. (2021) Analyzing of the Indian Ocean Dipole (IOD) Phenomena in Relation to Climate Change in Indonesia: A Review. *Journal of Physics: Conference Series*, **1918**, Article 022030.
<https://doi.org/10.1088/1742-6596/1918/2/022030>
- [48] Omondi, P., Ogallo, L.A., Anyah, R., Muthama, J.M. and Ininda, J. (2013) Linkages between Global Sea Surface Temperatures and Decadal Rainfall Variability over Eastern Africa region. *International Journal of Climatology*, **33**, 2082-2104.
<https://doi.org/10.1002/joc.3578>
- [49] Kotikot, S.M., Smithwick, E.A.H. and Greatrex, H. (2024) Observations of Enhanced Rainfall Variability in Kenya, East Africa. *Scientific Reports*, **14**, Article 12915.
<https://doi.org/10.1038/s41598-024-63786-2>
- [50] Wang, L., Wang, W.J., Du, H., Shen, X., Wu, Z., Ma, S., Liu, Z. and Jiang, M. (2022)

Was Warming Amplified Under Drought Conditions Across China in Observations and Future Projections? *Earth's Future*, **10**, e2021EF002614.

<https://doi.org/10.1029/2021EF002614>

- [51] Chivangulula, F.M., Amraoui, M. and Pereira, M.G. (2023). The Drought Regime in Southern Africa: A Systematic Review. *Climate*, **11**, Article 147.

<https://doi.org/10.3390/cli11070147>

- [52] Wang, Y., Wang, Y., Chen, Y., Chen, H., Li, X., Ding, Z., Han, X. and Tang, X. (2023) Spatial and Temporal Characteristics of Drought Events in Southwest China over the Past 120 Years. *Remote Sensing*, **15**, Article 3008.

<https://doi.org/10.3390/rs15123008>

- [53] Ayugi, B., Eresanya, E.O., Onyango, A.O., *et al.* (2022). Review of Meteorological Drought in Africa: Historical Trends, Impacts, Mitigation Measures, and Prospects. *Pure and Applied Geophysics*, **179**, 1365-1386.

<https://doi.org/10.1007/s00024-022-02988-z>