



TECHNICAL INNOVATION REPORT WITH ENVIRONMENTAL AND CLIMATE CHANGE STATISTICS USING BIG DATA



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The United Republic of Tanzania

TECHNICAL INNOVATION REPORT WITH ENVIRONMENTAL AND CLIMATE CHANGE STATISTICS USING BIG DATA



National Bureau of Statistics
Ministry of Finance
Dodoma



Office of the Chief Government Statistician
Presidents' Office – Finance and Planning
Zanzibar

The Technical Innovation Report with Environmental and Climate Change Statistics using Big Data was developed by the National Bureau of Statistics (NBS) and Office of Chief Government Statistician (OCGS) in collaboration with the Academic Institutions. This is the first comprehensive analysis of its kind to be conducted in Tanzania. This analytical work was funded by the Government of Tanzania through the Tanzania Statistical Master Plan II (TMSP II) funds. The technical assistance was provided by The World Bank.

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Preface

The National Bureau of Statistics (NBS) and the Office of the Chief Government Statistician (OCGS) are pleased to present the Technical Innovation Report with Environmental and Climate Change Statistics using Big Data.

This analytical work is a product of the experience gained in leveraging Big data and new technologies, in line with the implementation of the second phase of the Tanzania Statistical Master Plan (TSMP II - 2022/23 - 2026/27). The TSMP II has given special attention to administrative data and data emerging from non-traditional sources such as geospatial or earth observation and citizen generated data as compliment to other data produced from censuses and surveys. As such, the report supplements the other existing data sources on environment statistics, helping to meet the increasing demand of environment statistics. Thus, the report will contribute greatly to the production of a high-quality and evidence-based statistics, which will be influential in advancing environmental policies and climate change related initiatives in Tanzania.

We, therefore, take this opportunity to encourage researchers, policy makers, planners, program managers, and other stakeholders particularly those in the environment and agriculture sectors use these findings for making informed policy decisions based on quality planning, monitoring and evaluating programmes related to agriculture, environment and climate change. Finally, we also advise researchers and other experts to undertake further analysis of the available datasets, particularly in the areas that are not covered in this report. It is hoped that the analysed data will ultimately be made available for use by the relevant stakeholders and the general public.



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1.1 Introduction

Geospatial datasets empower practitioners to monitor environmental indicators with enhanced precision capturing everything from regional disparities in rainfall distribution and vegetation resilience to the accelerating transformation of forest ecosystems and the availability of freshwater resources. Although geospatial data are utilized throughout the chapters in the National Environmental Report of Tanzania Mainland, 2025 (NESR 2025), this report focuses specifically on their application in the context of Natural Extreme Events and Disasters and it covers the aspects of the United Republic of Tanzania. In contrast to the table based, nationwide historical reporting of extreme events in most of the national environmental statistics reports, this analytical report edition employs a spatially disaggregated approach. Focusing on droughts, floods, and heatwaves, it not only tracks when these hazards occurred historically but also pinpoints where they cluster, which communities are most exposed, and how household vulnerability intensifies overall risk.

This analysis applies the Hazard, Exposure, and Vulnerability framework, integrating high-resolution satellite data with Tanzania's 2022 Population and Housing Census (2022 PHC) to estimate the number of people that are exposed and vulnerable to climate related hazards. Within this framework, Hazard refers to the probability and intensity of extreme weather events, while Exposure captures the presence of people, settlements, critical infrastructure, and ecological assets situated in areas potentially affected by such events. The vulnerability dimension, derived from census based socioeconomic indicators, reflects how conditions such as limited human capital, a low household asset base, and restricted access to essential services increase a population's sensitivity to harm and reduce its capacity to cope with and recover from climate shocks. This spatially informed risk assessment lays the groundwork for prioritizing interventions by considering not only the frequency and intensity of hazards, but crucially where these hazards most acutely intersect with underlying household vulnerabilities.

While the use of big geospatial data holds significant promise for advancing national environmental statistics, its adoption in shaping national policy requires careful consideration. Geospatial datasets enhance both the spatial and analytical depth of assessments, but their application comes with important limitations that can affect the interpretation of results. These include variability in spatial resolution across datasets, inconsistencies in temporal coverage, and a reliance on modeled outputs that may not fully capture localized dynamics. Nevertheless, despite these challenges, the growing use of geospatial data continues to offer transformative

potential for deepening environmental risk assessments and informing spatially targeted policy interventions.

The remainder of this report is structured in four parts: first, it outlines the geospatial data sources underpinning the analysis; second, it introduces the analytical framework, beginning with hazard identification and the development of spatially disaggregated hotspot maps for droughts, floods, and heatwaves; third, it assesses exposure by overlaying these hazard maps with population data to quantify affected communities; and fourth, it examines how household vulnerability derived from Tanzania's 2022 Census intersects with climate hazard exposure. By integrating these dimensions, the report concludes by pinpointing priority geographic areas for targeted policy intervention and resilience building across Tanzania.

1.2 Data

Climate related extremes can be characterized by two key dimensions: their intensity and the likelihood of their occurrence. To estimate how many people are exposed to extreme events, population data is overlaid with probabilistic hazard maps to identify areas where specific intensity thresholds are met with at least a minimum probability. Intensity is measured using physical metrics, for example, the depth of floodwater in meters. However, it is important to recognize that relying on a single metric can oversimplify complex hazards. For instance, the impacts of flooding are also shaped by factors such as speed and duration, which are not always captured in standard models. Despite this limitation, the use of simplified and widely accepted intensity metrics allows for consistent and comparable risk modeling. In this analysis, drought is represented by the extent of cropland affected based on vegetation health indices, floods by maximum inundation depth, and heatwaves by the three day average of maximum Wet Bulb Globe Temperature (WBGT) (Table 1). By establishing clear intensity thresholds, the analysis focuses on events likely to pose significant threats to human wellbeing, while filtering out more manageable or less harmful occurrences.

To describe the probability of these events, return periods are commonly used. A return period represents the likelihood of an event of a given intensity occurring in any given year. For example, a 2 year return period corresponds to a 50% annual chance of occurrence, while a 100 year return period indicates a 1% annual chance. When we estimate the number of people in Tanzania exposed to a 100 year flood exceeding 50 cm, we refer to individuals living in areas with at least a 1% annual probability of experiencing a flood of that magnitude or greater. This

group includes people who may be at much higher risk or who face deeper floodwaters, but all are considered exposed according to the defined threshold.

In summary, we consider a location being at risk if there is a minimum annual probability (or maximum return period) of an event passing the intensity threshold. This approach applies across all the hazards we assess (drought, floods and heatwaves). The hazard data we use (Table 1) are based on today's climate, using models grounded in historical events and extreme value analysis. This means the data can capture possible events even if they have not yet occurred in a specific location, but they do not reflect how climate change might shift these patterns in the future. Lastly, the spatial resolution of these datasets varies depending on how localized the hazard is. Floods, which are very localized, are modeled on a 90-meter grid, while more widespread events like heatwaves use a 10-kilometer grid.

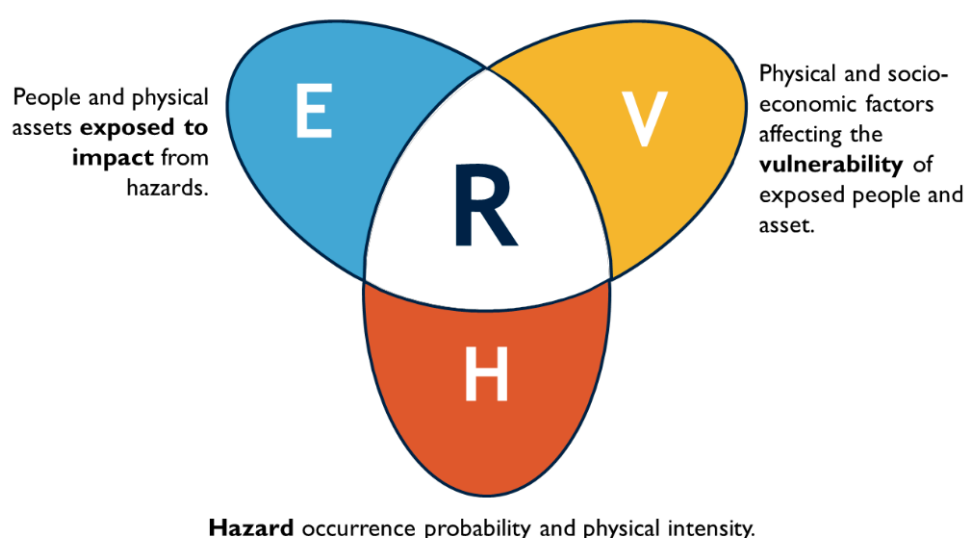
Table 1 Hazard Data

Hazard	Source	Platform	Spatial Resolution	Temporal Coverage	Exposure Threshold	Return Period (Years)
Drought	FAO Agricultural Stress Index (ASI)	FAO GIEWS Earth Observation	~1 km (30 arcseconds)	1984–2022	VHI < 35% for two consecutive seasons; ≥30% affected	5, 10, 15, 20, 40
Flooding	Fathom Global 2.0 + WB Global Flood Exposure Dataset	World Bank Flood Exposure Data	~90 m (3 arcseconds)	Static model (100-year RP)	Inundation depth ≥ 0.5 meters	5, 10, 20, 50, 75, 100
Heatwave	Ridder et al. (2017) using ERA-Interim reanalysis	WB Climate Risk Heatwave	~10 km (5 arcminutes)	1981–2010 (climatological)	3-day mean WBGT ≥ 33°C	5, 20, 100

1.3 Hazard, Exposure and Vulnerability Framework

This analysis adopts the hazard, exposure, and vulnerability framework often employed to assess disaster risk and the potential impacts of climate change. Welfare impacts result from dynamic interactions between hazards with the exposure and vulnerability of households. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes, policies and human decision making.

Figure 1 The hazard, exposure, and vulnerability framework

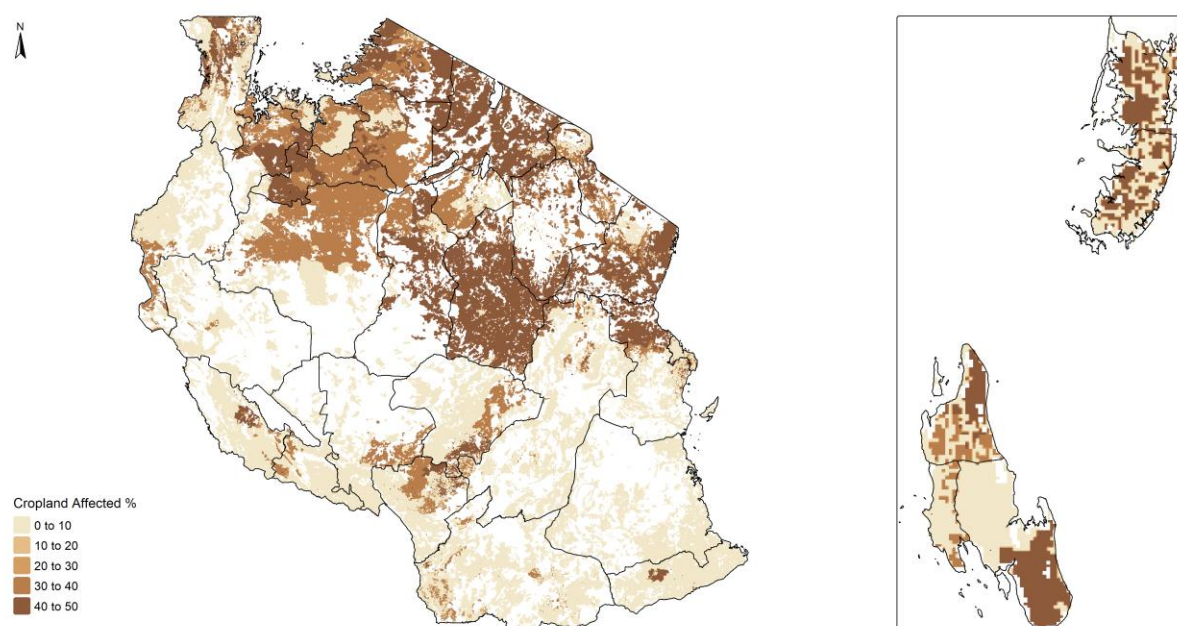


1.4 Hazard

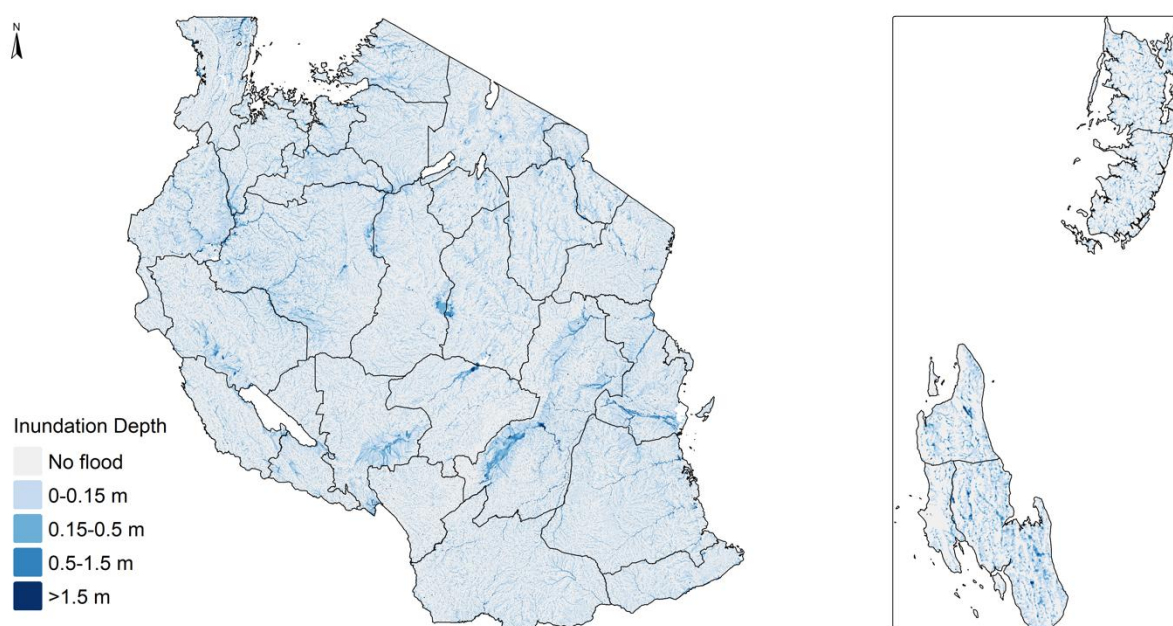
This section explores the spatial distribution of climate related hazards across Tanzania, focusing on both the intensity and probability of extreme weather events. Using high resolution hazard data, it maps the occurrence of floods, droughts, and heatwaves, pinpointing areas where these events are most likely to occur and most severe.

1.4.1 Drought

Map 1 Share of cropland or grassland affected by a 1-in-20-year agricultural drought (historical frequency)

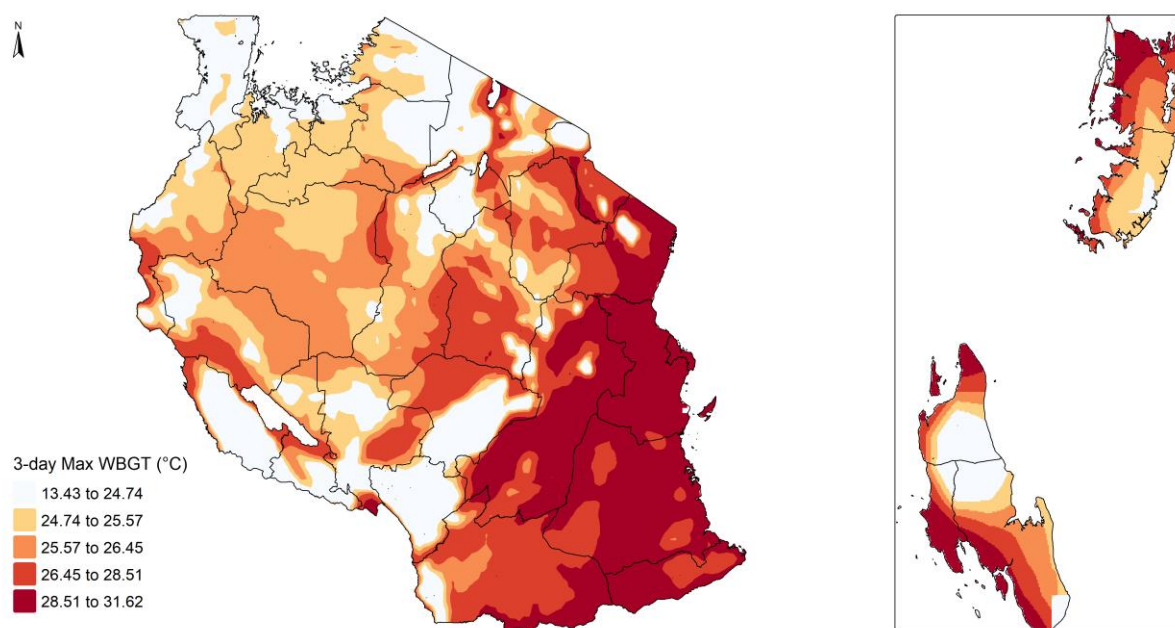


Map 2 Maximum inundation depth for a 1-in-20-year pluvial, fluvial or coastal flood (modelled)



Map 2 illustrates the spatial distribution of flood hazard across Tanzania, highlighting areas where surface water is likely to accumulate under a modeled extreme rainfall scenario. The most extensive zones of shallow flooding (up to 15 cm in depth) trace the country's major river systems and low lying. Notably, broad areas of inundation appear along the Rufiji and Wami-Ruvu river basins, affecting regions such as Morogoro, Pwani, and parts of Lindi, where river overflow and surface runoff are common during periods of heavy rainfall. Shallow flooding is also observed in Western Tanzania, particularly in Katavi and northwestern Rukwa, within the Lake Tanganyika catchment. In urban coastal areas, including parts of Dar es Salaam, shallow flood zones are present as well, largely due to impervious surfaces, drainage constraints, and low elevation, which together contribute to localized flooding during intense rain events. Moderate to severe flooding, defined as water depths exceeding 0.5 meters is more spatially concentrated but particularly notable in Central Morogoro, Southern Pwani (especially around Rufiji District), Western Ruvuma, and Eastern Mbeya, near the Kilombero Valley. These regions lie within floodplains and topographic depressions, where high river discharge and flat terrain lead to prolonged inundation. On the Zanzibar islands, both Unguja and Pemba display considerable flood exposure, particularly across central lowlands and eastern coastal zones, reflecting their flat terrain, limited drainage capacity, and sensitivity to both inland flooding and coastal surges.

Map 3 Average 3-day maximum WBGT of a 1-in-20-year heatwave (modelled)



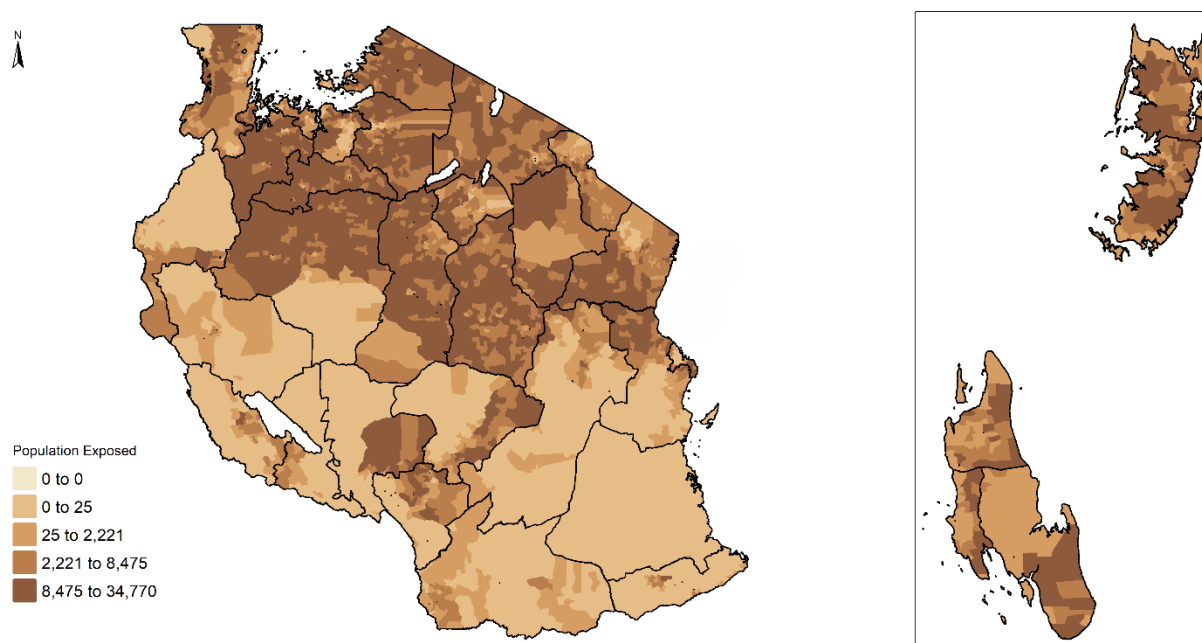
Map 3 depicts the spatial distribution of the average 3-day maximum Wet Bulb Globe Temperature (WBGT) during a 1-in-20-year heatwave event across Tanzania. The highest WBGT values, ranging from 28.5°C to 31.6°C, are concentrated along the Eastern and Southern coastal regions, notably in Dar es Salaam, Tanga, Lindi, Mtwara, and parts of Morogoro. These elevated levels signal severe heat stress conditions, where the combined effects of high temperatures and humidity dramatically reduce the body's ability to cool itself through sweating. Under such conditions, there is a heightened risk of heat related illnesses including heat exhaustion, heatstroke, and dehydration especially for populations engaged in outdoor labor, such as agricultural workers, construction crews, and informal sector vendors. Inland Central regions such as Dodoma and Singida register moderately high WBGT values between 25.6°C and 28.5°C. Although less extreme than coastal hotspots, these levels still present serious health risks, particularly when exposure is prolonged or when adaptive measures, such as access to shade, hydration, or cooling infrastructure, are limited. By contrast, the Northern Highlands regions including Arusha, Kilimanjaro, and parts of Manyara show lower WBGT values, generally below 25.6°C. These cooler conditions are largely due to higher elevations and lower humidity, which help mitigate the intensity of heat during extreme events. Similarly, areas around Lake Victoria, including Mwanza and Mara, experience moderate WBGT levels, where the lake's moderating effect on temperature and humidity provides some localized thermal relief. In Zanzibar, particularly along the coastal zones of Unguja and Pemba,

WBGT values are consistently high, mirroring those of the hottest Tanzania Mainland coastal regions. The islands' humid tropical climate contributes to significant heat stress, exacerbated by limited airflow in densely built environments and coastal humidity.

1.4.2 Exposure

This section presents the spatial distribution of exposure across Tanzania, focusing on where climate related hazards intersect with human settlements. By overlaying hazard maps with high resolution population data, the analysis identifies the specific areas where people are most likely to be affected by extreme events.

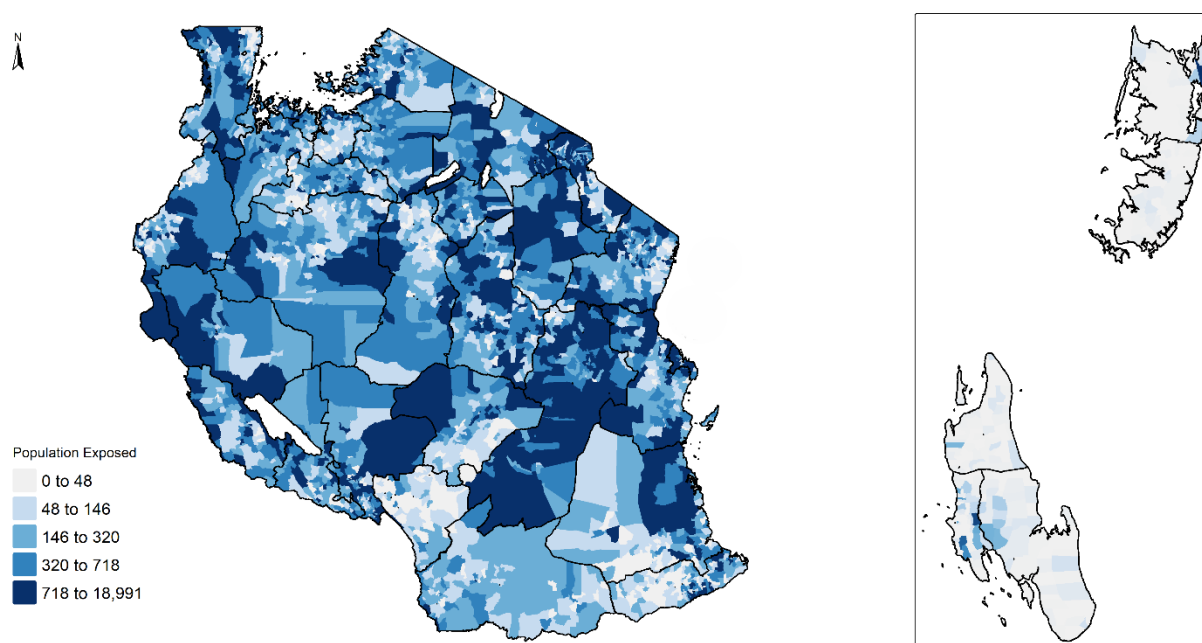
Map 4 Population exposed to drought (>30% cropland affected)



Map 4 portrays that the Northern and Central regions of Tanzania Mainland record the highest numbers of people exposed to agricultural drought. Regions such as Dodoma, Singida, and parts of Shinyanga and Arusha are particularly affected. These areas are characterized by semi-arid climates, with low and erratic rainfall, high evapotranspiration, and heavy reliance on rainfed agriculture. In contrast, regions in the Southern Highlands including Mbeya, Njombe, Iringa, and Ruvuma as well as parts of the Southern Coast, such as Lindi and Mtwara, show lower levels of population exposure to drought. These areas typically experience more consistent rainfall patterns, and in some cases, greater water availability or lower population densities, which together reduce overall exposure. However, these relative advantages do not

eliminate risk, especially in areas with growing demand for water or land use change. In Zanzibar, the map reveals generally low levels of population exposure to drought, though localized areas of moderate exposure are visible particularly in parts of Northern Pemba and Southern Unguja. While Zanzibar's coastal climate and smaller population size may help buffer against severe drought conditions, the limited availability of freshwater resources and dependence on seasonal rains mean the islands remain sensitive to rainfall variability.

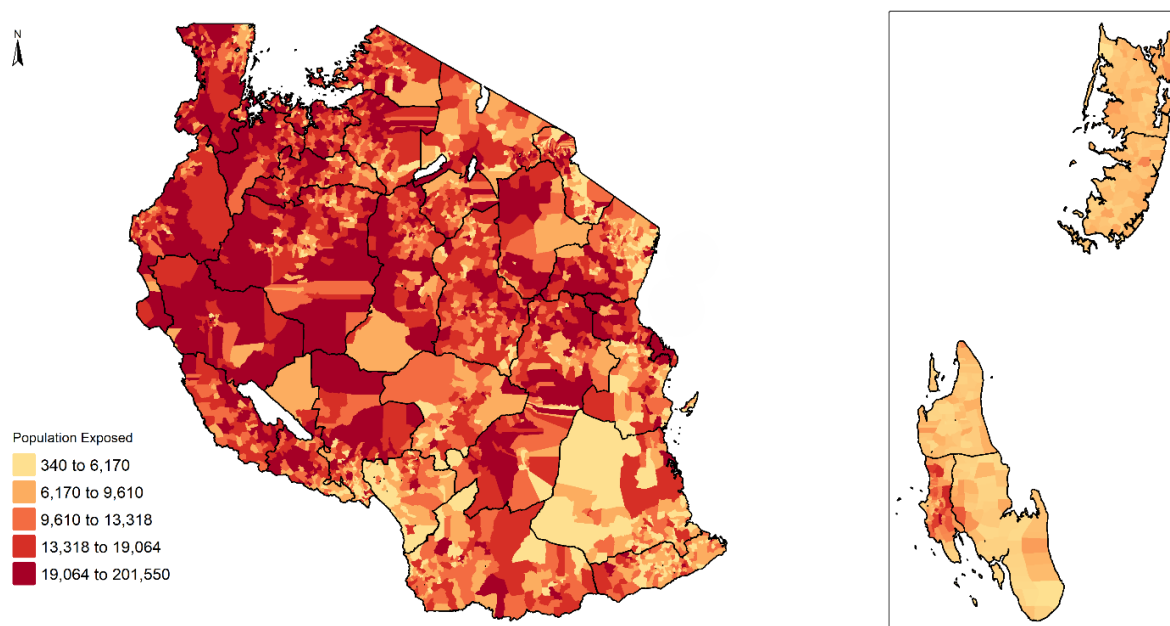
Map 5 Population exposed to pluvial, fluvial or coastal flood (>0.15m)



Map 5 illustrates the spatial distribution of population exposure to flood hazards across Tanzania, revealing a concentration of high-risk areas in the Eastern and Southern regions. Regions such as Morogoro, Pwani, Dar es Salaam, and Lindi exhibit the highest levels of flood exposure, particularly along major river basins, coastal lowlands, and urban zones. This pattern reflects a combination of seasonal rainfall intensity, topographic vulnerability, and rapid urban expansion, often outpacing the development of adequate drainage and flood control infrastructure. Specific flood prone hotspots such as Kilombero, Ifakara, Kibiti, and Temeke are especially exposed due to their location along river systems like the Rufiji and Wami-Ruvu, coupled with high population density and limited resilience infrastructure. These areas frequently experience fluvial and pluvial flooding, disrupting livelihoods, damaging property, and affecting public health particularly during the long rains (Masika). In contrast, Northern and Central regions, including Arusha, Manyara, Kilimanjaro, and Dodoma, show more spatially variable exposure. Urban districts such as Moshi and Babati report elevated risk,

largely due to localized flash flooding, urban runoff, and constrained drainage in hilly terrain. However, surrounding rural zones tend to exhibit lower flood exposure, reflecting lower population densities and less concentrated infrastructure. Meanwhile, the drier interior regions of Singida, Tabora, and Shinyanga demonstrate minimal flood exposure, consistent with their semi-arid climates and absence of major flood prone watercourses. In these areas, drought, rather than flooding, remains the predominant climate hazard. In Zanzibar, the distribution of flood exposure is uneven. Urbanized and low-lying coastal parts of Mjini Magharibi, as well as sections of Unguja South and Pemba North, face moderate flood risks, primarily from intense rainfall events and coastal surges. Contributing factors include flat terrain, limited stormwater infrastructure, and growing informal settlements. However, less densely populated and elevated inland areas on both Unguja and Pemba show relatively lower exposure.

Map 6 Population exposed to heatwaves (3-day max WBGT >28°C)



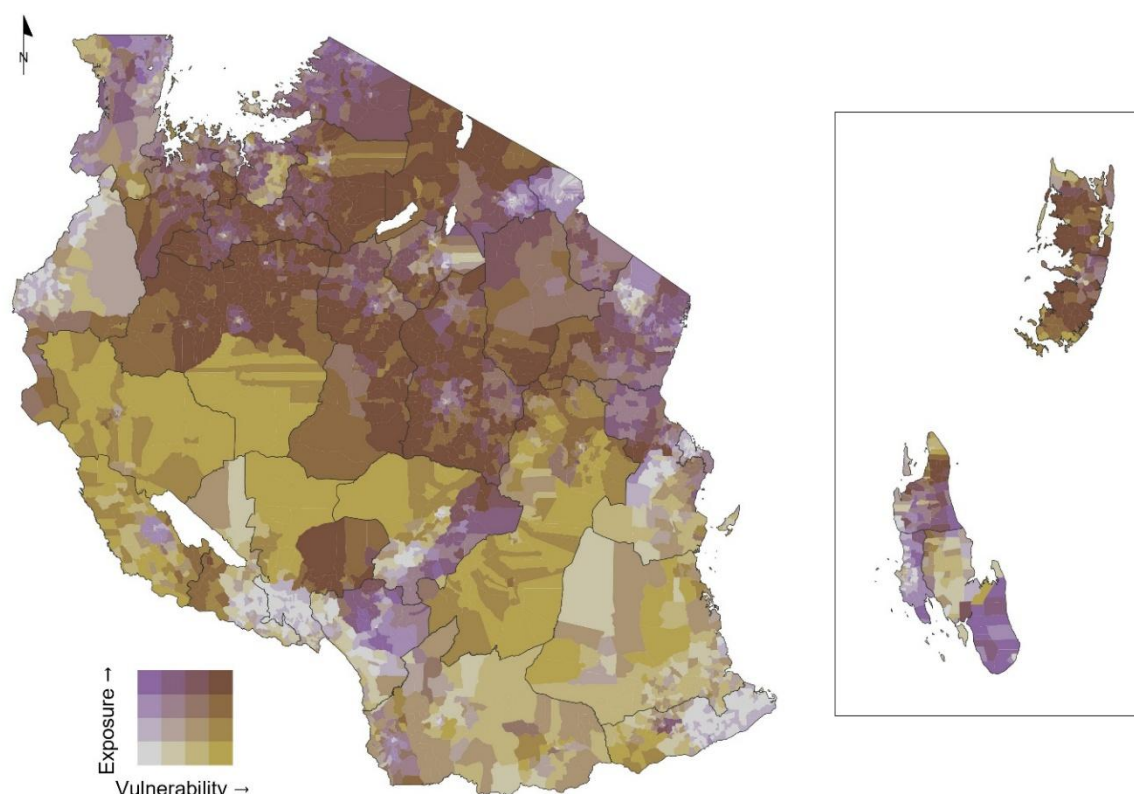
Map 6 illustrates the geographic distribution of heatwave exposure across Tanzania. The highest levels of exposure are concentrated in urbanized areas and regions with high population density. Specifically, the eastern coastline, including cities like Dar es Salaam and Tanga, as well as regions in the northwestern Tanzania, including Mwanza and Shinyanga, show the most intense heatwave exposure. These areas correspond to major economic hubs, transportation corridors, and dense settlements. Secondary pockets of elevated heatwave exposure appear along the southern coast and near inland water bodies, where high humidity and proximity to large bodies of water contribute to greater heat stress during extreme heat events. Coastal cities

such as Lindi and Mtwara, as well as regions near the Lake Tanganyika basin, experience significant heatwave exposure. In contrast, rural and sparsely populated regions exhibit lower exposure to heatwaves. Zanzibar reflects a similar pattern, with urbanized areas experiencing higher heatwave exposure due to dense settlements, limited green spaces, and the urban heat island effect. In contrast, less developed coastal and peripheral areas on both Unguja and Pemba show lower exposure, likely due to fewer buildings, more natural vegetation, and lower population concentrations.

1.4.3 Vulnerability

To assess household vulnerability, this analysis applies an asset-based approach to potential income (World Bank, 2016). This framework posits that a household's income potential and consequently its resilience to shocks is determined not only by the quantity of assets it possesses, but also by how effectively those assets are utilized, the returns they generate, and the level of risk and uncertainty the household faces. Using data from the 2022 Tanzania Population and Housing Census, we operationalize this approach by identifying specific indicators of deprivation across three dimensions: asset endowment, asset use, and returns to assets. A household is considered deprived of asset endowment if it owns no land, computer, livestock or motorcycle, and if the household head has only primary education or less. In terms of asset use, households where the head is out of the labor force regardless of education level are flagged as underutilizing assets. For asset returns, we identify deprivation through lack of electricity access and poor market connectivity; the latter is proxied using area level data on the Rural Accessibility index, which measures the proportion of rural households residing within 2 km of an all-season road. Based on these criteria, we calculate the percentage of vulnerable households in each council, generating a spatially disaggregated vulnerability score used in subsequent risk mapping.

Map 7 Population exposed to drought (>30% land affected) and household vulnerability



Map 7 presents a bivariate map that illustrates both the number of people exposed to agricultural drought (reflected on the vertical axis of the color-coded legend) and the share of those exposed who are socio-economically vulnerable (depicted on the horizontal axis). Wards with larger exposed populations and higher proportions of vulnerable individuals appear in darker shades, indicating areas of concentrated climate risk. From the map, wards located in Central and Western of Tanzania including those in Singida, Tabora, Dodoma, and Shinyanga, as well as northern parts of Arusha such as Ngorongoro and Longido stand out for their high levels of both exposure and vulnerability. This pattern suggests persistent limitations in access to public services, low levels of human development, and constrained livelihood opportunities, which collectively reduce community capacity to manage and recover from climate related shocks.

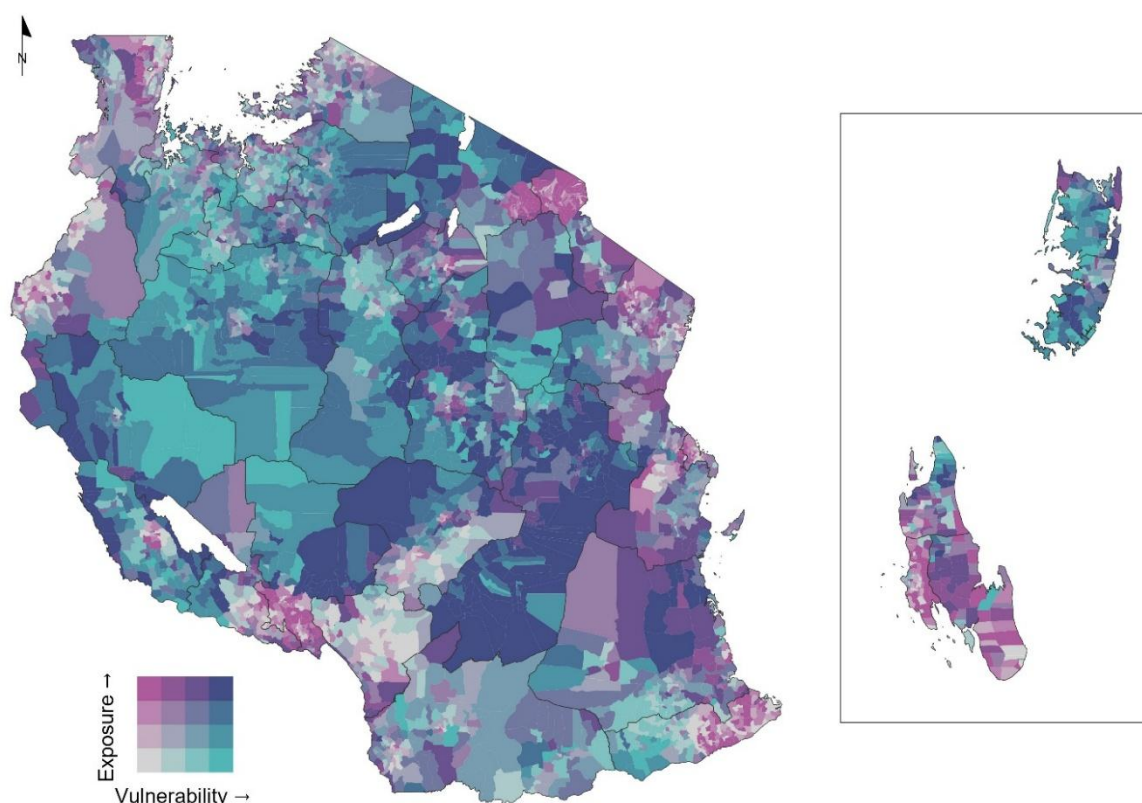
In the Southern Highlands, high vulnerability is evident in several specific locations, including central parts of Mbeya and Iringa and the Northern part of Songwe. Wards such as Luhanga, Imalilo Songwe, Mawindi, Nyanzwa, and Mahenge are particularly notable in this regard. These areas face challenges related to service delivery and economic diversification, which

when combined with climate stress can significantly elevate risk. Similarly, high vulnerability is observed in parts of Southern part of Tanzania, including districts in Lindi, Ruvuma, and Mtwara. While exposure levels in these areas may vary, limited household resources and gaps in essential infrastructure mean that even moderate drought events can result in substantial socio-economic disruption.

Northern and Northwestern regions such as Kilimanjaro, Mwanza, and Kagera generally display stronger socio-economic conditions, with many wards exhibiting lower vulnerability despite varying levels of exposure. Broader access to education, healthcare, and more resilient local economies enables households in these regions to better absorb and adapt to environmental stressors. Still, the data reveal that vulnerability is not uniformly low across these areas. In rural and agriculturally dependent wards, pockets of deprivation persist, underlining the importance of disaggregated analysis for identifying communities most in need of targeted resilience support.

Wards in Eastern Tanzania Mainland, particularly in Dar es Salaam, and several areas within the Zanzibar archipelago, generally show lower levels of vulnerability. Higher rates of urbanization, improved infrastructure, and more diversified income sources contribute to greater adaptive capacity in these regions. However, the presence of informal settlements and rapid urban expansion introduces localized risks, especially where public service provision has not kept pace with population growth. The spatial disparities shown in Map 7 highlight the need for finely tuned climate adaptation strategies ones that are not only hazard aware but also responsive to the socio-economic realities shaping vulnerability at the ward level.

Map 8 Population exposed to pluvial, fluvial or coastal flood (>0.15m) and vulnerability

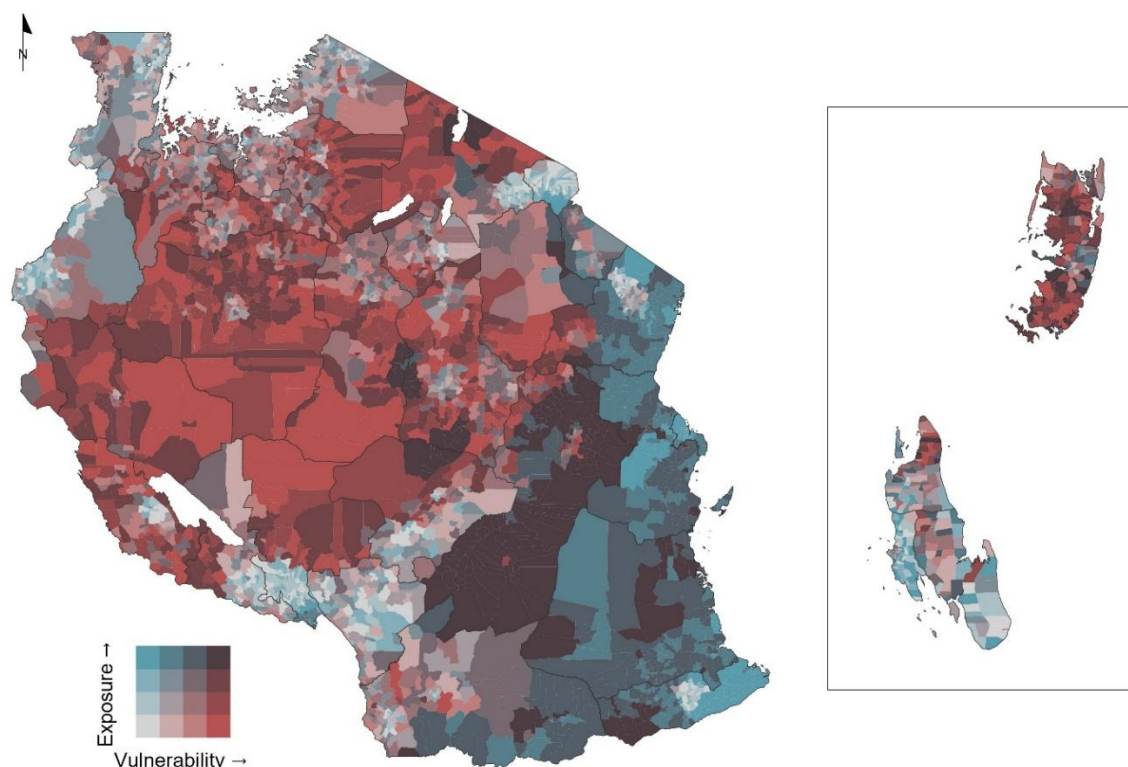


Map 8 reveals several clear patterns in the distribution of flood exposure and vulnerability across Tanzania. In the Lake Zone covering Kagera, Mwanza, Geita, and Mara flood exposure is visibly high across many wards, consistent with the region's proximity to major water bodies and seasonal rainfall dynamics. However, most wards in this zone exhibit relatively low levels of vulnerability, reflecting better baseline access to public services, diversified rural economies, and historically higher human development indicators. Still, disparities exist, and isolated wards within this region remain highly vulnerable, pointing to localized development gaps. Along Kilimanjaro regions and much of the Eastern seaboard, including coastal regions like Tanga and parts of Dar es Salaam, high exposure to floods is evident but is not always matched by high vulnerability. This suggests stronger adaptive capacity in many urban and peri-urban wards, likely linked to better infrastructure, access to services, and more varied income generating opportunities. However, the Southern coast presents a sharp contrast. In Lindi Region especially in wards such as Nanjirinji, Miguruwe, Njinjo, Kipatimu, Chumo, Kikole, and Kivinje both exposure and vulnerability are significantly elevated. These areas remain underserved in terms of basic infrastructure and social services, with local economies heavily reliant on climate sensitive sectors like subsistence agriculture and fishing.

The strongest convergence of flood exposure and vulnerability appears in Morogoro Region. Many wards across both urban and rural parts of Morogoro are shaded in the darkest tones, indicating a compounded risk environment. This reflects the region's hydrological features such as the Uluguru Mountains and seasonal river systems combined with long-standing development constraints in rural wards, particularly in relation to health, education, and livelihood diversification. A similar reinforcement of risk is seen in the Southern Highlands. Southern Mbeya and Northern Iringa especially wards like Luhanga, Imalilo Songwe, Idodi, and Mlenge stand out for both their flood exposure and limited capacity to cope, despite the overall relative affluence of these regions. This highlights persistent spatial disparities, particularly between urban centers and more isolated rural communities.

Other significant risk clusters are visible in parts of Rukwa, especially along the Lake Tanganyika shore, where terrain and water systems increase flood exposure, and socio-economic vulnerability remains elevated. Some wards in Dodoma also exhibit overlapping exposure and vulnerability, particularly in outlying rural areas that continue to face barriers to basic services and infrastructure. In Arusha Region, exposure varies, but in more remote northern wards like Longido, vulnerability remains high due to arid conditions and limited economic options.

Map 9 Population exposed to heatwaves (3-day max WBGT >28°C) and vulnerability



Map 9 reveals that the most pronounced overlap between high exposure to heatwaves and elevated levels of vulnerability occurs in Central and Southern parts of Tanzania. In particular, large swathes of Morogoro consistently appear as high risk areas, with many wards showing deep tones that reflect both frequent heatwave conditions and limited capacity to cope. This convergence likely stems from a combination of environmental exposure and systemic development gaps, particularly in rural wards with limited access to healthcare, water infrastructure, and adaptive livelihoods. Similarly, in the Southern Coastal and inland regions especially across Lindi, Mtwara, and Ruvuma numerous wards reflect this dual burden. These areas continue to grapple with historical under investment in public services, moderate to high poverty rates, and a dependence on rain fed agriculture, making them especially vulnerable to prolonged heat stress.

Moving to central Tanzania, the regions of Singida and Dodoma emerge as clear hotspots. Many wards here are shown in darker hues, indicating a compounding of heat exposure with socio-economic fragility. This reflects the arid and semi-arid nature of the central plateau, where daytime temperatures are high and water scarcity is recurrent. Combined with lower levels of human development, these conditions reduce household and community resilience, particularly in more remote or pastoralist areas. Despite Dodoma being the administrative capital, the vulnerability observed suggests that rural peripheries still lag in development indicators relative to urban centers.

Zanzibar, particularly Unguja North and South, shows a more mixed pattern. Some wards demonstrate notable exposure to heatwaves, particularly along the coastal strip and peri-urban areas, but in many cases, this is not matched with high vulnerability. This may reflect relatively better access to public services, improved housing, and connectivity to economic hubs compared to Tanzania Mainland rural areas. However, certain wards, especially on Pemba and parts of Central Unguja, do register both heat stress and higher levels of vulnerability, signaling localized development gaps that leave segments of the island population at greater risk.

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