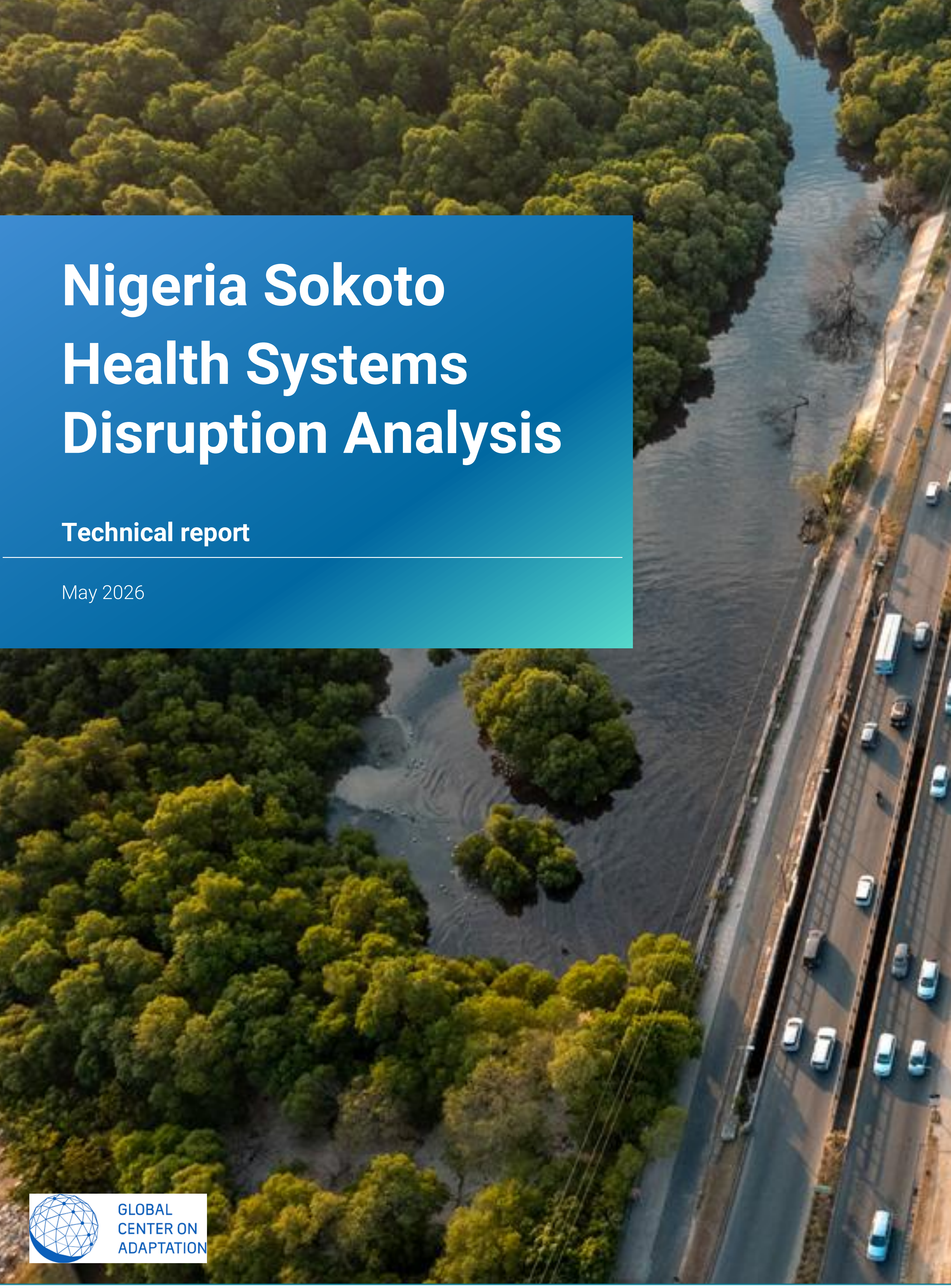

Nigeria Sokoto Health Systems Disruption Analysis

Technical report

May 2026

GLOBAL CENTER ON ADAPTATION

This series of GCA Learning from Practice notes provides a practical reference to support the design and implementation of climate adaptation analyses. Drawing on the experience and lessons from GCA programs, each note focuses on a specific methodological component, offering guidance on key concepts, minimum standards, and recommended practices to strengthen the quality, consistency, and usability of analytical outputs.

Intended for practitioners, analysts, and decision-makers, the notes aim to balance scientific rigor with operational relevance. By translating experience into clear methodological benchmarks and actionable guidance, the series supports credible analyses and enables more informed planning, investment, and adaptation decisions.

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GLOBAL CENTER ON ADAPTATION

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The Global Center on Adaptation (GCA) is an international organization, hosted by the Netherlands, which works as a solutions broker to accelerate action and support for adaptation solutions from the international to the local, in partnership with the public and private sector, to ensure we learn from each other and work together for a climate resilient future.

AFRICA ADAPTATION ACCELERATION PROGRAM

GCA is providing technical assistance under the African Adaptation Acceleration Program (AAAP), a joint initiative launched by the GCA and the African Development Bank in 2021.

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ABBREVIATIONS

Acronym	Definitions
CCKP	Climate Change Knowledge Portal
CRA	Climate Risk Assessment
EmONC	Emergency Obstetric Care
EM-Dat	Emergency Events Database
ER	Emergency Room
FNPH	Federal Neuro-Psychiatric Hospita
GIS	Geographic Information System
ICU	Intensive Care Unit
IHC	Illah Health Clinic
IsDB	Islamic Development Bank
ISO	International Organization for Standardization
ITCZ	Intertropical Convergence Zone
J-CHEW	Junior Community Health Extension Workers
LGA	Local Government Areas
MNCH	Maternal, New-born and Child Health
NBS	Nature Based Solution
NOAA	National Oceanic and Atmospheric Administration
NPHCDA	National Primary Health Care Development Agency
NPI	National Programme on Immunisation
O&M	Operation and Maintenance
PHCs	Primary Health Centres
RH	Relative Humidity
SoS	GCA/OIA *Healthcare System-of-Systems Vulnerabilities*
SSP	Shared Socioeconomic Pathways
VIIRS	Visible Infrared Imaging Radiometer Suite
WASH	Water, Sanitation and Hygiene
WSDI	Warm Spell Duration Index

EXECUTIVE SUMMARY

The Global Center on Adaptation (GCA) is providing technical assistance to the Islamic Development Bank (IsDB) for the integration of climate adaptation and resilience measures into the Sokoto State health system under the Sokoto Climate Resilient Healthcare Infrastructure Project.

Sokoto State, located in north-western Nigeria, has a population of approximately 4.2 million people, the majority of whom live in rural areas and depend primarily on the public health system for access to essential services. The health system operates through a three-tier service delivery structure (primary, secondary, and tertiary) and functions through community-level Health Posts and Health Clinics, ward-level Primary Health Centres (PHCs), LGA-level General and Zonal Hospitals, and state and federal-level tertiary and specialised facilities, supported by pharmaceutical supply chains and essential supporting systems, including energy, water, transport, digital and communication systems, and waste management.

The system faces existing structural and operational constraints, particularly at primary health care level, including:

- limited functionality of health facilities and infrastructure deficits;
- shortages of skilled health personnel;
- unreliable electricity and water supply;
- fragile cold-chain infrastructure and;
- constrained transport and referral capacity, with logistics depending heavily on unpaved roads and motorcycle transport and only a few ambulances available.

These constraints already affect health system functionality and access to services under baseline conditions, and seasonal pluvial flooding frequently renders roads impassable, disrupting both patient referrals and commodity flow.

This report assesses how climate hazards will further affect the functionality, interdependencies, and continuity of healthcare delivery across Sokoto State, including cascading impacts through referral systems, pharmaceutical supply chains, and essential supporting systems. It does so by identifying climate-risk hotspots where health facilities are exposed to high or extreme hazard levels; and by analysing how these hazards may disrupt healthcare delivery across primary, secondary, and tertiary facilities, including impacts on referral pathways and pharmaceutical logistics. Additionally, it assesses what these disruptions mean for overall system functionality and access to essential services, taking into account existing structural and operational constraints and the socio-economic dimension, with particular attention to more vulnerable populations and areas. In a fourth step, it provides the analytical basis for a long list of adaptation options to inform subsequent prioritisation and the development of implementation guidelines for climate-resilient healthcare facilities, services, and logistics.

The climate hazard analysis identifies extreme heat and flooding as the most consequential hazards for healthcare continuity in Sokoto.

- Extreme temperature and heatwaves: Under a high-emission scenario (SSP5-8.5), mean daily temperatures across Sokoto State are projected to rise by 1.7°C by mid-century (2041–2060) and by 4.5°C above baseline by end-of-century (2081–2100; multimodel median; baseline 1995–2014: 28.7–30.7°C). Under a moderate scenario (SSP2-4.5), the corresponding increases are +1.4°C and +2.2°C. The number of hot days (days exceeding the 90th-percentile temperature threshold) is projected to increase from approximately 36 days per year in the baseline to around 142 days per year by mid-century and 271 days per year by end-of-century under SSP5-8.5 (multimodel median). The mean daily temperature is expected to increase across all months, translating into more extremely hot days and longer, more persistent heatwaves. High ambient temperatures create unsafe indoor conditions and associated health risks – including heat stress for patients and staff, reduced clinical work capacity, and heightened risk of climate-sensitive disease outbreaks – in facilities that lack reliable electricity, cooling, or adequate ventilation. Particularly at the primary care level; these conditions reduce the physical work capacity of health workers and increase fatigue and the risk of service disruption. Extreme temperatures also place pressure on temperature-sensitive systems, and cold-chain infrastructure at PHCs and Health

Clinics is especially vulnerable where electricity supply is unstable or dependent on solar systems with limited storage capacity – a risk that applies to all health facilities across Sokoto State, with 100% projected to reach Very High extreme heat hazard under mid-term SSP5-8.5 projections (2041–2060) and Extreme hazard level under long-term projections. Power interruptions during periods of extreme heat increase the likelihood of vaccine temperature excursions and compromise the safe storage of heat-sensitive medicines.

- Flooding: For precipitation-related indices, extreme precipitation indices show more notable increases under higher-emission scenarios, with total annual precipitation projected to rise by up to 168 mm/year by mid-century and 226 mm/year by end-of-century under SSP5-8.5 (multimodel median; baseline: 469–975 mm/year), and maximum 1-day rainfall events intensifying by up to 22 mm/day, pointing to a higher likelihood of damaging flood episodes driven by intense rainfall bursts, rapid runoff, and river-system overflow, particularly where drainage and transport infrastructure are limited. Flooding has significant implications for health system functionality due to its combined effects on facility exposure, physical access, and service connectivity; under SSP5-8.5 mid-term (2050), 25 primary health facilities are identified in flood-exposed multi-hazard zones; by 2080, 27 facilities face escalating pluvial flood hazard levels. On key referral pathways, flooding is projected to increase travel times by 7.8 to 13.5 times baseline conditions (100-year return period, SSP5-8.5). Seasonal pluvial flooding frequently renders feeder roads impassable, constraining movement between communities and frontline facilities and delaying referrals from primary facilities to secondary and tertiary hospitals. Flood-related access disruption also affects routine service delivery, including immunisation outreach, commodity resupply, and health reporting, and over time repeated flood disruptions weaken service continuity and referral reliability, particularly in rural and flood-prone areas.

Based on that analysis, multi hazard hotspots were defined as areas where extreme heat, wildfire and flood hazards (100-year return period) coincide at High, Very High, or Extreme levels under mid-term (2050) climate projections. The hotspot selection is based on SSP5 (high-emissions scenario) for the mid-term time horizon, and it is recognized that extreme heat and wildfire are projected to occur at uniformly high hazard levels across Sokoto State and are therefore not used as ranking variables for hotspot selection, while remaining highly relevant for subsequent analyses. By contrast, pluvial flooding and fluvial flooding show clear spatial variability across wards and an initial preselection step is applied: only wards in which at least one health facility is exposed to pluvial flooding and/or fluvial flooding under the 24h 100-year return period rainfall event are retained for hotspot scoring.

For the preselected wards based on the multi-hazard hotspots, hotspot identification is based on a composite scoring approach to capture the convergence of flood-related hazard pressure (pluvial and/or fluvial), health system exposure (number of health facilities), and population affected. Wards exposed to both pluvial and fluvial flooding receive a higher flood-related score, while facility exposure and population size are converted into classes and combined in an additive index; where identical total scores occur, ties are resolved through hierarchical prioritization using larger absolute population size and higher absolute number of health facilities.

Based on this approach, 25 health facilities were identified in a multi-hazard zone with potential flood exposure under SSP5 mid-term (2050); all facilities identified are primary health facilities, with six excluded due to contradictory ward information. A ward-level socio-economic vulnerability analysis was conducted across the 17 multi-hazard hotspot wards to identify where climate-related disruptions are likely to have the most severe population impact. Two complementary analytical dimensions are applied: population-based impact potential, measuring the scale of populations with elevated healthcare dependency (infants, children aged 1–5, women of reproductive age, and adults aged 60 and above); and access fragility, reflecting structural gaps in facility density, service redundancy, and referral capacity. The highest-needs wards include Dukamaje, Makuwana, Kaura, Darna Sabon Gari, Gandi 1, and the urban ward of Sarkin Adar Gidan Igwai, with populations dependent on health services ranging from approximately 13,000 to over 24,000 individuals per ward. Access fragility is most pronounced in Bengaje, Gandi 1, Makuwana, Rarah, and Sanyinna, where low facility density and limited redundancy mean that even modest disruptions can translate into critical service gaps. These vulnerabilities are further amplified by prevailing security dynamics in parts of north-western Nigeria and cross-border health-seeking behaviour from Niger Republic, Kebbi State, and Zamfara State, which place additional pressure on already constrained primary facilities during periods of disruption.

From the ranked hotspot set, the following wards are included for a detailed disruption analysis:

1. Dukamaje ward, as it shows the highest population number among those scoring

2. Sarkin Adar Gidan ward (Tudun Faila Health Clinic), given that it is the only urban ward/health facility identified as hotspot.

3. Kware ward as a tertiary hospital that emerges as a critical node in the referral system.

- Illela ward is included to represent secondary-level service delivery, with selection guided by the same additive scoring process using population served and concentration of health facilities; Illela General Hospital shows the highest combined score among the secondary-level candidates.

The health system disruption analysis applies a structured framework to these four facilities, jointly assessing demand pressure, service capacity, and hazard-specific failure pathways. The framework follows a System-of-Systems approach, examining not only direct impacts on facility assets but also interdependencies with external infrastructure systems, including power supply, road networks, and pharmaceutical supply chains.

Illah Health Clinic (Dukamaje) presents the most pronounced structural imbalance in the assessed set, combining a high demand pressure score with the lowest capacity score across all six indicators. The facility operates without electricity, without a functional cold chain, and without any formal emergency preparedness. Its catchment of approximately 420 patients per week, predominantly women and children, depends on vaccine supplies transported from neighbouring facilities, and on referral pathways to Gada General Hospital that are severely disrupted by flooding. Road network analysis projects travel time increases of 7.8 to 11.4 times baseline conditions under projected flood scenarios (SSP2-4.5/2050: ~7.8×; SSP5-8.5/2080: ~11.4× baseline), making timely referral for obstetric emergencies and time-sensitive complications increasingly unreliable.

Tudun Faila PHC (Sarkin Adar Gidan Igwai), the only urban facility in the hotspot set, operates with a more functional infrastructure baseline but carries a critical single-point vulnerability: its solar backup system is non-functional, leaving cold chain operations entirely dependent on an unreliable grid. Extreme heat intensification across all future scenarios elevates the risk of vaccine temperature excursions and immunisation service interruptions. Road disruption impacts are comparatively limited given the urban road network, though alternative routing under flood conditions adds some travel time.

Illela General Hospital demonstrates strong internal capacity, including skilled clinical staff, a functional cold chain, and ambulance and referral systems. Its principal disruption risk is systemic rather than structural: as the main secondary referral anchor for Illela LGA and cross-border communities from Niger Republic, flood-induced access degradation across its feeder primary network generates indirect demand pressure that its capacity may not be formally prepared to absorb. Road network analysis shows travel time ratios reaching up to 13.5 times baseline for the most affected feeder routes under the SSP5 2080 scenario. The facility also operates on solar power without grid or generator backup, representing a targeted infrastructure vulnerability.

The Federal Neuro-Psychiatric Hospital, Kware carries the strongest capacity profile of the four assessed facilities. Its disruption risk is defined not by structural fragility but by the irreplaceable nature of its service function and the clinical non-deferrability of psychiatric care. Extreme heat intensification poses risks to its psychiatric medication supply chain, and flood-induced disruption of referral routes from surrounding secondary facilities — with projected travel time increases of up to 8.9 times baseline (SSP5-8.5, 2080 scenario) — threatens the continuity of patient transfers to this specialist centre. Given that FNPH serves patients from Sokoto, Kebbi, and Zamfara States, any disruption carries regional implications with limited substitution options.

The comparative disruption assessment synthesises these findings through a demand–capacity matrix, confirming that structural vulnerability is most concentrated at the primary care level, and that system-level resilience risks at secondary and tertiary facilities operate primarily through network dependencies and referral pathway exposure rather than internal fragility.

Conclusions and Key Recommendations

This report demonstrates that climate change poses compounding and increasingly severe risks to healthcare delivery across Sokoto State. Extreme heat operates as a near-universal chronic stressor affecting all health facilities by mid-century, while flooding acts as a spatially differentiated, episodic disruptor that can multiply referral travel times seven to fourteen-fold. Wildfire conditions compound heat stress and elevate respiratory disease burden during the October–May fire season. These hazards converge on a health system that is already structurally constrained at the primary care level, where the most acute climate-driven service failures will occur. The socio-economic vulnerability analysis confirms that the consequences will be most severely felt by the populations that depend most heavily on continuous primary care access: mothers, young children, and the elderly in rural and peri-urban wards. Key recommendations include:

- Prioritise energy reliability and cold-chain protection across all facility tiers. Energy instability is the single most consistent system-wide vulnerability, affecting cold-chain integrity, pharmaceutical storage, and essential service operations at every level. Adaptation measures should introduce redundant backup power, thermal protection for pharmaceutical storage, and solar systems with adequate battery capacity, with particular urgency at facilities currently operating without any electricity (e.g., Illah Health Clinic, Dukamaje) and those with non-functional solar backups (e.g., Tudun Faila PHC).
- Strengthen referral system resilience against flood-induced road disruption. Flood-induced travel time increases of 7.8 to 13.5 times baseline represent a systemic failure risk for Sokoto's linear referral architecture. Responses should combine road and drainage improvements on critical feeder routes, flood-safe routing protocols, pre-positioned transport options, and enhanced stabilisation capacity at primary facilities to reduce reliance on time-critical transfers during flood events.
- Invest in primary care infrastructure as a precondition for system-wide climate resilience. Structural vulnerabilities at the primary care level, such as absent utilities, no cold chain, inadequate staffing, no emergency preparedness, are the points at which climate hazards most efficiently convert into service failures. These gaps must be addressed as the foundation of any adaptation strategy; investment at higher facility tiers cannot substitute for baseline functionality at the primary tier.
- Protect the irreplaceable tertiary and specialist node at FNPH Kware. The Federal Neuro-Psychiatric Hospital serves as the sole regional specialist facility for psychiatric care across Sokoto, Kebbi, and Zamfara States. Its disruption risk is not internal fragility, but the irreversible consequences of any break in service continuity for a patient population that cannot defer care. Adaptation investment here is justified by irreplaceability: targeted pharmaceutical storage upgrades and referral pathway resilience measures represent high-return investments with regional impact.
- Address compound risk configurations at border wards. Heightened insecurity in Sabon Birni, Rabah, and Goronyo LGAs, combined with significant cross-border health-seeking behaviour from Niger Republic, Kebbi, and Zamfara, means that climate disruptions in these areas generate compound risk configurations the health system is not formally equipped to absorb. Adaptation planning must explicitly account for these dynamics and include inter-sectoral and cross-border coordination mechanisms

1. INTRODUCTION

This report presents the network-level healthcare delivery disruption analysis for the *IsDB Nigeria Sokoto Climate Resilient Healthcare Infrastructure Project*, implemented by the Global Center on Adaptation (GCA). This analysis forms part of the technical assistance provided by GCA to support the IsDB in integrating climate adaptation and resilience into the Sokoto State health system, with the overall objective of informing climate-resilient investment, planning, and operational decision-making across healthcare infrastructure and services. The assignment comprises a sequence of analytical outputs, including climate hazard assessment, climate risk and vulnerability assessment, and the identification of adaptation and resilience options. Within this framework, the network-level disruption analysis examines how climate hazards may propagate through health system interdependencies, affecting service delivery pathways, referral networks, and access to essential health services.

Sokoto State, located in north-western Nigeria, has a population of approximately 4.2 million people, the majority of whom live in rural areas and depend primarily on the public health system for access to essential services. The health system operates through a three-tier service delivery structure comprising primary, secondary, and tertiary health facilities, supported by pharmaceutical supply chains and essential supporting systems, including energy, water, transport, digital and communication systems, and waste management. The system faces existing structural and operational constraints, particularly at primary health care level, including limited functionality of health facilities, shortages of skilled health personnel, unreliable electricity and water supply, fragile cold-chain infrastructure, constrained transport and referral capacity, and uneven access to essential medicines. These constraints already affect health system functionality and access to services under baseline conditions. Within this context, increasing exposure to climate hazards, most notably extreme heat and flooding, poses risks not only to individual healthcare assets, but to the continuity of healthcare delivery across the interconnected health system.

Building on the climate hazard analysis and hotspot mapping, this report focuses on a health system-wide and network-level perspective, examining how climate hazards affect health system functionality, interdependencies, and service delivery pathways. The report is structured around four main analytical components. First, it presents the overall analytical approach and a Sokoto-wide climate hotspot analysis, combining climate hazard information with health facility distribution to identify priority areas of exposure. Second, it provides an overview of the Sokoto State health system, including service delivery levels, referral systems, pharmaceutical supply chains, supporting systems, and the socio-economic dimension, with a focus on populations and geographic areas that are particularly vulnerable to climate-hazard-induced disruptions in healthcare access. Third, it undertakes a health system disruption analysis, assessing how climate hazards may generate direct and cascading impacts on healthcare service delivery across facilities, referral pathways, and pharmaceutical supply chains within identified hotspots. Finally, the report concludes with a long list of adaptation options, which serves as an input to the subsequent adaptation and resilience options prioritisation and the development of implementation guidelines for climate-resilient healthcare facilities, services, and logistics, ensuring that downstream investment and planning decisions are informed by network-level climate risks and disruption pathways.

1.1. OBJECTIVES

The objective of this report is to conduct a network-level healthcare delivery disruption analysis to assess how climate hazards, particularly extreme heat, wildfire and flooding, may affect the functionality, interdependencies, and continuity of healthcare service delivery across Sokoto State's health system. The analysis moves beyond asset-level exposure to examine how localized climate impacts on health facilities and supporting systems may generate cascading disruptions across referral systems, pharmaceutical supply chains, and access to essential health services.

Specifically, the report aims to:

(i) identify climate-risk hotspots where health facilities are exposed to high or extreme levels of climate hazards;

(ii) analyse how climate hazards may disrupt healthcare delivery across primary, secondary, and tertiary health facilities, including impacts on referral pathways and pharmaceutical logistics;

(iii) assess the implications of these disruptions for health system functionality and access to essential health services, taking into account existing structural and operational constraints and the socio-economic dimension, with particular attention to populations and areas that are more vulnerable to climate-hazard-induced service interruptions; and

(iv) provide an analytical basis for a long list of adaptation options, which will inform subsequent project outputs, including the adaptation and resilience options prioritisation and the development of implementation guidelines for climate-resilient healthcare facilities, services, and logistics.

2. Sokoto Wide Health System Climate Analysis

This chapter presents a Sokoto-wide climate hotspot analysis, combining climate hazard information with health facility distribution to identify priority areas of exposure. To this end, it first provides an overview of the Sokoto State health system, including service delivery levels, referral systems, pharmaceutical supply chains, and supporting systems. The outcome of this overview is then combined with the results of the Climate Hazard Analysis, creating a Multi Hazard Hotspot Analysis. This analysis not only defines areas where extreme heat, wildfire and flood hazards coincide at High, Very High, or Extreme levels but also identifies patterns of exposure across facility types and service functions, providing a broader picture of how climate risks translate into system-level disruption over time. As a result, 25 facilities were considered as being in a multi-hazard zone and chosen for further analysis. In this context, this section relates to objectives I and II of the report.

Finally, the chapter conducts an analysis of the socio-economic dimension, with a focus on populations and geographic areas that are particularly vulnerable to climate-hazard-induced disruptions in healthcare access.

Overall, this section is structured as follows:

- Overview of the Sokoto State Health System
- Climate Hazard Analysis along relevant climate hazards
- Multi Hazard Hotspot Analysis with selection of hotspot facilities

The preselected wards based on the multi-hazard hotspot analysis form the foundation of the subsequent Health System Disruption Analysis in Section 4, which focuses on the risk and severity of service disruption in selected hotspot wards.

2.1. Sokoto State Health System

Sokoto State operates a tiered health service structure aligned with Nigeria's national Primary Health Care (PHC) strategy and the Federal Ministry of Health's three-level model of care (primary, secondary, and tertiary)[i]. The system functions through four operational layers that collectively support access to essential services across the state.

Community Level: Health Posts and Health Clinics constitute the most common frontline service delivery points in rural Sokoto. These facilities provide first-contact outpatient care, essential MNCH services, health promotion, community surveillance, and referrals to PHCs. Health Posts typically serve small settlements and are often staffed by Junior Community Health Extension Workers (J-CHEWs), operating with limited equipment and inconsistent power and water supply[ii] .

Ward Level: Primary Health Centres (PHCs) are the backbone of Sokoto's health service delivery model. The state has more than 500 PHCs, although national assessments indicate that fewer than 25–30% meet minimum functionality standards for infrastructure, staffing, equipment, and power supply[iii]. PHCs supervise community-level facilities, coordinate routine immunisation and outreach, manage uncomplicated deliveries, and serve as the principal referral and reporting nodes at ward level.

LGA Level: General and Zonal Hospitals deliver secondary care, including emergency obstetric care (EmONC), caesarean sections, surgical interventions, inpatient services, and laboratory diagnostics. Sokoto's 23 LGAs vary widely in population size and road accessibility, meaning referral travel times from rural communities to secondary hospitals often exceed 1–3 hours in normal conditions, and considerably more during floods or road disruptions[iv] .

State and Federal Level: Tertiary and specialised facilities provide specialist care, advanced diagnostics, and health workforce training. These facilities support not only Sokoto State but also neighbouring Kebbi and Zamfara, heightening pressure on services during climate-related disruptions[v] .

Health Supply Chain and Logistics System

Sokoto's health supply chain is structured around a centralised storage system and a tiered distribution network that supports routine immunisation, essential medicines, and commodities for primary care. The system comprises four main nodes: the State Cold Store, Local Government Area (LGA) cold-chain points, Primary Health Centres (PHCs), and outreach sites at Health Clinics and Health Posts.

State Level Storage: The State Cold Store in Runjin Sambo is the primary storage and distribution hub for vaccines and temperature-sensitive commodities. It receives supplies from national depots and distributes them to LGA cold-chain points. Operations rely on a combination of grid electricity, generators, and solar backup systems.

LGA-Level Cold Chain Points: Each LGA maintains a cold-chain point, typically located within the National Programme on Immunisation (NPI) office. These facilities store vaccines for onward distribution to PHCs and coordinate micro-planning, session scheduling, and reporting.

Primary Health Centres as Distribution Hubs: PHCs serve as the central operational nodes for last-mile vaccine delivery within Sokoto's supply chain. They maintain vaccine stocks and oversee the coordination of routine immunisation outreach to surrounding Health Clinics and Health Posts. PHCs are also responsible for redistributing vaccines and essential commodities to lower-tier facilities, ensuring that outreach sites receive adequate supplies for scheduled sessions. In addition, they manage reporting and monitoring tools for immunisation performance and act as the principal resupply point for essential medicines, diagnostics, and programme materials.

Transport and Logistics: Logistics operations depend heavily on unpaved feeder roads and motorcycle transport, with only a few ambulances available across the entire PHC network. Seasonal pluvial flooding frequently renders roads impassable, sometimes several times per week, disrupting both patient referrals and commodity flow.

While this structure reflects the intended design of the health supply chain, field-level functionality varies across LGAs and wards, with operational gaps emerging particularly at PHC and outreach levels.

Overview of existing infrastructure and system constraints

The Sokoto State health system presents structural and operational constraints that reduce service quality and system resilience. Evidence from the National Health Facility Survey 2023[vi] indicates that many facilities lack the minimum readiness required to deliver essential services reliably, including maternal care, immunisation, outpatient services, and emergency management. Shortages of skilled health workers, low functionality of basic utilities, and widespread deficits in medical equipment and diagnostics contribute to operational fragility across the country. These systemic challenges disproportionately affect rural areas, where dependence on PHC facilities is highest. The recurrent issues highlighted are unreliable electricity, inadequate water access, limited cold-chain capacity, insufficient staff mix, and weak referral mechanisms, which collectively reduce the resilience of frontline services to operational pressures or external climate shocks.

Building on the national picture, Sokoto State reflects many of the same systemic challenges, though the gaps are often more pronounced at the PHC level. According to the MyPHC Report 2024[vii] , infrastructure deficits are significant. Around half of Sokoto's PHCs are in visibly poor or deteriorated condition, and many facilities report multiple major building failures such as damaged roofs, broken ceilings, and compromised windows. Only about half of the PHCs have functional sanitation facilities, signalling widespread gaps in hygiene and facility safety.

Human resources remain a major bottleneck. Roughly one-third of posted staff are not actively present, and clinical personnel represent only a very small share of the workforce, with only a handful of nurses, midwives, and doctors across all surveyed PHCs. Most day-to-day service delivery therefore relies on

Community Health Extension Workers (CHEWs), who carry a disproportionate workload relative to available support.

Basic utilities are unreliable. Following data from Orodata Science, only 5% of the PHCs in in Sokoto are connected to the national grid, while 15% rely on solar energy, 2% use generators and 77% have no power supply at all. This situation is further complicated by non-functional solar installations (damaged panels, drained batteries) and generator fuel shortages due to rising prices PHCs cannot afford. Additionally, the few PHCs connected to the national grid face potential disconnections because of unpaid bills. These circumstances impede a constant supply of electricity in the project area and thus not ony limit the functionality of medical equipment but also affect cold-chain stability. Water supply is similarly constrained, with most facilities relying on boreholes or wells, reflecting limited access to dependable WASH infrastructure. [viii]

Cold-chain capacity is structurally fragile under baseline conditions. Based on expert data collected with local stakeholders, functional vaccine refrigerators are frequently lacking, and power interruptions make temperature control unreliable. As a result, immunisation services are highly susceptible to heat extremes and equipment downtime.

Transport and referral options are constrained. Only a small minority of facilities have access to an ambulance, with most patients and staff relying on motorcycles, walking, or public transport. These limited transport options hinder timely emergency referrals, especially during seasonal flooding or when rural roads become impassable.

Service utilisation trends reflect these structural barriers. Patient volumes remain modest; a notable share of households struggle to afford care, and overall facility ratings from service users lean toward poor. Based on MyPHC 2024 findings on low facility readiness and limited referral transport in Sokoto State, these structural constraints are likely to dampen health-seeking behaviour and disrupt continuity of routine PHC services.

Overall, these significant gaps substantially heighten the vulnerability of frontline facilities to climate-related disruptions and reduce the system's ability to maintain essential services under stress.

2.2. Climate Hazard Analysis

In order to develop robust insights into how the previously described Sokoto State Health System will be impacted by climate change, this section focuses on which hazards are most likely to occur in Sokoto State and what their implications would be for the health system infrastructure. To this end, it begins with a general overview of Sokoto's climatic and geographical conditions. This outline, which is based on the observation of both historical disaster records and regionalised multi-models suggests that increasing heat and rainfall are the most probable future climate threats in the region.

Building on this risk pattern, the following hazards are identified as the most relevant for the continuity of the health system infrastructure:

- Extreme temperatures: projected to intensify across the state, with long-term exposure affecting up to 94% of PHCs under long-term scenarios, and with key operational implications such as power interruptions and cold-chain vulnerability.
- Heatwaves: leading to prolonged periods of sustained thermal stress across health facilities with critical implications for the staff performance.
- Humidity: high relative humidity leading to impaired thermoregulation of patients and staff
- Wildfire: with smoke and reduced air quality during the fire season contributing to respiratory symptoms
- Flooding: directly affecting road accessibility, for which a dedicated road network accessibility analysis was produced

Finally, the chapter integrates these hazard results with the health system structure in a Multi-Hazard Hotspot Analysis. Hazard hotspots were defined as areas where extreme heat, wildfire and flood hazards (100-year return period) coincide at High, Very High, or Extreme levels under mid-term (2050) climate projections. These hotspots were used to identify patterns of exposure across facility types and service functions, and to assess how climate risks translate into system-level disruption over time.

An overview of the main hazards and their implications for Sokoto's Health System can be found in the table below:

Table 1 Summary of main findings for relevant climate hazards

Hazard	Projection	Main findings	Areas / systems most affected
Extreme heat	SSP2 - RCP 4.5	Moderate hazard level to extreme by late century across most of the state	All facilitites, staff performance, indoor conditions, maternal & child health services, cold chain infrastructure.
	SSP5 - RCP 8.5	Rapid intensification of hazard level, extreme hazard level by 2081-2100 across all state	
Heatwaves	SSP2 - RCP 4.5	High hazard level to extreme by late century across all state	Staff performance, cold chain infrastructure
	SSP5 - RCP 8.5	High and very high hazar level to extrme by late century across all state	
Relative humidity	SSP2 - RCP 4.5	Month that exhibited high or very high levels range from July to October	Indoor conditions, patient tolerance, staff performance, vulnerable population
	SSP5 - RCP 8.5		
Wildfire	SSP2 - RCP 4.5	High hazard level to very high by late century	Population health and health system operations
	SSP5 - RCP 8.5	High hazard level to extreme by late century across all state	
Flooding: Direct	SSP2 - RCP 4.5	Moderate increase in pluvial flood hazard by late century, with limited progression into the highest hazard category. Fluvial flooding remains comparatively stable and spatially localized.	Health facility infrastructure directly exposed to flooding, service continuity, equipment and essential services located at ground level
	SSP5 - RCP 8.5	Substantial increase in pluvial flood hazard by late century, with greater progression into higher hazard categories. Fluvial flood hazard shows comparatively smaller differences between periods.	
Flooding: Indirect	SSP2 - RCP 4.5	The majority of facilities classified under extreme hazard with gradual increase in disruption by 2080	Road connectivty between primary, secondary and tertiary health facilities, emergency referrals, service accessibility duting extreme rainfall events
	SSP5 - RCP 8.5	Marked increases in facilities classified under extreme, very high, and high hazard levels by 2080, indicating substantial increment in road network disruption	

General assumptions and Limitations of the climate hazard analysis:
Geospatial location of Primary Health Facilities was extracted from the National Primary Health Care Development Agency (NPHCDA), whereas the geospatial location of secondary and tertiary health facilities was filtered from NextGIS database.
Hazard thresholds are applied uniformly to all health facilities, without accounting for differences in capacity, resilience or design.

In addition, concrete assumptions and limitations for each individual hazard are laid out at the beginning of each hazard description.

2.2.1. Overview on climatic conditions

Sokoto State is in the northwestern part of Nigeria, sharing borders with the Niger Republic to the north and west. Within Nigeria, it is bordered by Kebbi State to the south and west, and Zamfara State to the east, placing it in the Sudano-Sahelian ecological zone.

According to ERA5-based data available in the Climate Change Knowledge Portal (CCKP), Sokoto has a hot semi-arid climate (BSh in the Köppen-Geiger classification system). The climate is marked by a long dry season from October to May and a short rainy season from June to September, controlled largely by the seasonal movement of the Intertropical Convergence Zone (ITCZ) and the onset of the West African Monsoon. Annual rainfall ranges between 300 mm and 1,000 mm, generally decreasing northward. Temperatures remain high throughout the year, with pre-monsoonal months often exceeding 40 °C. During the dry season, the Harmattan winds from the northeast bring hot, dry, and dusty conditions, while the rainy season is associated with moist southwesterly monsoonal flows linked to the ITCZ's northward migration.

The projections of the climate downscaling report for Sokoto point to intensifying heat and increasing rainfall as the main future hazards, consistent with the signals observed in the regionalised multi-model ensemble. Although the largest increases in extreme temperature occur during the warmest months, the mean daily temperature is expected to increase across all months. This translates into more extremely hot days and longer, more persistent heatwaves, which can accelerate the onset of water scarcity impacts when rains are delayed or end early and therefore reinforce drought risk.

For precipitation-related indices, while some indices indicate increases, model agreement is weaker than for temperature. The strongest changes occur during the rainiest months, and although there is no strong evidence of a broad shift in seasonality, extreme precipitation indices show more notable increases in certain scenarios, including a significant signal in September. In practical terms, this points to a higher likelihood of damaging flood episodes driven by intense rainfall bursts, rapid runoff, and river-system overflow—particularly where drainage and transport infrastructure are limited. At the same time, the combination of high inter-annual variability and mixed precipitation signals in the near and mid term suggests continued exposure to rainfall deficits in some years, meaning that flood and drought risks can coexist across different seasons and years, consistent with Sokoto's historical pattern of alternating hydrological extremes.

This future risk picture is consistent with Sokoto's historical disaster record. According to EM-DAT (CRED), between 1980 and 2024 epidemics accounted for around 47% of recorded disaster events in Sokoto State, followed by floods at approximately 42%.

Regarding epidemics, the historical record links climate conditions to outbreak risk. Sokoto lies in the African "meningitis belt" and has experienced major meningitis epidemics during hot, dry seasons, including the 1996 epidemic (Nigeria's deadliest on record) and the 2016–2017 outbreak in which Sokoto was among the epicenters, with large case numbers reported in the state. Flood events have also been associated with cholera risk, particularly where displacement and damage to water and sanitation conditions reduce access to safe water—such as after the 2010 floods—underscoring the compound nature of climate shocks in Sokoto (extreme weather events plus WASH disruption plus disease pressure).

In relation to floods, Sokoto has repeatedly been affected by rainfall- and river-driven flooding across the Sokoto–Rima system, impacting especially farmland, settlements, and transport links. The 2010 Goronyo Dam overflow led to severe displacement and bridge and road damage, while later events in 2012, 2018, 2020, 2022, and 2024–2025 repeatedly inundated riverine communities and low-lying urban areas, disrupting access to services and causing large agricultural losses (notably rice production in 2018).

Finally , the state has experienced repeated drought episodes over the past century (including 1903–1905, 1913–1914, 1942–1944, 1954–1956, the 1972–1974 Sahel drought, and the early 1990s drought), demonstrating long-standing vulnerability to rainfall deficits and early cessation of rains.

Based on these climatic conditions, a future climate hazard analysis shows relevant implications for health infrastructure in Sokoto state, which can be summarized as below.

2.2.2. Extreme Temperature

Methodological considerations

In Sokoto, the current maximum temperatures (TXx) are already extremely high, meaning that even a modest increase can have considerable implications for heat exposure and population health (see Annex 1 for an overview on heath thresholds in Nigeria). The maximum temperature represents the annual hottest day. An increase of less than 1.5 Celsius degrees may already indicate the possibility of multiple days exceeding current extreme heat thresholds. Therefore, the increase in 1.5 Celsius degrees was used a plausible lower threshold for identifying changes in extreme heat intensity.

The intensity was defined as the projected change in the annual maximum temperature (TXx):

- High: >= 3.0 Celsius degrees
- Medium: 1.5 – 2.9 degrees Celsius
- Low: <1.5 Celsius degrees.

The number of days per year when the daily maximum temperature exceeds the 90th percentile of the reference period was used to assess frequency. This was used as a proxy to measure how often extremely hot days occur. The frequency was defined as follows:

- High: >= 111 days (approximately 30% of days on a year)
- Medium: 37 – 110 days (approximately 10 – 30% of days on a year)
- Low: <36 days (approximately 10% of days on a year)

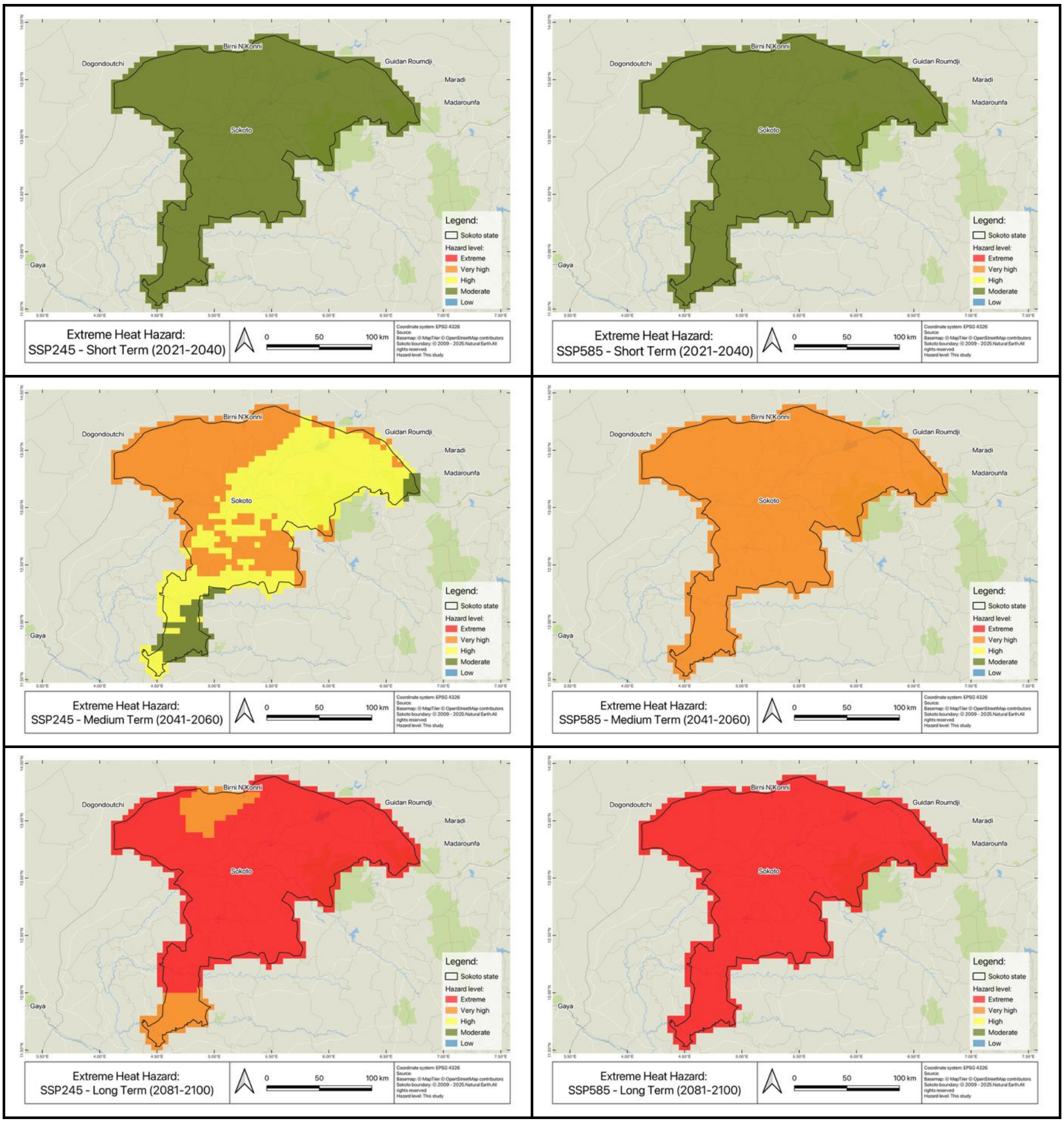
Assumptions and Limitations:

It is assumed that the annual maximum daily temperature represents extreme heat intensity and its potential health implications. While health impacts are typically driven by multi-day heat exposure, these are captured separately in the heatwave extreme weather events in the analysis. The annual maximum temperature is therefore used specifically to represent peak thermal stress.

The projections indicate that, in the short term (2021 – 2040), the entire state will be at a moderate extreme heat hazard level under both SSP2 and SSP5 scenarios. In the mid-term (2041 - 2060) there are differences between SSP2 and SSP5 scenarios. Under SSP2 scenario, it is projected that 1% of the primary health facilities will be at a moderate hazard level, 58% at a high level, and 41% at a very high hazard level (see ExtremeHeatHazardLevels.xlsx). For secondary and tertiary health facilitates, 17% are expected to be at a high hazard level and 7% at very high level (see ExtremeHeatHazardLevels.xlsx). In contrast, under the SSP5 scenario, all health facilitates are projected to be at a very high hazard level in the mid-term.

In the long term (2081 – 2100), future projections under SSP2 scenario indicate differences in hazard levels. Specifically, 94% of primary health facilities are projected to be at an extreme hazard level, while 6% will be at a very high level. For secondary and tertiary health facilities, 92% are expected to be at an extreme hazard level and 8% at a very high level (ExtremeHeatHazardLevels.xlsx). In contrast, under the SSP5 scenario all primary, secondary, and tertiary health facilities are projected to be at an extreme hazard level.

Figure 1 Extreme Heat Hazard in Sokoto State under SSP2 and SSP5 scenarios for 2021-2040, 2041-2060, and 2081-2100



Extreme temperature exposure has significant implications for health system functionality across Sokoto State. High ambient temperatures create unsafe indoor conditions in facilities that lack reliable electricity, cooling, or adequate ventilation, particularly at the primary care level. These conditions affect patient comfort and safety and reduce the physical work capacity of health workers, increasing fatigue and the risk of service disruption during peak heat periods. Extreme temperatures also place pressure on temperature-sensitive systems. Cold-chain infrastructure at PHCs and Health Clinics is especially vulnerable where electricity supply is unstable or dependent on solar systems with limited storage capacity. Power interruptions during periods of extreme heat increase the likelihood of vaccine temperature excursions and compromise the safe storage of heat-sensitive medicines.

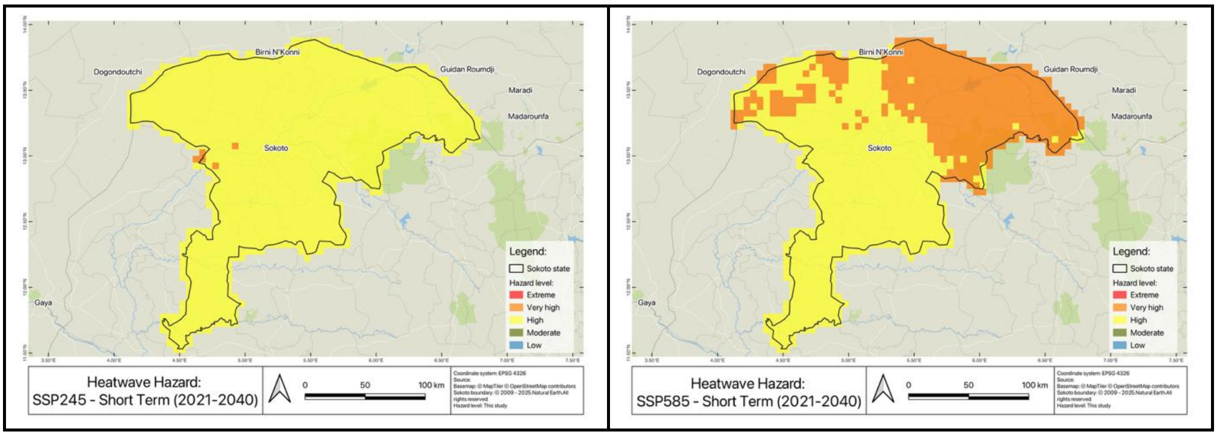
As exposure to extreme temperatures intensifies over time and becomes near-universal under higher-emission scenarios, these impacts are expected to amplify existing infrastructure and capacity constraints, increasing the risk of interruptions to routine services, particularly immunisation and maternal and child health services.

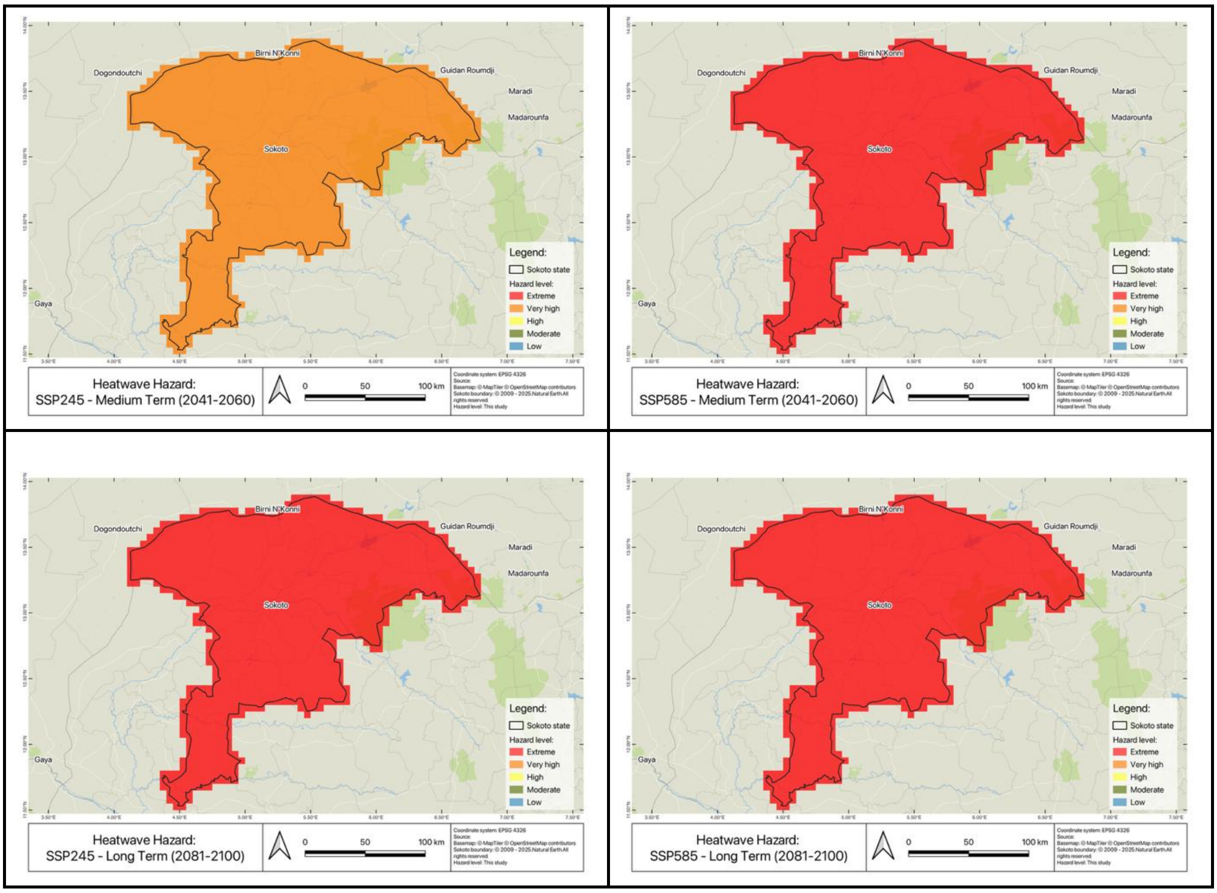
2.2.3. Heatwaves

Methodological Considerations
The Warm Spell Duration Index (WSDI) accounts for the number of days in a year with at least six consecutive days exceed the 90th percentile of daily maximum temperature. It already incorporates both frequency and intensity of heat events. Based on the maximum historical WSDI value of approximately 7 days in the downscaled dataset, the classification thresholds were defined to reflect the intensity and persistency of warm spells. Values above the 7 days represent a shift over current conditions, therefore it was used as the lower threshold for heatwave hazard, the other hazard levels were determined based on the proportion relative to the baseline as follows: • Low: <=7 • Moderate: 7 – 14 • High: 15 – 30 • Very high: 31 – 60 • Extreme: >=60
Assumptions and Limitations:
The maximum historical Warm Spell Duration Index (WSDI) value (approx. 7 days) from the downscaled dataset is assumed to represent current conditions and values exceeding this threshold are considered as a meaningful increase in heatwave hazard level.

The projections suggest that, in the short term, most of the primary health facilities will experience a high heatwave hazard level under the SSP2 scenario. However, Gadanbe Health Post and Betare Health Clinic are expected to face a very high hazard level. For secondary and tertiary health facilities, all will be at a high hazard level. In contrast, under the SSP5 scenario, 69% of the primary health facilities are expected to be at a high hazard level, while 31% will be at a very high level. For secondary and tertiary health facilities, 71% will be at a high heatwave hazard level, while 29% at a very high level.

Figure 2 Heatwave Hazard in Sokoto State under SSP2 and SSP5 scenarios for 2021-2040, 2041-2060, and 2081-2100





Heatwaves amplify the impacts of extreme temperatures by prolonging periods of sustained thermal stress across health facilities. Extended heatwave conditions reduce staff endurance, increase fatigue, and can affect the continuity and quality of service delivery, particularly in primary-level facilities that lack reliable power, cooling, or climate-adaptive building features.

Prolonged heat exposure during heatwaves also increases pressure on health facility operations by raising the risk of reduced operating hours, staff absenteeism, and interruptions to routine services. These effects are especially pronounced in rural and remote facilities, where staffing levels are already limited and substitution options are minimal.

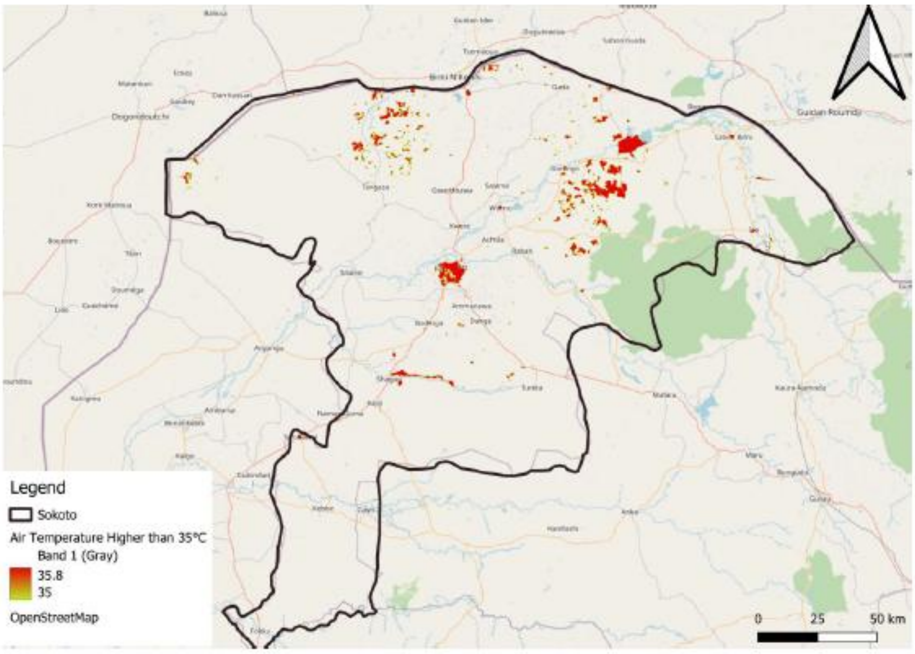
Heatwaves further heighten risks to cold-chain continuity. Sustained high temperatures increase the likelihood of equipment overheating or failure in facilities with unstable power supply, compounding the risk of vaccine temperature excursions and service disruptions. As heatwaves become more frequent and persistent under future climate scenarios, these impacts are expected to exacerbate existing system vulnerabilities and reduce resilience to concurrent shocks.

Box: Implications of changing heat patterns on health and disease outbreaks

Analyzing the temporal progression of climate projections reveals a consistent warming trend, not only with regards to the delta but also with regards to absolute temperatures. For SSP2-4.5, the mean temperature steadily increases from the short term to the long term. In the Short term, the maximum mean temperature in the northern central areas of Sokoto is 31.5°C, while by the long term, this maximum rises to 33.0°C, indicating a moderate increase. Under the SSP5-8.5 scenario, the warming trend is more pronounced. The short term period shows a maximum temperature of 31.5°C, which escalates to 32.5°C in the medium term and significantly reaches 35.3°C in the long term. This clearly shows that regardless of the emissions scenario, Sokoto is projected to experience hotter conditions in the future, with the rate of warming accelerating over time. Extreme daily temperatures over the northwestern areas of the state rise from 45.1°C in the short term to 46.8°C under the SSP2-4.5 scenario, and up to 49,5 °C under SSP5-8,5. (see the downscaling report for a detailed analysis on the maximum and mean daily temperatures).

In Sokoto and other parts of northern Nigeria, days with maximum temperatures above 35 °C are associated with notable increases in heat-related health complaints such as dehydration, heat cramps, and heat exhaustion and are considered a practical threshold for public health action. Temperatures of about 38 °C and higher are locally described as extreme heat conditions, often correlating with higher patient presentations for heat stress. When air temperatures reach 40-41 °C or more, the risk of heatstroke and serious dehydration rises sharply, especially for vulnerable groups such as children, the elderly, and those with chronic illness. In biometeorological terms, Thermal Stress Index values above 32–41 indicate a transition into heat exhaustion risk, while values above 41 suggest conditions where heatstroke and cognitive disruption are likely without cooling intervention. (see Annex 1 for further information on the classificaitons of heat thresholds in Nigeria). An Invest analysis undertaken by the consultant team found that in the long term, the increase in mean daily temperature would put a significant proportion of the population in Sokoto at a general health risks from extreme heat, with more then 1 Million people under heat stress in the SSP 2-4,5 and an estimated 5,3 million people under the SSP5-8,5 scenario (see Annex 6 for the Invest Analysis). At the same time extreme temperatures, also during heat waves, will often surpass dangerous temperature thresholds for human health.

Figure 3 Areas at risk under the SSP 2-4,5 scenario



The reported health risks are also related to disease outbreaks, which can be expected to increase over time if heat further increases. During the early 2025 February to May season, Sokoto State experienced a significant outbreak of cerebrospinal meningitis (CSM) a disease highly sensitive to heat, dry conditions, and dust exposure typical of northern Nigeria's hot season. Outbreak surveillance reported approximately 303 suspected meningitis cases in Sokoto alone, making it one of the most affected states in the country during this period. Although official data did not disaggregate deaths by state, the national outbreak overall recorded 1,826 suspected cases with 151 deaths, yielding a case fatality rate (CFR) of about 8.3%, and Sokoto's case share suggests a substantial contribution to this burden. Age and gender patterns from the national data which serve as a reasonable proxy for Sokoto indicate that children aged 5-14 years were most affected, and about 60% of suspected cases were male. This outbreak occurred amid prolonged extreme heat and dry conditions, which are well-documented drivers of meningitis outbreaks within the African meningitis belt. High temperatures and low humidity increase the vulnerability of mucosal surfaces, facilitate bacterial transmission, and challenge physiological defenses. In the context of Sokoto's health system where primary health centers face heat-induced power instability, limited cold chain reliability, and disrupted referral pathways such outbreaks compound pressure on already strained services. The outbreak also heightened demands on surveillance, case management, and inpatient care precisely when climate hazards were undermining access and continuity of care.[ix]

Dengue was not a disease common in Sokoto State, but has started to appear recently. The increase in temperatures shortens the mosquito's development time from egg to adult, that is, more mosquitoes emerge in a shorter time. Warmer temperatures also increase biting frequency, so infected mosquitoes feed more often, raising the chance of virus transmission. At temperatures above 30°C, the extrinsic incubation period (EIP) the time between a mosquito biting an infected person and becoming capable of infecting another shortens from 12 days to 7-8 days. At the same time increased flooding leads to more stagnant water bodies, also favourable to the spread of Dengue. In late 2023, the Nigeria Centre for Disease Control and Prevention confirmed a dengue outbreak with 13 laboratory-verified cases among 71 suspected, across three LGAs in Sokoto, without reported fatalities. This early event highlighted the local presence of dengue transmission and the need for surveillance beyond malaria diagnostics. By November 2025, ongoing transmission was observed with 29 suspected cases, six confirmed infections, and the first recorded dengue-associated death in the state. During January to November 2025 nationally, Sokoto was one of the states with the highest number of suspected cases outside Edo State, indicating that the state has become a persistent focus of dengue activity.[x]

Nevertheless, while moderate heat increases transmission (as is experienced now), extreme heat (above 35-40°C, as is projected under future climate change scenarios) can reduce mosquito survival, limiting transmission. So therefore, while the current outbreaks can be partly related to climate change, the expected future developments with regards to extreme heat especially under the SCP 5- 8.5 scenario could also lead to limited transmission due to extreme heat.[xi]

2.2.4. Humidity

Methodological considerations

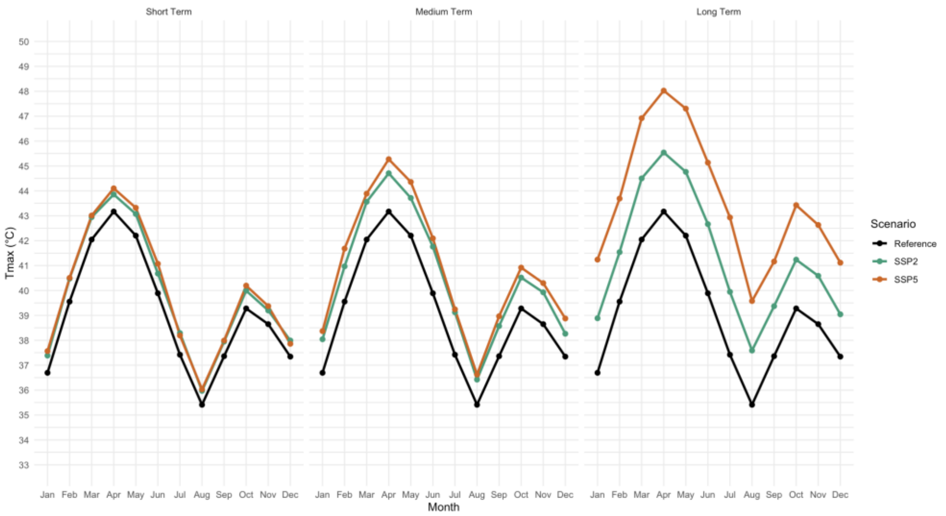
Relative humidity (RH) was included as an indicator of potential heat stress, as high RH reduces the efficiency of evaporative cooling through sweating and hence exacerbates thermal discomfort and physiological strain (Ashworth, 2025). [xii]The following thresholds were used:

- Early risk: [60 – 70%]. This represents conditions in which evaporative cooling becomes less efficient, particularly during warm periods, increasing the likelihood of heat discomfort.
- High risk: [71 – 80%]. Corresponds to conditions associated with increased heat stress, impaired thermal comfort, and greater difficulty maintaining hydration and adequate sleep, particularly for vulnerable populations.
- Very high risk: [81 –100%]. Indicates conditions in which the body's ability to regulate temperature may be severely compromised, potentially leading to dangerous heat stress during extreme heat events, especially among children, elderly and individuals with pre-existing health conditions.

The relative humidity (RH) analysis indicates that very high RH risk levels occur predominantly in August and September across all future scenarios. Based on the adopted RH thresholds, these months fall within the very high risk category, reflecting conditions in which evaporative cooling through sweating becomes significantly less effective.

However, interpretation of TH-based risk must consider monthly maximum temperatures (Tmax). Although August and September exhibit the highest RH-related risk, monthly Tmax data during these months remains comparatively lower than other months. In contrast, other months for example October is characterized by lower RH-based risk but substantially higher monthly Tmax (see Figure 4).

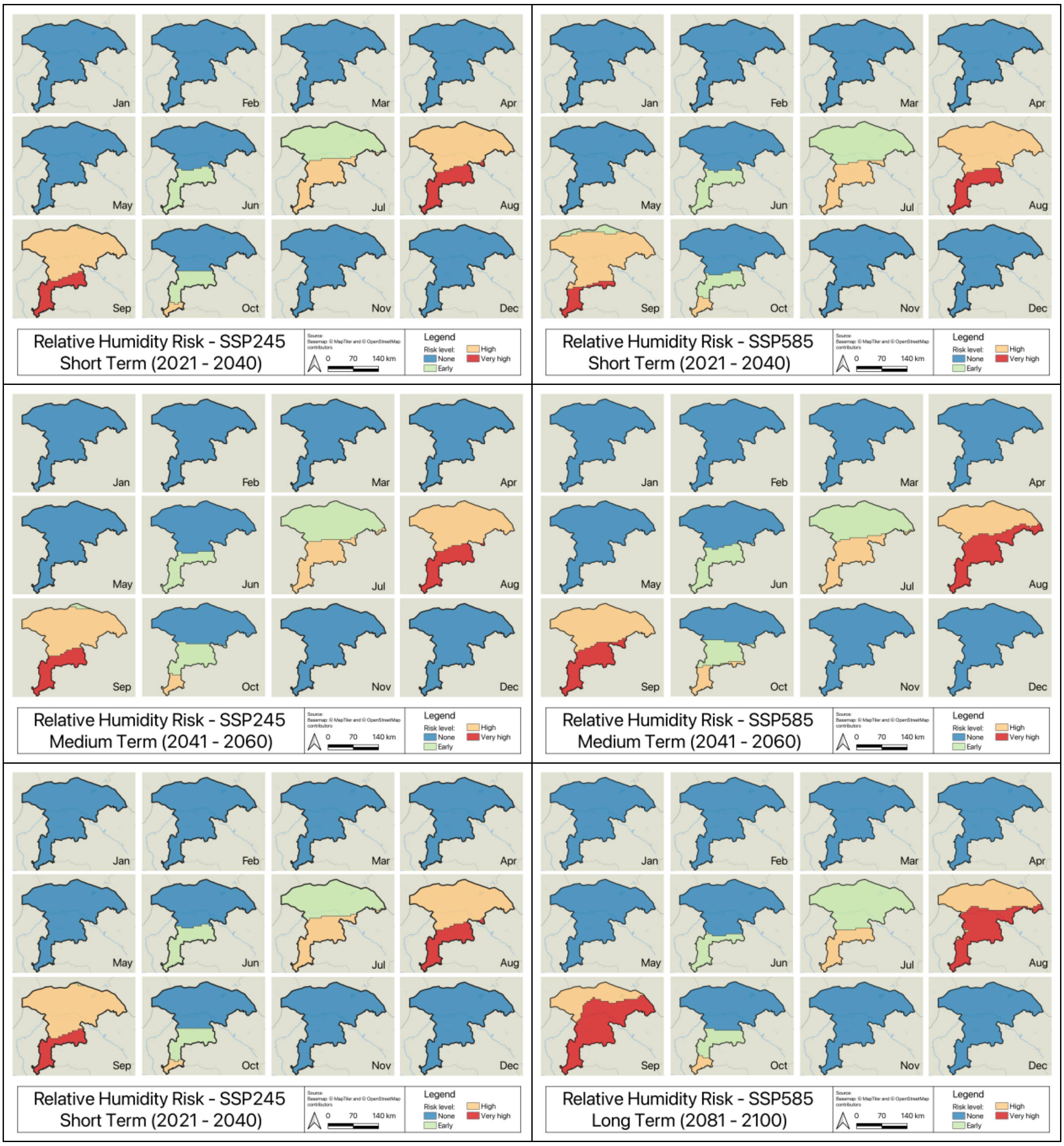
Figure 4 Monthly max temperature in Sokoto state under SSP2 and SSP5 scenarios for 2021-2040 (short term), 2041-2060 (medium term), and 2081-2100 (long term).



This contrast highlights that months with lower relative humidity but higher maximum temperatures may impose equal or greater heat-related health stress, as periods of high relative humidity exacerbate thermal discomfort and physiological strain for both patients and health workers by reducing the body's ability to regulate temperature through sweating. In health facilities without adequate ventilation, cooling, or climate-adaptive design, high humidity contributes to uncomfortable indoor environments that can affect patient tolerance, staff performance, and overall service conditions.

Conversely, very high RH during months with lower Tmax may contribute to discomfort, particularly for vulnerable population, including children, elderly individuals, and patients with chronic or cardiovascular conditions, who may be more sensitive to impaired thermoregulation, but does not necessarily correspond to peak heat stress. For health workers, prolonged exposure to humid conditions can reduce concentration and endurance, especially when combined with moderate to high temperatures. Therefore, RH-based risk categories represent potential impacts on thermoregulation rather than a direct indicator of heat stress.

Figure 5 Relative Humidity Risk Sokoto in Sokoto state under SSP2 and SSP5 scenarios for 2021-2040, 2041-2060, and 2081-2100



2.2.5. Wildfire

Methodological considerations

Analysis of VIIRS (Visible Infrared Imaging Radiometer Suite, a powerful sensor aboard NOAA (National Oceanic and Atmospheric Administration from the United States of America) satellites that provide daily global fire monitoring) active fire detections indicates an overall increase in the number of fires across Sokoto state in recent years. The detections also show a strong seasonal pattern, with most fire occurrences concentrated between October to May. The wildfire hazard analysis incorporated two primary variables representing heat and dryness: the number of days exceeding the 90th percentile of daily maximum temperature (TX90p), and relative humidity (RH). Dryness was calculated to its inverse form as:

$$Dryness = 1 - RH/100$$

Values close to 0 indicate humid conditions and values near 1 indicate very dry conditions.
Both variables were analysed per month, focusing only on months when fires are likely to occur (October to May).

The monthly wildfire hazard index was calculated as the average of the normalized heat and dryness:

$$Wilfidre_{hazard} = 0.5 * TX90p_{norm} + 0.5 * RH_{dryness}$$

Where TX90pnorm represents the fraction of days in a month above the 90th percentile threshold, and equal weighting (0.5 each) was assigned for both variables. The resulting values were classified into five hazard levels using equal-interval thresholds:

- Low: 0.00 – 0.20
- Moderate: 0.20 – 0.40
- High: 0.40 – 0.60
- Very high: 0.60 – 0.80
- Extreme: 0.80 – 1.00

Finally, to complement the climatic hazard index, a spatial analysis of historical fire detections (VIIRS, 2016–2025, high-confidence records only) was incorporated. The density of fire detections was calculated and normalized to a 0–1 scale to identify areas with recurrent fire activity. This historical layer was then used to slightly adjust the climatic hazard values, ensuring that locations with frequent past fire events received proportionally higher hazard scores. In addition to reflect wildire reoccurrence, this adjustment indirectly accounts for the presence of combustible vegetation, which is a key component of wildfires.
The adjustment was applied conservatively, with maximum increases of 5–10% to avoid overestimating hazard levels. The updated hazard surface therefore integrates both climatic conditions and historical fire recurrence, resulting in a more realistic spatial representation of wildfire risk across Sokoto State.

Assumptions and Limitations:

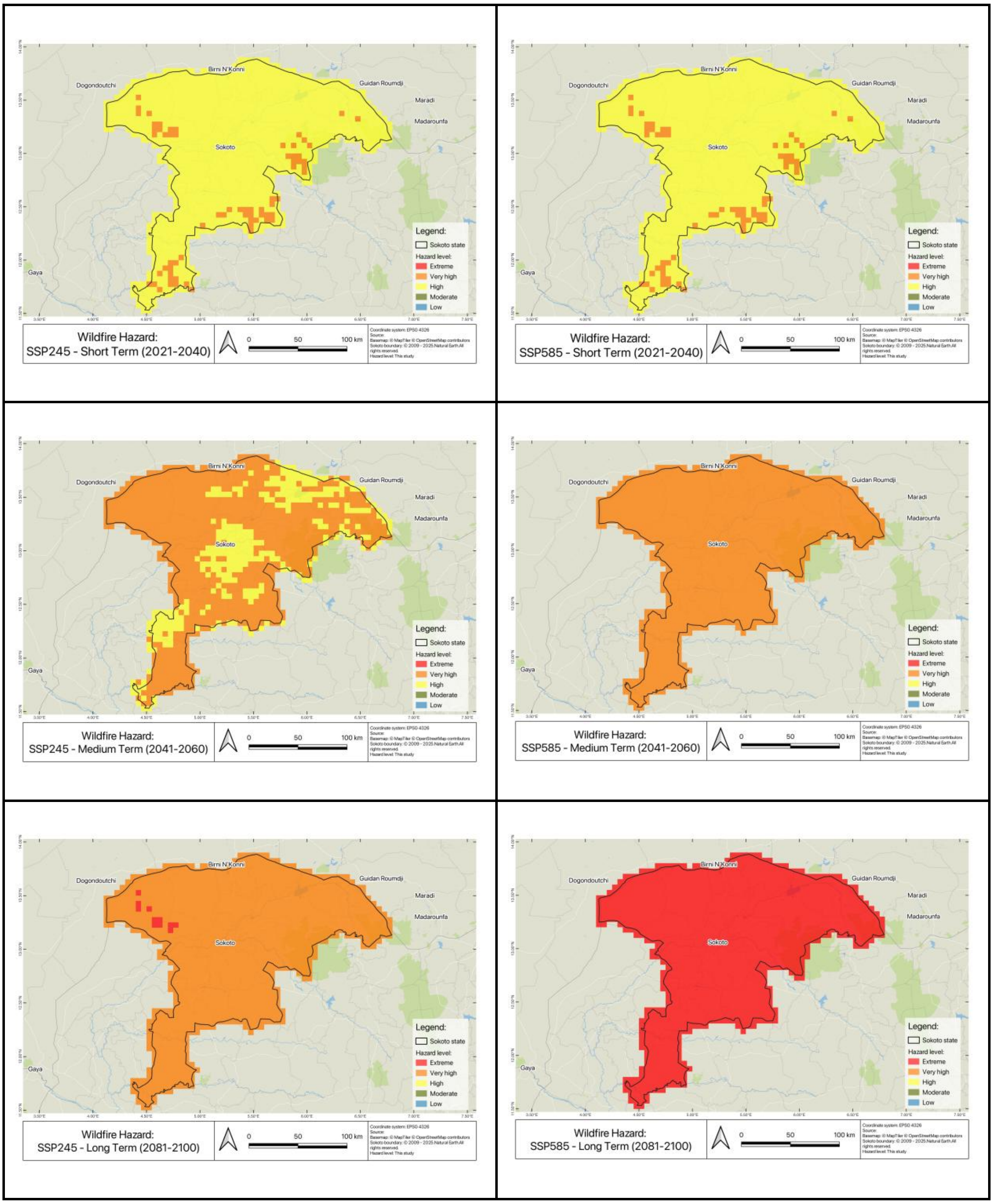
- Heat and dryness are assumed to contribute equally to wildfire hazard.
- Monthly remotely sensed information suggests that wildfire hazard season is between October and May. Hence, these were the months that were analysed to determine wildfire hazard level.

Wildfire across Sokoto State shows a progressive increase across time horizons and future projections during the fire season (October-May). Under the short-term horizon (2021-2040), wildfire hazard is generally high across most of Sokoto state under both SSP2 and SSP5 scenarios. However, localized increases to very high hazard levels are evident in some areas.

By the medium-term period, wildfire hazard intensifies significantly, especially under the SSP5 scenario, where very high hazard level is projected across Sokoto state. Even under SSP2 scenario, hazard levels are projected to rise, with very high hazard levels areas expanding compared to the short-term period.

Finally, under the long-term projections there is a substantial increase in wildfire hazard, particularly under the SSP5 scenario, where extreme hazard levels emerge across Sokoto state.

Figure 6 Wildfire Hazard Sokoto in Sokoto State under SSP2 and SSP5 scenarios for 2021-2040, 2041-2060, and 2081-2100



Increasing wildfire hazard has implications for both population health needs and health system operations. Smoke and reduced air quality during the fire season contribute to respiratory symptoms and exacerbation of existing conditions, increasing outpatient demand, particularly at primary-level facilities.

Wildfire conditions also coincide with periods of high temperature and low humidity, compounding heat-related stress for both patients and health workers. These combined conditions place additional pressure on facilities with limited ventilation, cooling, or protective infrastructure, especially in rural and remote areas.

While wildfires do not typically cause direct damage to health facilities, their interaction with extreme heat, seasonal access constraints, and increased service demand can contribute to service strain and temporary disruptions, particularly at the primary care level during peak fire periods.

2.2.6. Flooding

Flood hazard was assessed using two complementary analyses, designed to capture both direct impact on health facilities and indirect impacts on accessibility through the road network. This approach considers that flooding can affect health services not only through inundation of facilities themselves (direct), but also by disrupting access routes between primary health facilities and second and tertiary health facilities (indirect).

Direct hazards were assessed for both pluvial (rainfall-driven) and fluvial (river-related) flooding. However, the indirect accessibility analysis was conducted for pluvial flooding only, as insufficient data on bridge locations and river-crossing infrastructure limited the ability to reliably assess fluvial impacts on road connectivity.

Direct Flood Hazard to Health Facilities

Methodological considerations: Direct Flood Hazard to Health Facilities

The direct flood hazard to health facilities was assessed based on flood depth, following approaches commonly used to evaluate impacts on people and buildings. Maranzoni et al. (2022) provide a comprehensive review of flood hazard assessment methods, noting that flood depth and flow velocity are the primary indicators in most frameworks. However, as flow velocity data were not available for this project, a depth-only approach was adopted.
To remain cautious with respect to potential disruption on health facility operations, the method proposed by Mani et al. (2014 cited in Marazoni et al. 2022[xiii]), was adapted. While Mani et al (2014)[xiv] applied a five-level hazard classification incorporating depth, flow velocity and flood duration, this analysis used a three-level classification based solely on flood depth. Reliable data on flow velocity and flood duration were not available for Sokoto state; therefore only flood depth could be used across scenarios. Flood hazard levels thresholds were defined as the following:

- Low: 0.10 – 0.20 m
- Medium: 0.21 – 0.60 m
- High: >60 m

Flood depth was obtained from Fathom for both, pluvial and fluvial (undefended) flooding. The same thresholds were applied consistently to both flood types. Flood hazards levels were assigned to health facilities by spatially intersecting facility locations with flood depth rasters for each scenario.

Assumptions and Limitations:

- Flood depth was assumed to be sufficient to represent direct flood hazard to health facilities due to the absence of flow velocity data.
- Flood depth thresholds adapted from Mani et al. (2014) are assumed to be applicable when simplified from a five-level to a three-level classification.
- The main analysis focuses on the 100-year return period; results for shorter return period are provided in Annex 2.

Direct flood hazard to health facilities: Pluvial

Direct pluvial flood hazard to health facilities varies notably across return periods, time horizons and climate scenarios, with return period as the dominant drives of hazard magnitude.

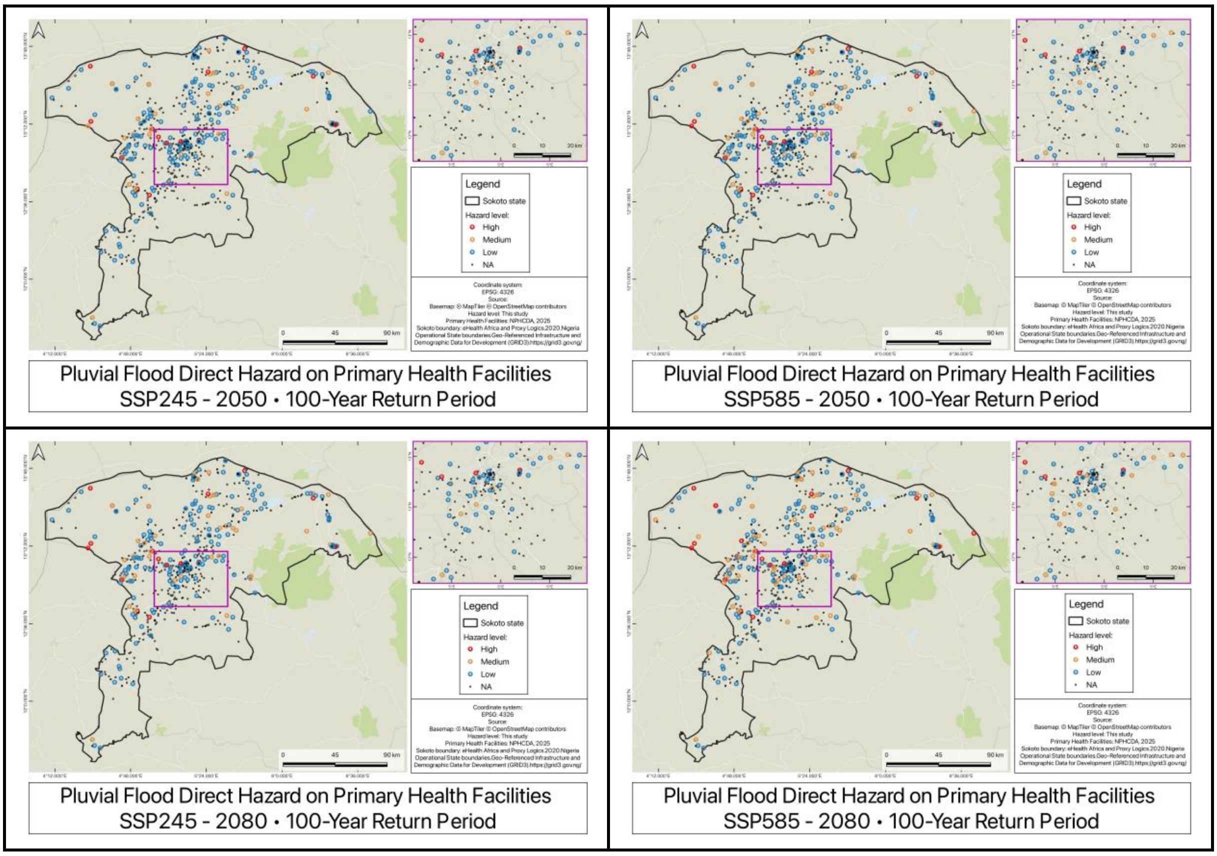
100-year return period

At the 100-year return period, direct flood hazard to health facilities increases substantially relative to both 5-year and 10-year return periods (Annex 2). A considerably larger number of facilities are classified as medium and high hazard levels. This pattern is consistent across scenarios and time horizons, indicating that pluvial flooding shows a significant risk to health facilities regardless of future climate change scenarios.

Under the SSP2 scenario, 11 health facilities are projected to increase their pluvial flood hazard level from low to medium between 2050 and 2080. In contrast, under the SSP5 scenario, 27 facilities are expected to experience the same increase in hazard level over the same period.

Transitions from medium to high hazard levels represent a more critical escalation. While only one facility is projected to increase from medium to high hazard between 2050 and 2080 under SSP2, this number increases to seven under SSP5, indicating a substantially greater progression.

Figure 7 Pluvial flood direct hazard healthcare facilities 100 year return period in Sokoto State under SSP2 and SSP5 scenarios for 2021-2040, 2041-2060, and 2081-2100

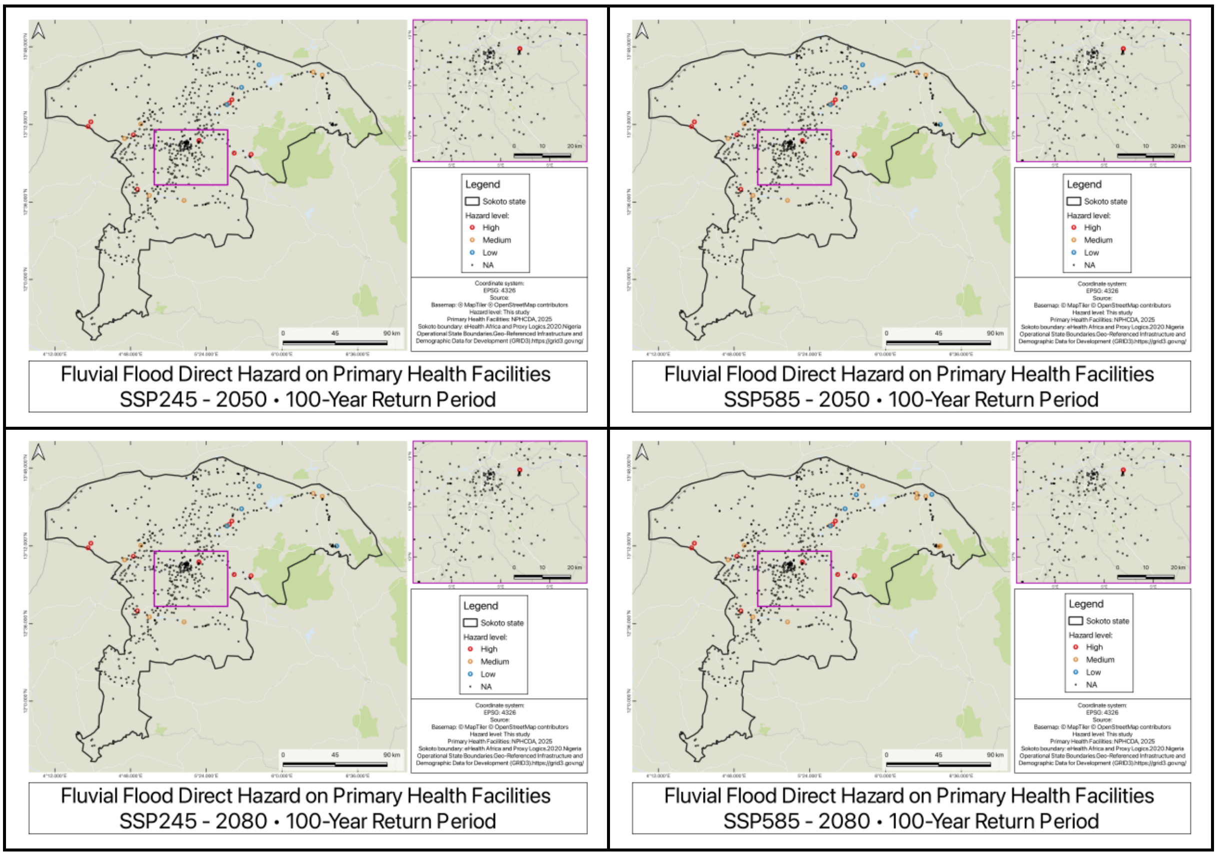


Direct flood hazard to health facilities: Fluvial

Direct fluvial flood hazard to health facilities is consistently lower than pluvial flood hazard across all analysed scenarios, time horizons and return periods. Overall, fewer health facilities are exposed to fluvial flooding compared to pluvial flooding.

No significant differences are observed between scenarios or periods; however, hazard levels increase with return period (Annex 3).

Figure 8 Fluvial flood direct hazard health facilities 5 year return period in Sokoto State under SSP2 and SSP5 scenarios for 2021-2040, 2041-2060, and 2081-2100



Indirect Flood Hazard: Road network

Methodological considerations: Flood impact on accessibility: road network analysis
The road network for Sokoto state was obtained from NextGIS. The dataset included road classification attributes. They were reprojected from EPSG 4326 to EPSG 3857 to enable metric-based operations.
Baseline traves speeds (km/h) were assigned to each road class using values adapted from the global OpenStreetMap speed table for Nigeria developed by Weiss et al. (2020) as: primary (70 km/h), secondary (60 km/h), tertiary (50 km/h), residential (30 km/h), trunk (120 km/h), unclassified (50 km/h), service (20 km/h), and track (30 km/h). The only road type that was reclassified to match this classification was “living street” which was considered as residential. It is important to note that even if the speed for some of the roads may seem too high (for example 120 Km/h) they are not being considered as raw values for this assessment. Instead, we rely on the relative difference, which reduces the overestimation.
Pluvial flood depths were obtained from Fathom for two climate scenarios (SSP2 and SSP5), two periods (2050 and 2080) and three return periods (5, 10 and 100 years). The flood depth information from these datasets were spatially linked to the road network to determine which road segments were affected under each scenario. For each flood map, the maximum flood depth intersecting a road segment was extracted and associated with that segment. These depth values were then used to determine whether a road remained passable and to adjust travel speeds accordingly.
Flood impact on travel speed was modelled using a depth-dependent rule set derived from vehicle stability literature, which identifies approximately 30 cm as the threshold at which standard passenger vehicles are likely to lose traction or float[1].
For each flood scenario, a new speed field (speedFL) was calculated:

- 0 cm: 100 of baseline speed
- 1 – 10 cm: 80% of baseline speed
- 11 – 20 cm: 50% of baseline speed
- 20-31 cm: 30% of baseline speed
- >= 32 cm: road segment removed, treated as impassable

All segments exceeding the 32 cm thresholds were deleted from the road network prior to the network route analysis, ensuring that the connectivity model reflected road closures rather than reduced speed. The speed reduction rates were assigned to reflect likely conditions in flood events that could potentially impact travel speed considering reduced tire friction and breaking.
This method was applied for each scenario (2020, SSP2-2050, SSP5-2050, SSP2-2080, SSP5-2080) and for each return period (5, 10, 100 years). Thus, each scenario had an independent flood- adjusted road network.
Routes: Primary health facilities were treated as origins, whereas secondary and tertiary facilities as destinations. Routing was performed using QNEAT3 OD Matrix for Layers tool with:

- Network layer:
  - Baseline: roads with speedFL from Fathom 2020.
  - ScenariosL roads with scenario specific speedFL and flooded roads removed
- Speed field: speedFL
- Topology tolerance: 500 meters
- Output: travel time in seconds

For each primary facility, the minimum travel time to any secondary or tertiary facility was extracted as its effective accessibility metric for that scenario.

Delay calculation and hazard levels

For each primary facility, percentage change in travel time between the baseline (2020) and future scenarios was computed as:

$$\% \ change = \frac{Time_{scenario} - Time_{2020}}{Time_{2020}} * 100$$

Hazard levels were determined as:

- Low: <20%
- Moderate: 21 – 40%
- High: 41 – 60%
- Very high: 61 – 80%
- Extreme: > 80%

Facilities that became completely unreachable produced null values; however, since this isolation may result from incomplete road data, these cases were assign to the Extreme category rather than flagged separately.

[1] https://doi.org/10.1016/j.rineng.2024.102540

<u>Assumptions and Limitations:</u>

- The NextGIS road network is assumed to represent real-world connectivity and type of roads. Missing or miss-classified roads may affect real-world accessibility estimates.
  - Despite some assigned speeds (e.g. 120 Km/h) may exceed realistic values, it is assumed that relative differences between road types are more important than absolute speeds.
  - The analysis assumes standard vehicles and does not differentiate between vehicle types or emergency transport conditions.
  - The flood depth reductions in speed based on vehicle stability from the literature is assumed to represent realistic travel disruption during flood events.
  - Roads exceeding 32 cm flood depth are assumed to be impassable. This assumption reflects car stability from the literature, which identifies approximately 30cm of flooding as a critical loss of control threshold for standard vehicles[xv]. The same literature was used to determine depth dependant speed reductions when flooding was less than 32 cm.[xvi]
  - The minimum travel time to the nearest secondary or tertiary health facilities is assumed to be indicative of healthcare accessibility.
- Health facilitates that could not be connected to the road network due to data or network gaps were assumed to experience extreme accessibility hazard. Instead of treating these cases as data limitations, they were classified as worst-case accessibility conditions, acknowledging that disconnected health facilitates are likely to be effectively inaccessible during hazard events. This approach may overestimate the accessibility hazard for some facilities but avoids underestimating service disruption where network connectivity in uncertain.

The main analysis focuses on the 100-year return period; results for shorter return period are provided in Annex 4.

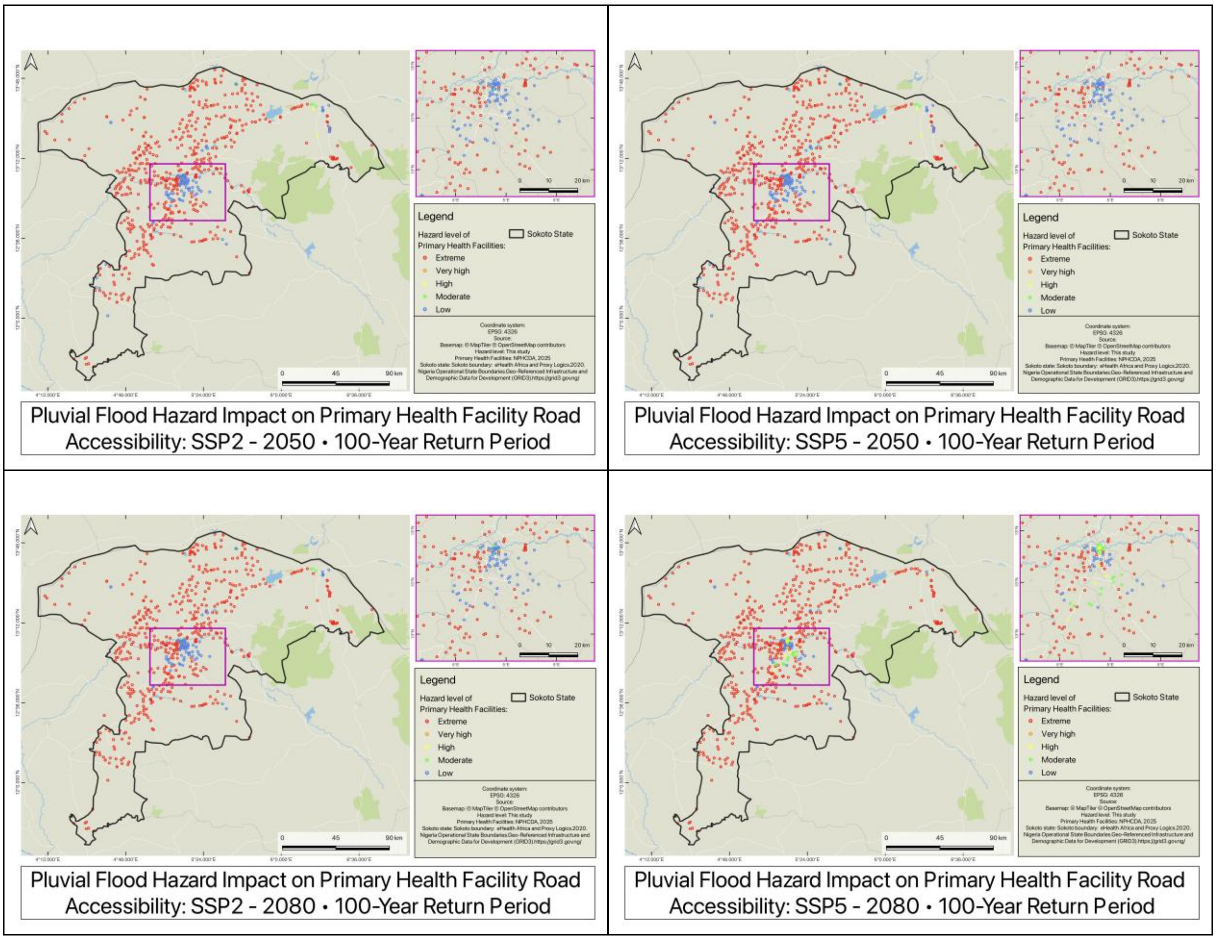
Seasonal pluvial flooding is a major driver of transport network interruptions across Sokoto State, particularly in rural areas, where many access roads become impassable multiple times per week during the rainy season. These routes form the primary connection between dispersed settlements and frontline health facilities, especially Health Posts, Health Clinics, and PHCs, creating recurrent gaps in service access when road conditions deteriorate. This situation worsens for the different climate scenarios, as well as for the different return periods.

A considerable higher number of facilities are impacted, and under the 100 year return period most facilities (with exception of the majority of those located inside Sokoto city limits) have an extreme hazard level. Pluvial flood hazard road accessibility for 5-year and 10-year return periods are noted in Annex 4.

At 100-year return period, in 2050 indirect flood hazard to health facility accessibility shows small differences between SSP2 and SSP5. The majority of facilities are already classified within the extreme hazard category under both scenarios.

By 2080, differences between scenarios are more evident. Under SSP2, changes remain moderate, with a gradual increase in facilities classified under extreme hazard. In contrast, under SSP5, the number of facilities classified under extreme hazard increases significantly, along with notable increases in high and very high hazard categories.

Figure 9 Pluvial flood hazard road accessibility in Sokoto State under SSP2 and SSP5 scenarios for 2021-2040, 2041-2060, and 2081-2100:, across 5, 10 and 100 year return periods



While direct inundation of health facilities is most pronounced during extreme flood events, even moderate flooding disrupts service delivery by affecting access routes and supporting infrastructure.

Flooding: Implications for health service

Seasonal pluvial flooding frequently renders feeder roads impassable, particularly in rural LGAs, such as Sabon Birni, Isa, Goronyo, Rabah, and Illela. When access routes are disrupted, movement between communities and frontline facilities is constrained, and referrals from primary facilities to secondary and tertiary hospitals are delayed. Because Sokoto's referral architecture is linear and depends on a limited number of feeder roads, even short-term disruptions result in delays in reaching PHCs and secondary hospitals. The problem is amplified by the absence of alternative routes and very limited ambulance availability; most emergency transfers rely on motorcycles or public transport, which cannot operate during flooding. As a result, time-sensitive conditions, such as obstetric emergencies, severe malaria, respiratory distress, trauma, and neonatal complications, face substantial delays in care.

Flooding affects both emergency and routine health services. Emergency referrals for obstetric complications, severe malaria, trauma, and neonatal conditions are particularly sensitive to road disruption. At the same time, routine service delivery, including immunisation outreach, antenatal care, commodity resupply, and health reporting, is often suspended during flood events. Additionally, vaccines resupply is delayed. For communities served by exposed Health Posts and Clinics, flooding can temporarily cut off access to primary care altogether. These interruptions also have broader implications for the health system. Reduced access to primary facilities increases demand for spikes at non-flooded PHCs and hospitals, contributing to congestion and longer waiting times. Surveillance systems are also weakened when Health Posts and PHCs become unreachable, delaying detection of climate-sensitive outbreaks such as cholera, meningitis, and malaria.

Flood-related access disruptions also have implications for cold-chain functionality. When roads are flooded, health workers may be unable to collect vaccines from functional cold-chain points or conduct outreach sessions as planned, leading to cancelled sessions and missed vaccinations. In areas where caregivers are redirected to attend services in other wards, long travel distances, heat exposure, and seasonal flooding further discourage attendance.

Over time, repeated flood disruptions weaken service continuity, referral reliability, and disease surveillance, particularly in rural and flood-prone areas. As flood frequency and intensity increase under future climate scenarios, these impacts are expected to generate cascading effects across the health system, compounding existing infrastructure and access constraints and increasing vulnerability to concurrent shocks.

2.2.7. Multi Hazard Hotspot Analysis

Hazard hotspots were defined as areas where extreme heat, wildfire and flood hazards (100-year return period) coincide at High, Very High, or Extreme levels under mid-term (2050) climate projections. These hotspots were used to identify patterns of exposure across facility types and service functions, and to assess how climate risks translate into system-level disruption over time.

Methodological considerations

The hotspot selection is based on SSP5 (high-emissions scenario) for the mid-term time horizon, reflecting a plausible worst-case trajectory for climate impacts relevant to health system resilience. Flooding hazards are assessed using a 100-year return period, consistent with the objective of identifying high-impact but plausible disruption scenarios for critical infrastructure.

Climate Hazards

Four climate hazards are considered in the analysis:

- heatwaves
- wildfire,
- pluvial flooding, and
- fluvial flooding.

However, the role of these hazards in hotspot selection differs based on their spatial characteristics. Extreme heat and wildfire are projected to occur at uniformly high hazard levels across Sokoto State under the selected scenario and time horizon. As a result, these hazards do not provide spatial differentiation between wards and are therefore not used as ranking variables for hotspot selection. Nevertheless, they remain highly relevant for subsequent system disruption and asset-level analyses. By contrast, pluvial flooding and fluvial flooding show clear spatial variability across wards (while consistently “high” where they are projected to occur) and represent key drivers of location-specific health system disruption, particularly through impacts on facility access, referral pathways, and service continuity.

Based on this distinction, an initial preselection step is applied - only wards in which at least one health facility is exposed to pluvial flooding and/or fluvial flooding under the 24h 100-year return period rainfall event are retained for hotspot scoring.

General assumptions and Limitations for the Health System Impact:

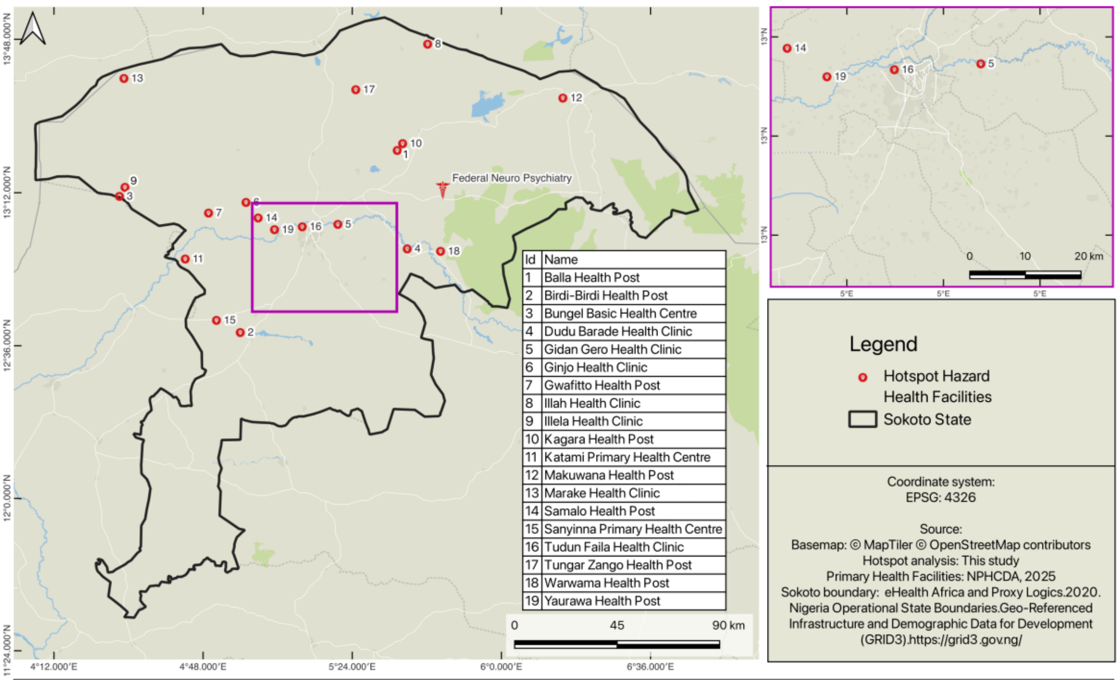
- The health system impact analysis translated spatial climate hazard outputs into network-level implications for health service delivery in Sokoto State. The analysis adopted a health systems perspective, recognising that climate hazards affect functionality, connectivity, and reliability across interlinked service pathways.
- The assessment was anchored in Sokoto State's three-tier service delivery structure (primary → secondary → tertiary) and built on climate hazard mapping that identified health facilities located within multi-hazard hotspot zones, where extreme heat and flooding coincide at high to extreme levels. Facilities within these zones formed the initial analytical sample for assessing system-level exposure. Health facilities were classified by service level—health posts, health clinics, Primary Health Centres (PHCs), secondary hospitals, and tertiary hospitals, and analysed according to their typical service functions and referral roles within the health system network. This enabled interpretation of how climate hazards may disrupt continuity of care, referral pathways, and service availability. Referral relationships and service functions were interpreted using standard health system structures in Sokoto State, as facility-specific patient flow and service readiness data were not consistently available.
- A healthcare system hotspot scoring was applied to prioritise facilities and geographic areas where climate hazards are most likely to generate amplified health system impacts. The scoring combined three dimensions: (i) multi-hazard severity (extreme heat, wildfire, and flooding), (ii) the number of health facilities within each hotspot, and (iii) the size of the population potentially dependent on services in the affected area (see also chapter 4).
- The resulting prioritised subset of hotspot facilities formed the basis for a focused healthcare disruption analysis. This analysis examined how climate hazards may impair service delivery through both direct facility-level impacts, such as damage, overheating, or access constraints, and indirect, cascading effects across the referral network, including delays, service overload at higher-level facilities, and interruptions to routine and emergency care.
- The analysis relies on available spatial health facility datasets and standard service-level classifications. Detailed information on service readiness, staffing, utilisation, and surge capacity was not consistently available across facilities. Referral pathways and service functions were therefore interpreted using established health system structures and typical patient flows in Sokoto State, rather than empirical referral data, which may vary in practice.
- Of the 28 facilities identified in hazard hotspot zones, a subset (n=9) could not be assigned precise geographic coordinates. These facilities were included in the qualitative functional analysis to understand service roles and network dependencies but were excluded from the quantitative healthcare system scoring and site-specific spatial interpretation for the disruption analysis.

Health facility hotspots are predominantly distributed across the central and northern parts of the state as shown in the following table and map; indicating that populations in these areas are more likely to be affected by multi-hazard impacts on health facility access.

Figure 10 Hotspot Hazard Health Facilities in Sokoto State under SSP2 and SSP5 scenarios for 2021-2040, 2041-2060, and 2081-2100:

Balla Health Post	Kagara	Goronyo
Birdi-Birdi Health Post	Bengaje	Yabo
Bungel Basic Health Centre	Karfe Chana	Gugu
Dudu Barade Health Clinic	Rarah	Rabah
Gidan Gero Health Clinic	Durbawa	Kware
Ginjo Health Clinic	Inname	Binji

Gwafitto Health Post	Soron Gabas	Binji
Illah Health Clinic	Dukamaje	Gada
Illela Health Clinic	Karfe Chana	Gugu
Kagara Health Post	Kagara	Goronyo
Katami Primary Health Centre	Katami North	Silame
Makuwana Health Post	Makuwana	Sabon Birni
Marake Health Clinic	Marake	Gudu
Samalo Health Post	Gwamatse	Wamakko
Sanyinna Primary Health Centre	Sanyinna	Tambuwal
Tudun Faila Health Clinic (urban)	Sarkin Adar Gidan Igwai	Sokoto North
Tungar Zango Health Post	Darna Sabon Gari	Illela
Warwama Health Post	Gandi 1	Rabah
Yaurawa Health Post	Kaura	Wamakko



Hotspot Hazard Health Facilities in Sokoto State

Primary care facilities dominate the exposure profile: 14 Health Posts, 9 Health Clinics, 3 PHCs, and 1 Basic Health Centre. Under mid-term (2050) conditions, exposure is already evident under both SSP2 and SSP5, with more facilities affected and more frequent disruption under the high-emissions pathway. By long-term (2080), particularly under SSP5, exposure becomes widespread and persistent across primary-level facilities. This concentration of exposure indicates that climate hazards intersect directly with the system's most frequently used and least resilient tier, amplifying existing constraints related to infrastructure, staffing, power, and water. Health Posts, typically the least equipped and serving remote communities, represent the largest exposed group, while Health Clinics and PHCs provide higher-volume services and

cold-chain functions that become increasingly vulnerable as heat extremes and flooding intensify over time.

Table 2 Hotspot Facilities and Affected Essential Services

Facility Type	Number in Hotspots	Key Services Provided	Most Likely Climate-Hazard Impacts
Health Posts	14	First-contact care; maternal, newborn and child health counselling; hosting of outreach immunisation sessions; basic disease surveillance	Flooded access routes; unsafe indoor temperatures; cancellation of outreach sessions; temporary interruption of routine services.
Health Clinics	9	Outpatient consultations; minor emergency care; session-site immunisation; short-term stabilisation	Heat stress affecting staff and patients; increased risk of vaccine temperature excursions; higher caseload during heatwaves; disruption to outreach and resupply during floods.
Primary Health Centres	3	Maternal, newborn and child health services; deliveries; vaccine storage and immunisation coordination; referral management; health reporting	Disruption affecting multiple dependent facilities; heat-sensitive commodities at risk; delays in emergency referrals during flood events.
Basic Health Centre	1	Outpatient care; maternal health services; stabilisation before referral	High sensitivity to flooding; risk of temporary closure and reduced service capacity.
Federal Neuro-Psychiatric Hospital	1	Specialist mental health care; inpatient and emergency psychiatric services	Heat-sensitive medication storage issues; compromised access during floods; interruption of critical specialised care.

The exposure of the Federal Neuro-Psychiatric Hospital in Sokoto, a major regional referral facility for specialist mental health services in the north-west, introduces a distinct system-level risk. While limited exposure is observed in the mid-term, long-term exposure under SSP2 represents a critical vulnerability, given the facility's reliance on controlled indoor environments, uninterrupted medication supply, and secure transport. Disruption at this level has limited substitution options and carries implications beyond Sokoto State, affecting patients from neighbouring Kebbi and Zamfara States.

Most hotspot facilities sit at the point where communities first enter the health system, and climate stresses are likely to affect essential services across the continuum of care. Maternal, newborn, and child health (MNCH) services are particularly vulnerable: high indoor temperatures affect antenatal, delivery, and postpartum care in facilities without stable power or ventilation, while flooding delays movement to PHCs for emergency obstetric management.

Routine immunisation is exposed through two main pathways. Heatwaves increase the risk of cold-chain failure, which is already under stress due to unreliable access to energy, in PHCs and Health Clinics where vaccine storage occurs, while floods disrupt outreach and re-supply. Health Posts, which typically do not store vaccines but host outreach sessions, are highly sensitive to access barriers; when roads are cut off, immunisation sessions are cancelled, reducing coverage in remote settlements.

While system-level information indicates that all wards are intended to maintain cold-chain capacity, field-level evidence suggests that functional cold-chain coverage is uneven. Field interviews indicated that in several wards, vaccine refrigerators have been non-functional for extended periods, requiring health workers to travel to neighbouring wards with operational cold-chain facilities to collect vaccines for scheduled sessions. In these cases, vaccines are transported manually and any unused doses are returned the same day to avoid spoilage. Where cold-chain access is unavailable, caregivers may be directed to attend immunisation services in other wards. For many households in remote communities, this effectively results in missed vaccinations. Walking remains the dominant mode of transport, with caregivers often travelling in groups and lacking the financial means to use commercial motorcycles. Long distances, heat exposure, and seasonal flooding further discourage attendance, contributing to drop-offs in routine immunisation coverage.

These informal coping mechanisms allow services to continue in the short term but introduce significant vulnerabilities. Vaccine transport without dedicated cold boxes, repeated handling, and exposure to extreme heat increase the risk of temperature excursions. Reliance on cross-ward travel also makes immunisation services highly sensitive to transport disruptions during floods and to staff availability during heatwaves.

Outpatient management of malaria, diarrhoea, respiratory infections, and febrile illnesses may also be constrained. Heatwaves both increase caseloads and reduce staff capacity, while floods limit patient movement and delay treatment, with consequences for morbidity in high-burden LGAs. Disease surveillance is similarly affected. Health Posts and PHCs provide the bulk of community-level reporting; when access is disrupted, delays occur in detecting and escalating cases of cholera, meningitis, malaria, and other climate-sensitive diseases.

Emergency stabilization at Health Clinics and PHCs relies on functional roads and power supply, which are often compromised during heat and flood events. Even when secondary hospitals remain operational, disrupted primary-level access weakens referral pathways and increases downstream pressure on higher-tier facilities.

Supply chain operations for essential medicines and reporting forms are similarly affected, creating knock-on effects for stock availability, programme continuity, and data reporting. For communities served by exposed facilities, particularly the 14 Health Posts located in hotspot zones, road disruption effectively cuts off access to primary care, forcing households to postpone treatment or travel much longer distances when roads eventually reopen.

3. Socio Economic Vulnerability in Hazard Hotspot Wards

The social vulnerability assessment aims to identify where disruption of the health system is likely to have the most severe impact on the population, especially in the multi-hazard hotspot zones (with future exposure to heatwaves, wildfire, and flooding). It takes into account healthcare demand and where access to healthcare is structurally most fragile in the event of such disruption. The analysis seeks to support climate-resilient health system planning by linking population characteristics with the spatial configuration of healthcare access.

3.1. Methodology

The quantitative analysis is conducted at ward level for Sokoto State. This spatial scale aligns with the availability of population and health facility data and with the planning relevance of the results. Neighboring states are not included in the quantitative indices or classifications. However, inter-state dynamics relevant to the functioning of Sokoto's health system, such as potential cross-border referrals, are addressed qualitatively where relevant. All indicators are interpreted in relative terms across wards, rather than as absolute measures of risk.

Social vulnerability is operationalized through two complementary analytical pillars, each capturing a distinct mechanism through which climate-related disruptions may affect people. The first pillar captures population-based impact potential, reflecting how many people with elevated dependence on health services would be affected if access were disrupted. The second pillar captures access fragility, reflecting how resilient or fragile local access to healthcare is in the face of service or infrastructure disruption. The two pillars are intentionally kept analytically separate (i.e., they are not collapsed into a single index). They describe different aspects of vulnerability but are interpreted jointly.

1. **Pillar 1: Population-based impact potential**
   The population-pillar measures the scale of potential social impact associated with health system disruption. It is based on the absolute number of people belonging to population groups that typically rely more strongly on continuous access to healthcare services, namely infants (0-1 years of age), children between one and five years of age, women of reproductive age (15–49), and older adults (60+). Available population data derived from GRID3 indicate that age-group shares are uniform across wards, reflecting downscaling from higher administrative levels. Consequently, age-specific population counts are perfectly collinear with total population. Treating individual age groups as independent indicators would therefore create a false impression of differentiation. To address this constraint transparently, the analysis aggregates the three age groups into a single composite indicator representing the total population with elevated healthcare dependency.

   This composite indicator is expressed in absolute numbers, log-transformed to reduce the influence of extreme values, and classified into tertiles. The resulting classes represent relative levels of impact potential across wards. High values indicate wards where a larger number of people would be affected if healthcare access were disrupted. They do not indicate higher susceptibility, poorer health status, or greater socio-economic deprivation.

2. **Pillar 2: Access fragility and system redundancy**
   The access-pillar assesses how fragile or resilient local access to healthcare is if facilities or services are disrupted. It focuses on the structural configuration of access, rather than on service quality, utilization, or outcomes. Access fragility is derived from three complementary indicators.

- The first indicator captures basic first-contact access through the presence or absence of at least one primary healthcare facility in the ward. This indicator reflects whether local access to basic care exists at all.
- The second indicator captures redundancy at the primary care level, measured as the density of primary healthcare facilities relative to population (number of PHC per 10,000 people). This indicator reflects whether the loss of a single facility is likely to result in a critical access failure, allowing to distinguish between wards with buffering capacity and those with single points of failure.

- The third indicator captures referral system layering, distinguishing between i) wards with no secondary or tertiary facilities, ii) those with one level of higher care, and iii) those with both. This indicator reflects the depth and redundancy of the local referral ladder, rather than the quality or capacity of individual facilities.

The three indicators are normalized and combined into a single continuous score representing access resilience, which is then inverted for interpretive clarity (higher values indicate structurally more fragile access in the event of disruption) and classified into tertiles of access fragility. Wards without any health facilities are fully included in the quantitative analysis and, by design, show high access fragility. Their reliance on facilities in neighboring wards is acknowledged in the interpretation of results, rather than being modelled explicitly through inter-ward access adjustments.

The two pillars then are interpreted jointly to characterize different patterns of social vulnerability. In particular, the overlay of population-based impact potential and access fragility highlights wards where large numbers of healthcare-dependent populations coincide with structurally fragile access. This joint interpretation is used to describe socio-spatial patterns of potential social impact and resilience.

Although the quantitative assessment is limited to Sokoto State, the analysis explicitly recognizes that the state's health system operates within a wider regional context. Border wards and higher-level facilities may serve populations from neighboring states and may be subject to additional pressure during disruptions. These dynamics are addressed through qualitative interpretation and narrative discussion, without extending the quantitative indices beyond the project's geographic scope, acknowledging inter-state dependencies while avoiding unsupported precision or scope expansion.

Complementary indicators

Comorbidity-related care intensity - In addition to the two core pillars, the analysis includes a complementary indicator capturing spatial patterns of population groups associated with higher care intensity due to comorbidities. This indicator is derived from GRID3 and combines information on elderly populations (number of people older than 50 years) and female adult obesity rates (share of female adults aged 15 to 49 with a body mass index > 30), following the GRID3 comorbidity risk methodology. The resulting surface is aggregated to ward level and classified into relative classes for interpretive purposes.

The comorbidity indicator is not incorporated into the population impact or access fragility indices, as it conceptually overlaps with age- and gender-related population characteristics and would risk double counting. Instead, it is used as an interpretive lens to highlight areas where health service disruption may entail more complex or resource-intensive care needs, complementing the assessment of impact potential and access fragility.

Security – security conditions were not included as a quantitative indicator in the spatial analysis due to the absence of publicly available, ward-level data of sufficient reliability. Instead, indicative information on security dynamics was drawn from consultations with local practitioners and operational partners familiar with access constraints in Sokoto State. This information is used qualitatively to contextualize and interpret potential disruption impacts, rather than as a basis for classification or scoring.

Spatial analysis and visualization

GIS is used to spatially join, map, and visualize the results of the social vulnerability analysis. All indicators, transformations, and classifications are computed as attribute data prior to visualization. GIS is then used to display these pre-classified results at ward level, to overlay complementary indicators, and to support interpretation of spatial patterns.

- Assumptions and limitations
- While the initial intent was to conduct a broader socio-economic vulnerability assessment, the methodology described above was designed in response to the limited data availability and quality. In particular, the absence of reliable, spatially differentiated data on health conditions, income, livelihoods, or poverty called for a narrower approach. The assessment therefore focuses health system-relevant social vulnerability based on relevant gender-disaggregated age groups, and structural healthcare access, rather than on socio-economic vulnerability in a broader sense (comprehensive measure of socio-economic disadvantage).
- The methodology assumes that available population and facility datasets provide a reasonable basis for comparative spatial analysis at ward level, despite known limitations in demographic differentiation. It further assumes that structural characteristics of healthcare access are meaningful proxies for access fragility in the absence of detailed utilization or referral flow data.

3.2. Results - Distribution of Health Care Needs Across Hotspot Wards

Below map (Figure 11) shows the relative impact potential of health care needs across wards in Sokoto State. Wards are classified into low, medium, and high impact potential based on the concentration of population groups with elevated health care needs, indicating areas where disruptions to health services would potentially affect a larger number of people.

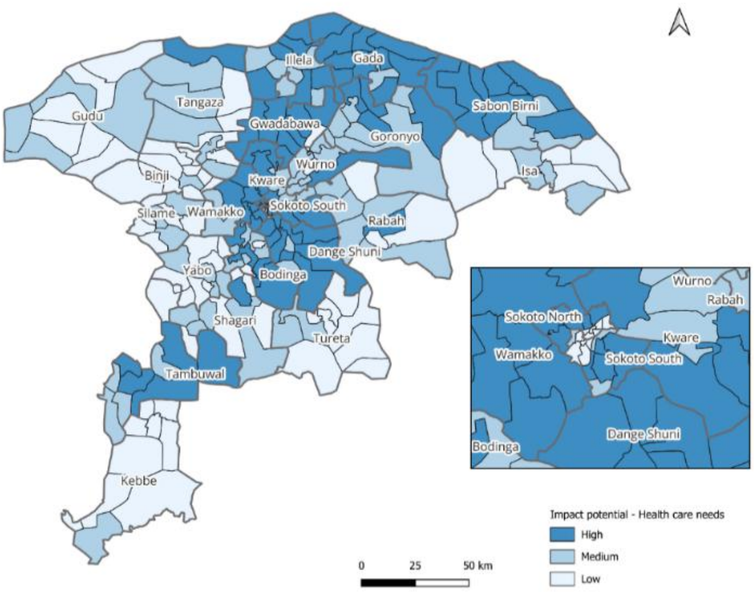


Figure 11: Impact potential of health care needs by ward

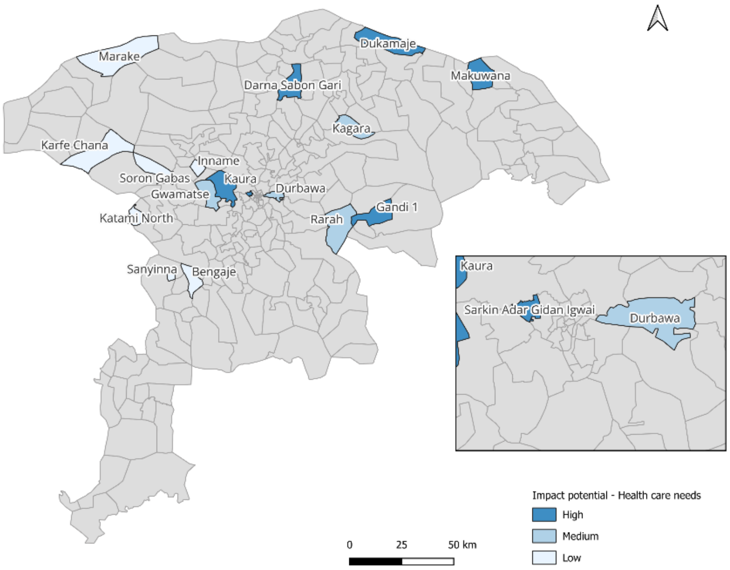


Figure 12: Impact potential of health care needs in hazard hotspot wards

Across the 17 multi-hazard hotspot wards (Figure 12), the distribution of populations with higher health care needs shows clear differentiation. Six wards fall into the highest needs class, four into the medium class, and seven into the lowest class, indicating that vulnerability is spatially concentrated rather than evenly distributed.

The **highest-needs class** includes the rural wards Dukamaje (Gada), Makuwana (Sabon Birni), Kaura (Wamakko), Darna Sabon Gari (Illela), and Gandi 1 (Rabah), as well as the urban ward Sarkin Adar Gidan Igwai (Sokoto North). In these locations, the number of people with elevated health care needs ranges from approximately **13,000 in Gandi 1 to over 24,000 in Dukamaje**, reflecting substantial baseline demand for health services even before climate-related pressures are considered.

Across this group, the demographic structure is broadly consistent, with high concentrations of young children (1 to 5) and women of reproductive age driving overall need. Dukamaje, for example, illustrates the scale of this demand particularly clearly, with more than 11,700 children aged 1–5, approximately 1,450 infants, over 9,300 women of reproductive age, and nearly 1,500 adults aged 60 and above. This concentration implies sustained pressure on maternal and child health services, and a high sensitivity to any disruption affecting facility functionality, staffing, or supply chains.

A similar pattern is observed in Makuwana and Kaura, where the same age structure translates into slightly lower but still substantial absolute numbers: In Makuwana, the high-needs population includes around 1,177 infants, 9,503 children aged 1–5, 7,574 women of reproductive age, and 1,205 older adults. Kaura shows a comparable profile, with approximately 1,164 infants, 9,405 children aged 1–5, 7,496 women of reproductive age, and 1,192 adults aged 60 and above. In these wards, the scale of demand across multiple age groups underscores the potential for rapid service overload if access is disrupted.

Gandi 1 (Rabah) and Darna Sabon Gari (Illela) also fall within the highest-needs category, with total high-need populations exceeding 13,000–17,000 people. In both cases, large numbers of young children and women of reproductive age dominate the needs profile, while the presence of sizeable older populations further increases sensitivity to service interruptions, particularly in relation to chronic disease management and continuity of care.

The **middle-needs class**, including Durbawa, Gwamatse, Kagara, and Rarah, occupies an intermediate position, with typically **8,500 to 11,500 people with higher health care needs**. Although overall population pressure is lower than in the highest-needs wards, these locations still host substantial vulnerable groups. For example, Durbawa includes over 5,000 children aged 1–5 and more than 4,000 women of reproductive age, while Gwamatse shows a similar pattern with more than 4,400 women of reproductive age and around 5,500 young children. In Rarah, the number of children under five exceeds 5,400, indicating a continued reliance on maternal and child health services despite the ward's mid-range classification.

In the **lowest-needs class**, comprising Bengaje, Karfe Chana, Inname, Marake, Katami North, Soron Gabas, and Sanyinna, the absolute number of people with elevated health care needs is smaller, generally between **2,500 and 7,500 individuals**. Nevertheless, important pockets of vulnerability remain. For instance, Bengaje and Soron Gabas have over 3,400 children aged 1–5, while Sanyinna includes more than 2,600 young children and over 2,100 women of reproductive age. Karfe Chana, with the lowest absolute number of people with higher health needs among the hostpot wards (2576), counts with 156 infants, 1258 children aged 1-5, 1003 women of reproductive age, and 159 adults aged 60+.

Overall, the distribution of health care needs across hotspot wards highlights that vulnerability is shaped not only by exposure to climate hazards but also by the absolute number and composition of populations dependent on health services. Because age group data are only available in relative terms at the state level, the demographic structure is uniform across wards. However, differences in scale are substantial, meaning that climate-related disruptions are likely to have particularly severe consequences in wards where large numbers of infants, women of reproductive age, and older adults are concentrated.

Access Fragility Across Hotspot Wards

The following map (Figure 13) illustrates the relative fragility of access to health services across wards in Sokoto State. Wards classified as highly fragile are those with limited local service presence, low redundancy, or weak referral capacity, making access more vulnerable to disruption.

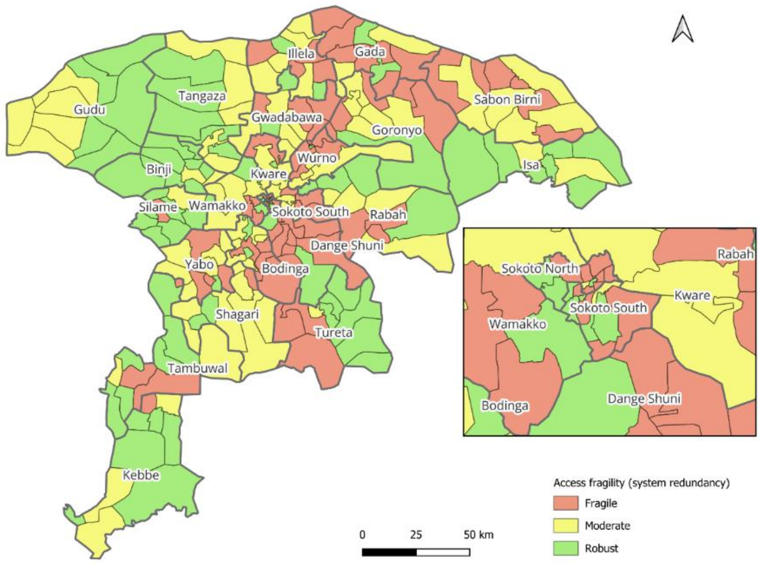


Figure 13: Access fragility of the health system by ward

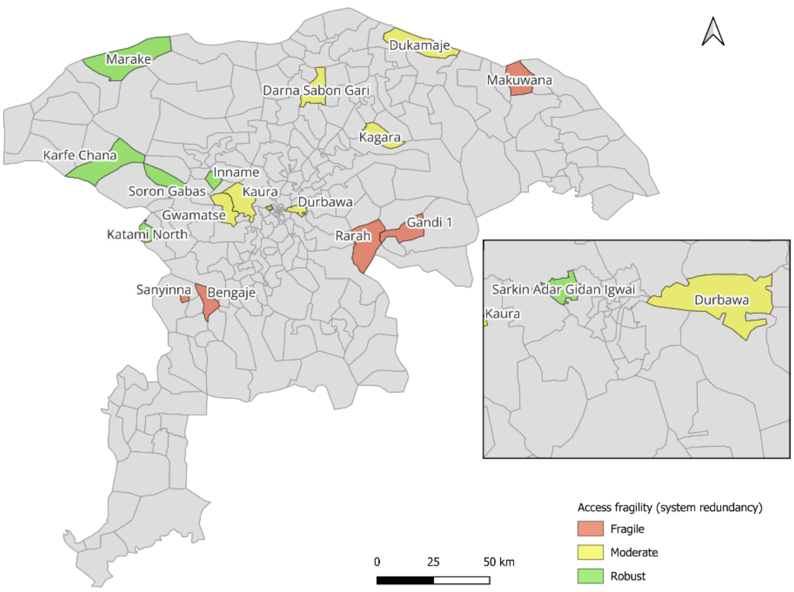


Figure 14: Access fragility of the health system in hazard hotspot wards

Access fragility across the hotspot wards (Figure 14) reflects variation not in the presence of basic health infrastructure, but in its density, level of care, and capacity to support referrals under conditions of stress. While all hotspot wards have at least one PHC facility, the robustness of access differs substantially across locations, shaping how well communities can cope with climate-related disruptions.

All 17 hotspot wards have PHC presence, indicating a baseline level of physical access to primary care services across the study area. However, the number of facilities per ward varies considerably, ranging from a single PHC in Sanyinna to nine PHC facilities in Dukamaje. Most wards are served by between two and four PHCs, which limits redundancy and increases sensitivity to facility-level disruptions such as staff shortages, infrastructure damage, or temporary closures.

These differences are reflected in PHC density, which varies widely across hotspot wards. Density ranges from approximately 0.6 facilities per 10,000 people in the lowest-coverage wards, such as Sanyinna and Karfe Chana, to nearly 4.7 facilities per 10,000 people in better-served locations such as Dukamaje, with an overall average of around 2.4 PHCs per 10,000 people. Wards at the lower end of this range face heightened access fragility, as even modest increases in demand or short-term service disruptions can quickly overwhelm available capacity.

Beyond primary care, access fragility is further shaped by the limited availability of higher-level services. None of the hotspot wards hosts a tertiary health facility, and only Sarkin Adar Gidan Igwai (Sokoto North) contains a secondary-level facility. As a result, most wards depend on referral pathways outside their immediate area for more complex care, increasing vulnerability to disruptions affecting transport, road access, or referral coordination.

Based on these conditions, hotspot wards fall into three broad access fragility classes. Wards such as Bengaje, Gandi 1, Makuwana, Rarah, and Sanyinna fall into the highest fragility class, characterised by low facility density and limited redundancy. Darna Sabon Gari, Dukamaje, Durbawa, Gwamatse, Kagara, and Kaura occupy an intermediate position, where access is generally adequate under normal conditions but vulnerable to compound stresses. The lowest fragility class—including Sarkin Adar Gidan Igwai, Inname, Karfe Chana, Katami North, Marake, and Soron Gabas—benefits from relatively stronger access conditions, though even these wards remain dependent on fragile referral systems.

Overall, access fragility across hotspot wards is driven less by the absence of health services than by uneven service density, limited redundancy, and constrained referral capacity, all of which heighten the risk that climate-related shocks will translate into disruptions in care delivery. It is also worth noting that Makuwana ward borders Sabon Birni, one of only 5 wards in Sokoto State with no health facilities. Sabon Birni is adjacent to four neighboring wards, including Makuwana, suggesting that health-seeking movements from this ward are likely distributed across multiple directions. While the scale of these movements cannot be quantified, the absence of local services increases the likelihood of spillover demand, which may place additional pressure on facilities in adjacent hotspot wards, particularly during periods of insecurity or service disruption.

In addition to structural access constraints, the vulnerability of hotspot wards is further shaped by prevailing security conditions and their geographic position relative to neighboring states. Several LGAs within the study area; most notably Sabon Birni, Rabah, and Goronyo, are currently affected by heightened insecurity, reflecting broader instability in parts of north-western Nigeria. Movement restrictions, reduced staff mobility, and disrupted transport corridors can limit the effective functioning of facilities even where physical infrastructure is present. Referral pathways are particularly sensitive to these conditions, as insecurity can delay or prevent patient transfers to higher-level facilities. This is especially relevant given that nearly all hotspot wards already rely on external referrals for secondary and tertiary care.

Moreover, the location of 6 of the 17 hotspot wards along international or inter-state borders increases the likelihood of cross-border health-seeking behavior. Dukamaje, Makuwana, and Marake all border the Republic of Niger, while Karfe Chana and Katami North border Kebbi State, and Rarah borders Zamfara State. During periods of heightened insecurity or service disruption, population movements into adjacent wards may intensify. Such movements can place additional pressure on already constrained primary health care facilities, particularly in wards with high access fragility and limited service redundancy. These dynamics suggest that conflict and cross-border mobility act as risk multipliers, amplifying the impacts of both health system fragility and climate hazards. Wards that already exhibit high or moderate access fragility are therefore likely to experience disproportionate strain when insecurity, population movement, and climate stressors coincide.

Table 1: Hotspot Wards Located Along International and Inter-State Borders

Ward	LGA	Bordering State/Country
Dukamaje	Gada	Republic of Niger
Karfe Chana	Gudu	Kebbi State
Katami North	Silame	Kebbi State
Makuwana	Sabon Birni	Republic of Niger
Marake	Gudu	Republic of Niger
Rarah	Rabah	Zamfara State

Integrated Assessment of Population Needs and Health Service Access

When health care needs and access fragility are considered jointly, a more differentiated picture of vulnerability emerges across Sokoto state and across the hotspot wards (Figure 15 and Figure 16). This combined reading helps distinguish between areas where vulnerability is primarily driven by the scale of population demand (impact potential of health care need, yellow tones), those where it is shaped by structural access constraints (access fragility, blue tones), and those where both factors intersect equally (violet tones). Darker shades point to wards with a higher concern, which may warrant closer attention in subsequent analysis, indicating stronger need for resilience-increasing initiatives. Figure 17 and Figure 18 complement this integrated assessment by illustrating comorbidity-related care intensity across hotspot wards, highlighting spatial patterns of population groups associated with higher expected health care demand due to age structure and female adult obesity prevalence.

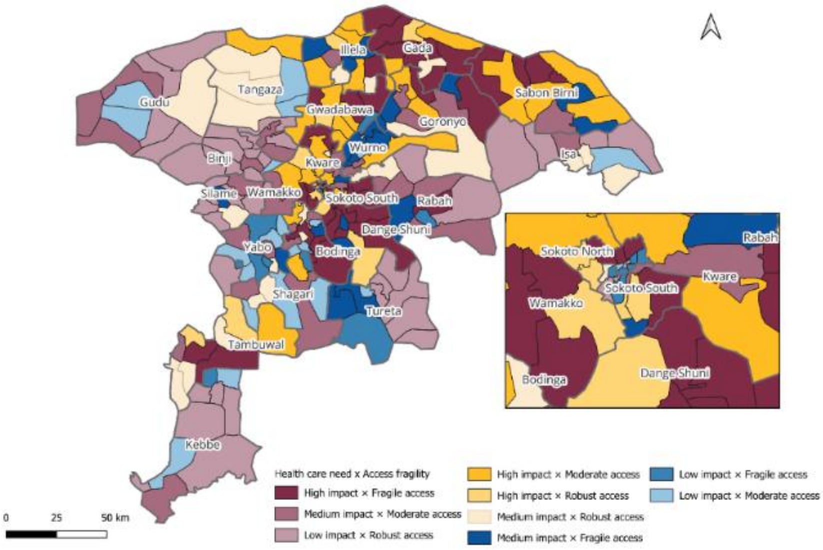


Figure 15: Combined impact potential of health care needs and access fragility by ward

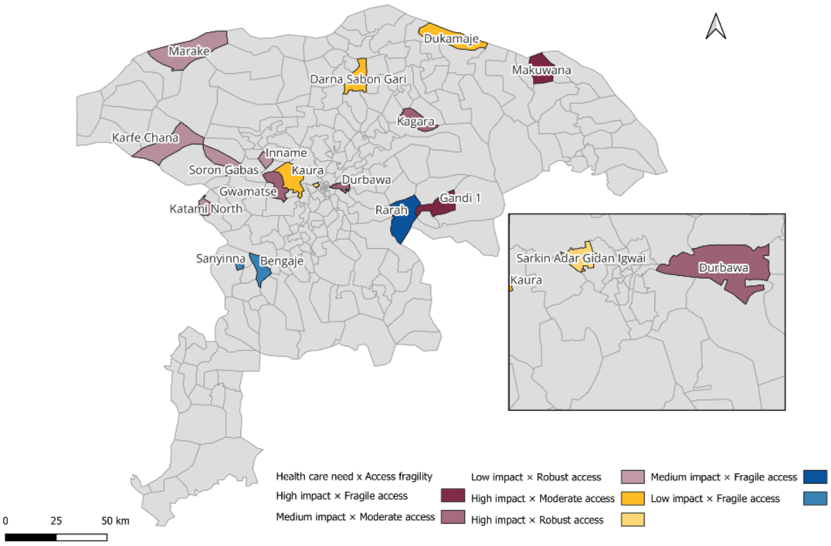


Figure 16: Combined impact potential of health care needs and access fragility in hazard hotspot wards

Several multi-hazard hotspot wards combine **high health care needs with elevated access fragility**, most notably Gandi 1 (Rabah) and Makuwana (Sabon Birni). These wards represent the most structurally exposed profiles within the hotspot set, as large populations with elevated care needs depend on comparatively fragile access conditions. In both cases, comorbidity levels further reinforce vulnerability: Makuwana in particular also records a high comorbidity score, suggesting that health outcomes in the event of service disruption may be more severe or complex to manage. These locations therefore may be considered of higher priority to strengthen system preparedness and resilience.

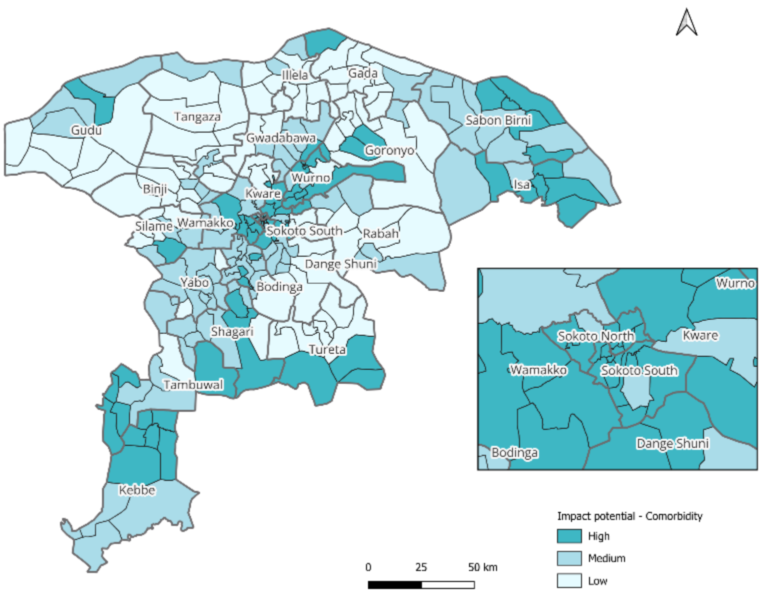


Figure 17: Impact potential of comorbidity by ward

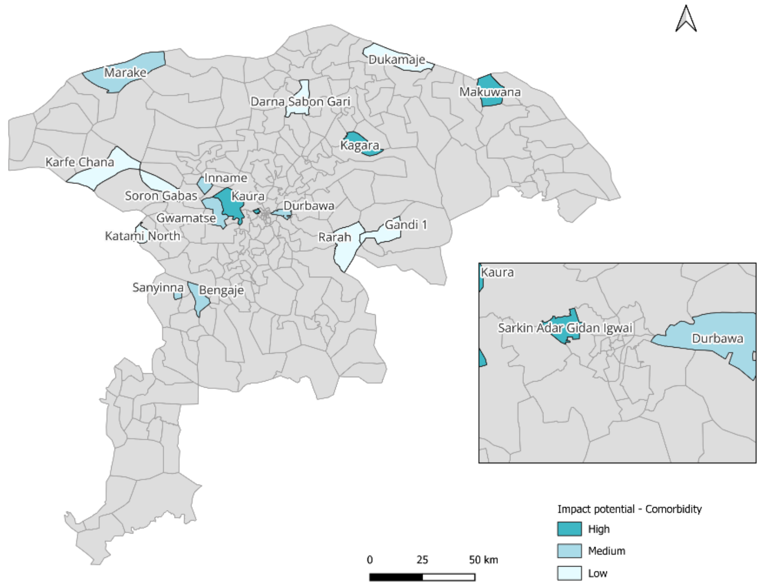


Figure 18: Impact potential of comorbidity in hazard hotspot wards

A second group of wards—including Dukamaje (Gada), Darna Sabon Gari (Illela), and Kaura (Wamakko)—is characterised by high health care needs combined with moderate access fragility. Here, vulnerability is driven primarily by the size of the dependent population rather than by severely constrained access. Within this group, comorbidity levels help refine interpretation: Kaura, which also shows elevated comorbidity risk, may experience more acute health impacts under disruption than Dukamaje or Darna Sabon Gari, where comorbidity levels are lower. This suggests that similar levels of service disruption might have differing consequences across otherwise comparable wards.

Conversely, some wards exhibit moderate or lower population needs but relatively high access fragility, notably Rarah (Rabah), Bengaje (Yabo), and Sanyinna (Tambuwal). In these locations, vulnerability is driven less by population scale and more by structural constraints affecting access to care. While absolute numbers of high-need individuals are smaller, limitations in service availability or connectivity mean that even modest disruptions could translate into meaningful service gaps. Comorbidity levels in these wards are generally moderate, reinforcing their role as secondary, but still relevant, areas of concern.

Sarkin Adar Gidan Igwai (Sokoto North), the only urban ward with a facility in a multi-hazard hotspot, represents a distinct profile. It combines one of the highest concentrations of people with elevated health care needs with comparatively stronger access conditions. However, the presence of high comorbidity levels adds an important layer of sensitivity, indicating that adverse health outcomes could escalate rapidly if service continuity were compromised, despite relatively better baseline access.

Finally, wards such as Inname, Karfe Chana, Katami North, Marake, and Soron Gabas display both lower population pressure and comparatively stronger access conditions. These areas represent the lower end of the vulnerability spectrum within the hotspot set, though they remain exposed to broader system-level disruptions and should not be interpreted as risk-free.

3.3. Conclusions and implications for climate-resilient health system planing

The analysis identifies a clear hierarchy of vulnerability across Sokoto State's multi-hazard hotspot wards, with meaningful implications for where health system resilience investments will have the greatest impact on the most exposed communities. Gandi 1 (Rabah) and Makuwana (Sabon Birni) represent the highest-priority locations: in both wards, large concentrations of infants, young children, women of reproductive age, and older adults depend on comparatively fragile access conditions, meaning that even temporary disruptions to health services are likely to translate into significant unmet need among the groups least able to absorb that gap. In Makuwana, elevated comorbidity burden adds a further layer of concern, as disrupted access may lead to more severe and harder-to-manage health outcomes. A second tier of high-concern wards, including Dukamaje (Gada), Kaura (Wamakko), and Darna Sabon Gari (Illela), also warrants close attention: here, the sheer scale of healthcare-dependent populations means that even partial or short-lived service disruptions carry significant societal consequences, with tens of thousands of vulnerable individuals facing interrupted access to maternal care, child health services, and management of chronic conditions.

The structural access gaps identified across hotspot wards have direct consequences for the communities that depend on them. In wards with the lowest facility density, most notably Sanyinna, served by a single PHC, and Karfe Chana, the closure or incapacitation of one facility eliminates local primary care access entirely, leaving infants, young children, and women of reproductive age with no immediate alternative. Investing in facility redundancy and community health worker capacity in these locations is, in effect, an investment in maintaining a safety net for the most vulnerable in the event of a disruption. More broadly, the near-total reliance on external referral pathways across all but one hotspot ward means that more complex care needs (e.g., obstetric emergencies, severe childhood illness, management of chronic conditions in older adults) depend entirely on transport infrastructure and referral coordination that are themselves vulnerable to climate-related disruption. Strengthening these referral chains is therefore not a secondary operational concern but a prerequisite for ensuring that the groups identified in this analysis can actually reach the care they need when local services are compromised.

The risks facing these communities are further compounded by factors that extend well beyond the health sector. In LGAs affected by heightened insecurity, particularly Sabon Birni, Rabah, and Goronyo, the populations most dependent on health services are also among those most exposed to movement restrictions, disrupted supply chains, and interrupted facility operations. For border communities in Dukamaje, Makuwana, Marake, Karfe Chana, Katami North, and Rarah, cross-border and inter-state population movements can intensify pressure on already stretched facilities, with the burden falling disproportionately on local vulnerable groups who have fewest alternatives when services are overwhelmed. When climate hazards, insecurity, and population displacement coincide, the indirect societal impacts of health system disruption are likely to be felt most acutely by precisely the groups this analysis has sought to identify. Addressing this requires coordination across health, security, and administrative boundaries, not health system action alone.

The assessment presented in this chapter was originally designed to span a broader range of socio-economic vulnerability dimensions, including income, livelihoods, poverty, and health status. The severe limitations in spatially differentiated data at ward level for Sokoto State ultimately constrained the analysis to healthcare-relevant population groups and structural access indicators, resulting in a methodologically sound but necessarily partial picture of the indirect societal impacts of climate hazard-induced health system disruption. Several data gaps stand out as priorities for future work: ward-level poverty and livelihood data would allow the analysis to capture economic barriers to health-seeking behavior; spatial data on nutrition and baseline health status would strengthen the assessment of population susceptibility; and improved information on actual referral flows and facility utilization would make access fragility estimates considerably more precise. As these datasets become available, whether through national surveys, administrative health records, or dedicated data collection efforts, the framework developed here can be readily extended to produce a more comprehensive assessment of the socio-economic dimensions of climate-related health vulnerability in Sokoto State.

4. Health System Disruption Analysis

The preselected wards based from the multi-hazard hotspot analysis form the foundation for the Health System Disruption Analysis, which focuses on the risk and severity of service disruption in selected hotspot wards.

In this context, the section starts with the selection of a total of four Health System Hotspots that are proposed for the Health System Disruption Analysis. This selection is based on a composite scoring approach, to capture the convergence of flood-related hazard pressure, health system exposure, and population affected and represents the first part of the chapter. The four selected wards are then subjected to a Disruption Analysis that consists of two parts: an analysis of the risk and severity of service disruptions and a subsequent analysis of the risk drivers and failure pathways. For the first part, an analytical framework consisting of three interrelated categories (capacity, population vulnerability and demand pressure) is applied to each of the wards, resulting in a final vulnerability scoring. Following the GCA/OIA *Healthcare System-of-Systems Vulnerabilities (SoS)* approach the analysis does not only cover the assets strictly within the healthcare system, such as buildings and personnel, but also the external infrastructure systems on which they are dependent. The second part focuses on the identification of the most important risk drivers and failure pathways affecting the four hotspots.

Overall, this section is structured as follows:

1. Selection of Health System Hotspots
2. Analysis of the risk and severity of service disruptions in selected hotspots
3. Analysis of risk drivers and failure pathways

The identification of the main risk drivers and failure pathways is essential to pinpoint how interventions can most effectively reduce the disruption risk. Therefore, it provides the necessary basis for the identification of potential adaptation options.

4.1. Selection of Health System Hotspots

For the preselected wards based on the multi-hazard hotspots, hotspot identification is based on a composite scoring approach, to capture the convergence of flood-related hazard pressure, health system exposure, and population affected. Three components are combined:

Flood-related hazard score - A multi-hazard flood score representing exposure to pluvial flooding, fluvial flooding, or both. Wards exposed to both flood types receive a higher score, reflecting increased likelihood of service disruption and access constraints.

Facility exposure score - The number of health facilities within the ward is converted into classes, representing the extent of exposed health system assets (<3 facilities = 1) (3 to 5 facilities = 2) (6 to 10 facilities = 3) (>10 facilities = 4) respectively. At this stage, facilities are treated uniformly (i.e., no criticality distinction according to the facility level – primary, secondary, or tertiary), as only primary-level facilities were identified in the preselection.

Population score – Similarly, ward-level population size is converted into classes (<10k people = 1) (10k to <20k people = 2) (20k to <30k = 3) (≥30k people = 4) to represent the scale of population potentially affected by health system disruptions, while avoiding distortion from absolute population values.

The three components are combined in an additive index, ensuring that hotspot selection reflects a balanced interaction between hazard exposure, system exposure, and population dependence.

<u>Complementary selection of system-critical facilities</u>
While the hotspot scoring focuses on flood-related spatial differentiation under SSP5 mid-term, it is recognized that certain system-critical health facilities at higher levels of care warrant targeted inclusion in the disruption analysis, even where they are not part of the ranked flood-based hotspot set. This applies where climate risks either arise from hazard exposure that does not differentiate spatially across wards

(such as extreme heat and wildfire), or where flood exposure emerges under a different time horizon than that used for hotspot ranking. Such facilities are included without necessarily applying the full scope of aforementioned approach, and analyzed as complementary cases alongside the flood-based hotspots.

Prioritization

Due to the nature of the scoring system and components, identical composite scores may occur. In such case, ties are resolved using a hierarchical prioritization:

- larger absolute population size, and
- higher absolute number of health facilities

A) *Primary health facilities*

Overall, 25 health facilities were identified as being in a multi-hazard zone with potential flood exposure based on SSP5, mid-term (2050). All facilities identified are primary health facilities. However, for six facilities contradictory information on the ward they are located in was identified, which does not allow for a meaningful analysis. They were, therefore, excluded from the list.

The following table shows the health facilities identified and the scoring results for each related ward. The only urban facility/ ward identified is included in the ranking, while considering it as a standalone hotspot (independent from the scoring result, highlighted yellow).

Table 3 Climate Hotspot PHCs

Facility	Ward	LGA	P_{fe}	F_{fe}	#F	Pop	MHS	FS	PS	TS
Balla Health Post	Kagara	Goronyo		x	4	14120	1	2	2	5
Birdi-Birdi Health Post	Bengaje	Yabo	x		3	12117	1	2	2	5
Bungel Basic Health Centre	Karfe Chana	Gugu	x	x	2	4243	2	1	1	4
Dudu Barade Health Clinic	Rarah	Rabah		x	2	18405	1	1	2	4
Gidan Gero Health Clinic	Durbawa	Kware	x	x	2	17182	2	1	2	5
Ginjo Health Clinic	Inname	Binji	x		2	5928	1	1	1	3
Gwafitto Health Post	Soron Gabas	Binji		x	2	11707	1	1	2	4
Illah Health Clinic	Dukamaje	Gada	x		4	39575	1	2	4	7
Illela Health Clinic	Karfe Chana	Gugu	x	x	2	4243	2	1	1	4
Kagara Health Post	Kagara	Goronyo		x	4	14120	1	2	2	5
Katami Primary Health Centre	Katami North	Silame	x		4	9531	1	2	1	4
Makuwana Health Post	Makuwana	Sabon Birni	x		5	32051	1	2	4	7
Marake Health Clinic	Marake	Gudu	x		1	6722	1	1	1	3
Samalo Health Post	Gwamatse	Wamakko	x		5	18696	1	2	2	5
Sanyinna Primary Health Centre	Sanyinna	Tambuwal	x	x	1	9029	2	1	1	4
Tudun Faila Health Clinic (urban)	Sarkin Adar Gidan Igwai	Sokoto North	x		2	32467	1	1	4	6
Tungar Zango Health Post	Darna Sabon Gari	Illela	x		6	27858	1	3	3	7
Warwama Health Post	Gandi 1	Rabah		x	5	21729	1	2	3	6

Facility	Ward	LGA	P_{fe}	F_{fe}	#F	Pop	MHS	FS	PS	TS
Yaurawa Health Post	Kaura	Wamakko	x		4	31718	1	2	4	7

F_{fe} – fluvial flood exposure; P_{fe} – pluvial flood exposure; #F – number of facilities in the ward; Pop – population size in the ward; MHS - Multi-hazard score; FS – facility score; PS - population score, TS – total score.

Based on the scoring and related considerations, the following four wards are proposed for the health system disruption analysis:

A score of 7 is shown for four wards/facilities. Applying the hierarchical prioritization outlined above, it is suggested to consider for the disruption analysis

1. Dukamaje ward – it shows the highest population number among those scoring

Although scoring lower (6), it is recommended to also analyze in more detail the

2. Sarkin Adar Gidan Igwai ward (Tudun Faila Health Clinic), given that it is the only urban ward/health facility identified as hotspot.

B) Complementary higher-level facilities

One tertiary hospital was additionally included to represent system-critical referral infrastructure within the Sokoto health system. While the hotspot scoring focuses on flood-related spatial differentiation under SSP5 mid-term, higher-level referral facilities can represent critical nodes whose disruption would have system-wide implications. For this reason, it is suggested to also conduct a disruption analysis for the Federal Neuro Psychiatry.

3. Kware ward (Federal Neuro Psychiatry)

Additionally, one secondary-level facility is selected to represent district-level service delivery under uniformly high extreme heat and wildfire exposure. Selection is guided by the size of the population served, and the concentration of health facilities in the ward, applying the same additive scoring process as above (see table below). Based on this scoring, it is suggested to include:

4. Illela ward (Illela General Hospital)

Table 4 Climate Hotspots Secondary Facilities

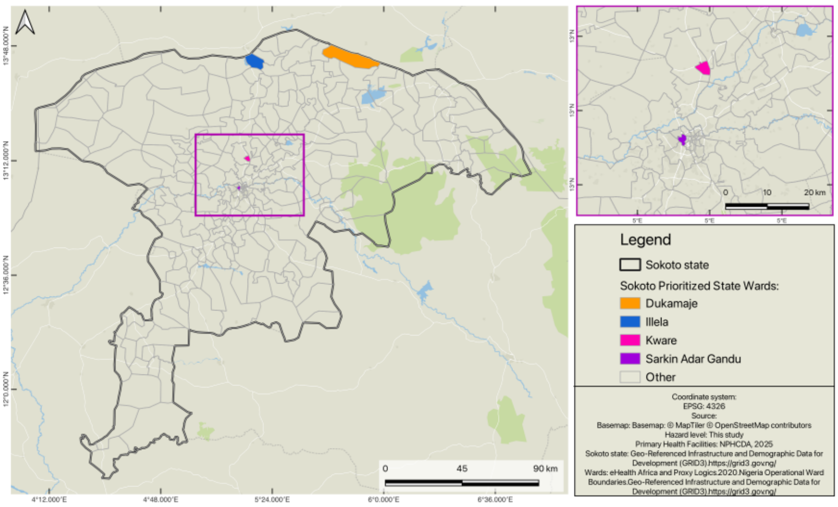
Facility	Ward	LGA	#F	Pop	FS	PS	TS
Balle General Hospital	Balle	Gudu	4	13321	2	2	**4**
Binji General Hospital	Binji (Binji)	Binji	2	8913	1	1	**2**
Bodinga General Hospital	Bodinga/Tauma	Bodinga	2	17347	1	2	**3**
Dogon Daji General Hospital	Dogon Daji	Tambuwal	7	23282	3	3	**6**
Prison Clinic	Fajaldu	Dange-Shuni	4	20782	2	3	**5**
Gada General Hospital	Gada	Gada	5	26697	2	3	**5**
Gwadabawa General Hospital	Gwadabawa	Gwadabawa	10	41458	3	4	**7**
Illela General Hospital	Illela	Illela	12	48988	4	4	**8**
Isa General Hospital	Isa South	Isa	7	18837	3	2	**5**
Kebbe General Hospital	Kebbe West	Kebbe	2	6505	1	1	**2**

Facility	Ward	LGA	#F	Pop	FS	PS	TS
Kware General Hospital	Kware	Kware	2	13322	1	2	3
Wurno General Hospital	Magarya	Wurno	1	6564	1	1	2
Rabah General Hospital	Rabah	Rabah	5	13831	2	2	4
Sabon Birni General Hospital	Sabon Birni G/Karma	Sabon Birni	16	12794	4	2	6
Shagari General Hospital	Shagari	Shagari	4	18480	2	2	4
Silame General Hospital	Silame	Silame	5	8112	2	1	3
Tambuwal General Hospital	Tambuwal	Tambuwal	4	37094	2	4	6
Tangaza General Hospital	Tangaza	Tangaza	6	18852	3	2	5
1 Brigade Medical Center	Tuntube Tsefe	Dange-Shuni	6	51105	3	4	7
Tureta General Hospital	Tureta	Tureta	3	10820	2	2	4
Orthopaedic Hospital	Wamakko	Wamako	5	13702	2	2	4
Yabo General Hospital	Yabo A	Yabo	5	14323	2	2	4

#F – number of facilities in the ward; Pop – population size in the ward; FS – facility score; PS - population score, TS – total score.

Below map shows the geographical location of the four prioritized wards in Sokoto state.

Table 5 Prioritized wards for disruption analysis



Priority Wards Identified for Multi-Hazard Health System Disruption Analysis in Sokoto State

The different facilities have very different key characteristics, level of service delivery and type of infrastructure. The following table provides context with regards to each of the facilities and helps to situate the reader and to provide a better understanding of the relevant facilities.

Table 6 Summary of selected hotspot facilities

Name and picture	Summary of key characteristics
Federal Neuro Psychiatric Hospital, Kware 	• Tertiary facility, rural town (peri-urban) • Infrastructure: good status, maintained by work and services department • Access to energy: facility is connected to the electric grid, solar plant and standby generator. • Contains primary, secondary and tertiary services within the facility • Reported disruptions related to extreme weather events: No
Illela General Hospital, Illela 	• Secondary facility, rural (border) town • Infrastructure in good status • Access to energy: No connection to grid electricity, key functions operate on solar power, no back up generator. • Offers primary and secondary services but outdated medical equipment • Reported disruptions related to extreme weather events: No
Tudun Faila PHC, Sarkin Adar Gidan Igwai 	• Primary facility, urban • Infrastructure (structure) in fair status, interior in poor status • Access to electricity : Grid connection • Offers primary health services • Reported disruptions related to extreme weather events: Yes
Illah PHC, Dukamaje Ward 	• Primary facility, rural • Infrastructure in poor status (structural integrity at risk) • Access to electricity: None, which also means no cooling facilities for vaccinations • Offers primary health services • Reported disruptions related to extreme weather events: Yes

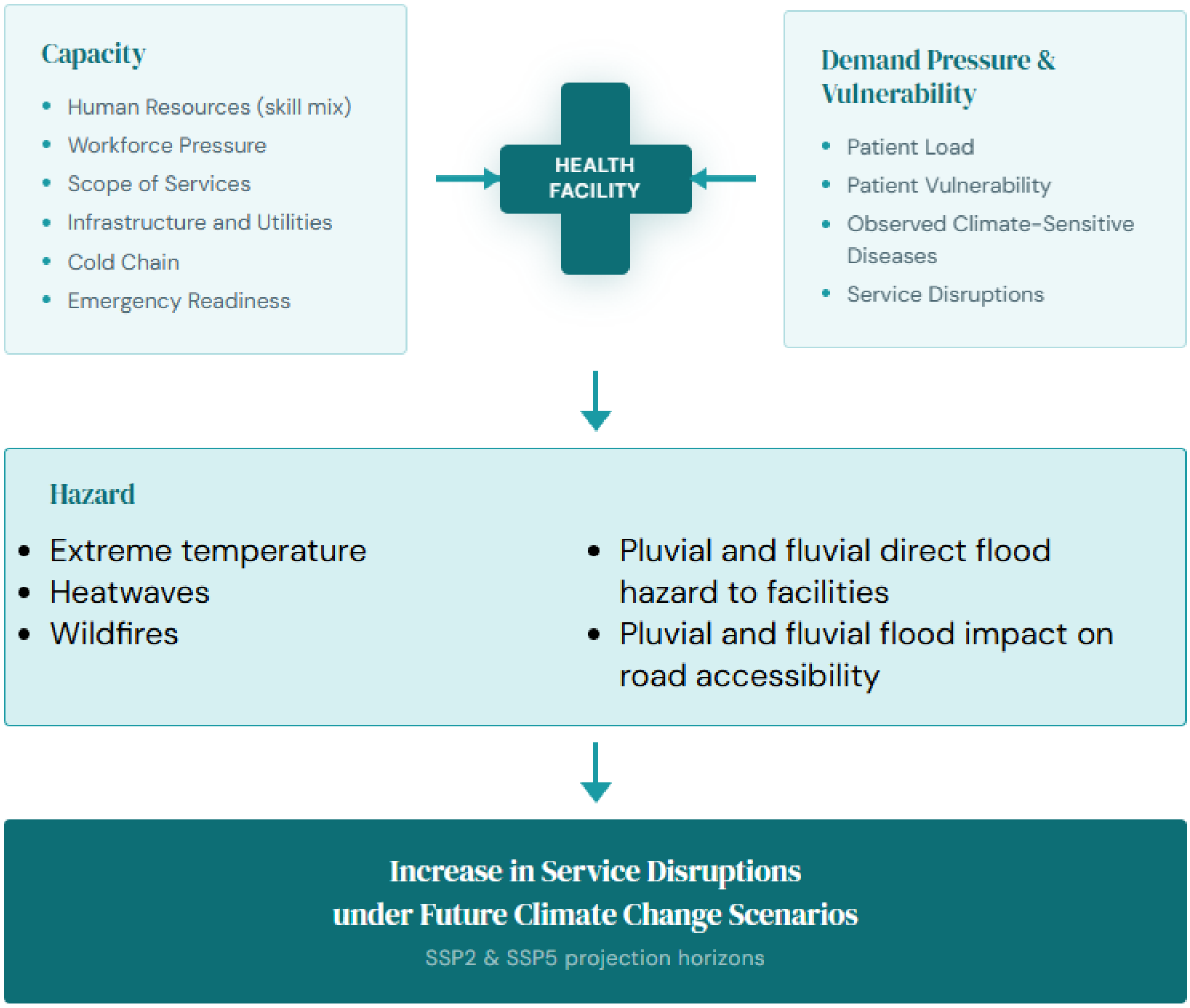
4.2. Methodology to define service disruptions

The analysis assesses the risk and severity of service disruptions by jointly considering three interrelated categories:

- The hazard results from the multi-hazard hotspot analysis
- The capacity of health centers
- The demand pressure on the health centers, including the vulnerability of the population

Following the GCA/OIA *Healthcare System-of-Systems Vulnerabilities (SoS)* approach, the analysis does not only cover the assets strictly within the healthcare system, such as buildings and personnel, but also the external infrastructure systems on which they are dependent. For this reason, energy and water supply are included in the capacity category and the dependency on the transport network will be analyzed separately through possible transport and supply chain disruptions, especially related to flooding. Figure 19 : Analytical framework offers a visual representation of this analytical framework.

Figure 19 : Analytical framework:



Demand indicators capture the scale and sensitivity of service dependence, reflecting how many and how vulnerable patients rely on continuous service delivery. Capacity indicators assess the absorptive and adaptive strength of facilities, including workforce adequacy, infrastructure reliability, and emergency preparedness. Disruption risk arises when climate-related hazards interact with increased service demand and buffering capacity constraints.

Each category included in the disruption risk assessment contains multiple variables that are relevant for the measurement of the risk and severity of service disruptions. The data was consistently converted into a scale of 1-3 for both demand pressure and service capacity in order to ensure comparabality across categories and allow a final rating. However, note that the interpretation of the scale differs between the two dimensions: higher scores indicate higher demand pressure, while for capacity higher scores indicate stronger buffering capacity (i.e., lower structural vulnerability).

The data for the hazard category was retrieved from the climate hazard analysis in the previous chapter using the multi hazard hotspot analysis. The data for all other categories was collected in person and by phone from the health centers and the external infrastructure systems using a checklist and questionnaire developed for this assignment.

The following tables present the study variables, interpretation and scaling for each category.

Table 7 Study variables, interpretation and scaling of the vulnerability category

Indicator	Rationale	1 Low	2 Moderate	3 High
Patient load/ week	Captures the scale of service dependence on a facility: Facilities serving higher absolute patient volumes are responsible for larger populations and therefore face greater baseline service demand. Under disruption scenarios, higher volumes imply more patients affected by service interruption, greater potential backlog accumulation, and higher cascading impact on referral networks. Importantly, this indicator reflects magnitude of reliance rather than workforce adequacy.	<500/ week	500–1,000 per week	>1,000
Patient vulnerability	Reflects the susceptibility of the facility's patients to health deterioration if services are disrupted, capturing potential impact severity. Facilities serving predominantly women, children, elderly persons, or socioeconomically vulnerable groups face higher demand sensitivity because service interruptions may lead to immediate health consequences, preventive and maternal services are time-sensitive, and coping capacity is often limited.	Low	Mixed	High/ Predominantly vulnerable
Observed climate-sensitive diseases	Captures dynamic demand escalation risk under projected climate change: Facilities with a higher burden of climate-sensitive diseases (e.g., malaria, meningitis, cholera, heat-related illnesses) experience demand fluctuations that correlate with environmental variability. This increases seasonal surge pressure, sensitivity to climate extremes, and the likelihood of compound stress during hazard events.	None/ Rare	Occasional	Regular/ Frequent outbreaks
Service disruptions	Reflects how demand is already affected by environmental conditions: Reported service interruptions due to flooding, access barriers, or environmental stress indicate existing demand-side fragility. Past disruptions signal structural exposure to hazard pathways and recurrent strain under seasonal variability.	None	Rare	Frequent
Demand Pressure scores	*Composite demand pressure scores represent the unweighted average of the four demand indicators (scale 1–3). Because the composite score can take values only in increments of 0.25, thresholds were defined to distribute the possible score values evenly across three categories low, moderate, and high.*	≤1.50	1.75–2.25	≥2.50

Table 8 Study variables, interpretation and scaling for the capacity category

Indicator	Rationale	1 Low	2 Moderate	3 High
Human resources (skill mix)	Captures the system's ability to absorb demand spikes without service collapse: Human resources represent the primary operational buffer within healthcare systems. Adequate and skilled staffing enables clinical flexibility, surge response, and redistribution of workload during emergencies. Limited staffing reduces redundancy and constrains adaptive response capacity.	Very limited	Basic to skilled mix	Skilled mix
Workforce pressure	Reflects capacity saturation risk: Patients-per-clinical-staff/day measures operational demand pressure relative to available human resources. High ratios indicate limited surge capacity and reduced flexibility under additional stress. Unlike absolute patient load, this indicator captures immediate workload intensity, reduced absorptive margin, and increased risk of service degradation during climate hazard events.	<10	10-30	>30
Scope of services	Reflects the clinical service depth and functional resilience and layering of the facility: Facilities offering emergency and referral-level services have broader treatment capacity, and greater stabilization capability. Limited-service scope, in contrast, constrains the ability to manage complications locally during referral disruption.	Minimal services	Basic	Emergency care & surgery or higher
Infrastructure & utilities	Captures direct physical vulnerability: Reliable energy, water, and physical infrastructure are foundational to service continuity. Facilities lacking stable electricity, backup systems or water reliability are directly exposed to climate hazards, especially extreme heat and flooding.	Poor or unreliable	Basic but functional	Reliable with backup sources
Cold chain	Captures heat buffering capacity: Cold chain capacity determines the facility's ability to maintain vaccine integrity, store heat-sensitive pharmaceuticals, and preserve biological samples. In high-heat environments such as Sokoto, lack of thermal control significantly increases disruption risk.	None or weak	Functional	Robust with backup
Emergency readiness	Captures adaptive coordination capacity, reflecting the facility's ability to stabilize acute cases, coordinate referrals, and activate contingency plans: Facilities without structured emergency systems are highly	None or weak	Functional	Strong and well-coordinated

	dependent on uninterrupted external networks.			
Capacity Pressure scores	*Composite capacity scores represent the unweighted average of the six capacity indicators (scale 1–3). As the composite score can take values only in increments of approximately 0.17, thresholds were defined to distribute the possible score values as evenly as possible across three categories.*	*≤1.50*	*1.67-2.33*	*≥2.50*

The report applies the scoring framework to each hotspot facility using the qualitative data collected during field visits to all facilities. Scores are relative and based strictly on reported patient load, catchment size, vulnerability, climate sensitivity, infrastructure, staffing, and emergency readiness. The purpose is to identify pressure–capacity gaps rather than produce exact measurements.

Analysis limitation and scope: Detailed logistics chain analysis was not undertaken due to lack of facility-level data on pharmaceutical distribution routes, storage capacities, and resupply schedules. The assessment therefore focuses on critical logistics dependencies identified through facility interviews and infrastructure indicators.

The demand and capacity pressure scores refer to the current situation in the different health facilities. To better understand future disruptions and risks under different climate scenarios, an analysis of risk drivers and failure pathways has been undertaken along the different relevant climate hazards.

Following the System of Systems framework, the analysis focuses not only on direct impacts on the healthcare systems but also on the effects on its external systems, such as power supply. For this reason, failure pathways were categorized into three types:

- Direct failure pathways: Climate hazards directly affect health facilities or on-site assets, leading to reduced or suspended service provision (e.g. inundation of operational areas during flooding)
- Indirect failure pathways: Hazards disrupt external systems on which facilities depend, such as road access, electricity, water supply, or cold-chain logistics, thereby constraining service delivery without direct damage to the facility itself
- Cascading failure pathways: Failures in one external system trigger failures in another external system or the healthcare system directly, amplifying disruption impacts (e.g. flood-induced road closures delaying referrals and resupply, which in turn increase congestion and demand pressure at non-affected facilities).

The risk drivers are identified by examining which categories and variables from the composite indices (capacity, and vulnerability and demand pressure) contribute most strongly to elevated disruption risk at hotspot level along the different future hazard scenarios.

The identification of the main risk drivers and failure pathways is essential to pinpoint how interventions can most effectively reduce the disruption risk. Therefore, it provides the necessary basis for the identification of potential adaptation options.

4.3. Facility disruption analysis

4.3.1. Illah health clinic, Dukamaje

Among the four prioritized hotspots, Illah Health Clinic (IHC) shows the most pronounced structural imbalance between service demand and adaptive capacity. Its demand pressure score (2.5 – high) combined with a capacity score of 1.0 (low) places it in the most fragile position when comparing the four facilities. While tertiary and secondary facilities operate under high patient volumes, they retain internal redundancy mechanisms (such as staff depth, energy systems, cold chain infrastructure, and referral networks) that buffer against disruption. IHC, by contrast, operates without such absorptive capacity. This distinction is critical. The disruption risk at IHC is not only a function of workforce pressure but also of the facility's limited ability to cope with even moderate external stressors. In comparative terms, IHC represents the clearest case of structural vulnerability within the assessed facilities: relatively high service dependence combined with minimal systemic buffering.

4.3.1.1. Demand pressure risk drivers

The following table summarises the demand pressure assessment for Illah Health Clinic across five indicators. The results reflect a facility operating under high structural demand pressure, driven by the vulnerability profile of its catchment population, rising climate-sensitive disease incidence, and recurring access disruptions that intensify service pressure precisely when operational capacity is most constrained.

Table 9: Demand Pressure Assessment of Illah Health Dispensary, Dukamaje ward, Gada LGA

Indicator	Basis from Data	Score
Patient load	420 patients/week in rural PHC	1
Patient vulnerability	Mostly women, children, vulnerable farmers	3
Climate-sensitive disease burden	Malaria and typhoid increasing	3
Service disruptions	Flooding + insecurity affecting referrals	3
Average demand score		*2.5 (High)*

Illah Health Clinic serves approximately 420 patients per week across six communities within an estimated 14 km catchment radius. In absolute terms, this volume is lower than at secondary or tertiary facilities. However, when combining it with the existing capacities (no doctors), demand pressure becomes more evident.

The composition of the served population further amplifies demand pressure. The catchment is predominantly rural and socioeconomically vulnerable, with women and children constituting the majority of service users. Maternal and child health services, including antenatal care, immunization, minor deliveries, and outpatient treatment, form the core of service utilization. These services are highly sensitive to interruption. Delays in antenatal care or immunization are not easily deferrable without health consequences.

In addition, the facility reports increasing malaria and typhoid incidence, conditions associated with seasonal rainfall variability and extreme heat. While direct attribution to climate change cannot be asserted at facility level, the pattern suggests heightened exposure to climate-sensitive disease burdens. Under flood conditions, delayed access may lead to more severe cases arriving at the facility, which in turn may increase pressure on already limited clinical resources. Under extreme heat conditions, dehydration, febrile illnesses, and exacerbation of chronic vulnerabilities may increase caseload further.

Importantly, flooding during the rainy season disrupts internal community roads and delays referrals to General Hospital Gada (see transport disruption analysis for further details). When referral pathways are constrained, the PHC must manage cases beyond its optimal service scope. This shifts the facility from a routine primary care role into a temporary stabilization node without the infrastructure required to safely perform that function. Demand pressure therefore intensifies precisely at the moment when capacity is least adaptable. Security challenges compound this situation, further limiting timely access to higher levels of care. When referrals are delayed, emergency obstetric cases may not reach secondary care facilities in time, some patients resort to traditional birth attendants, and time-sensitive complications risk worsening clinical outcomes.

4.3.1.2. Capacity risk drivers

The following table presents the capacity assessment for Illah Health Clinic across six indicators. The results reflect a facility with severely limited operational capacity, characterised by the absence of basic infrastructure systems, minimal staffing depth, and no formal emergency or contingency arrangements, conditions that leave the facility with little absorptive capacity when external stressors disrupt service delivery.

Table 10: Capacity Pressure Assessment of Illah dispensary, Dukamaje Ward, Gada LGA

Indicator	Basis from Data	Score
Human resources	CHEW/JCHEW, limited skills, no doctor	1
Workforce pressure	42 patients/clinical staff/day	1
Scope of services	Basic PHC services only	1
Infrastructure & utilities	No electricity, limited storage	1
Cold chain & temperature control	No cold chain, room temperature storage	1
Emergency & referral readiness	No ambulance, no response plan, disrupted referrals	1
Average capacity score		*1.0 (Low)*

The defining characteristic of Illah Health Clinic is a structural fragility. The facility operates without electricity supply, without a functional cold chain, and without temperature-controlled pharmaceutical storage. In Sokoto's extreme heat context, where temperatures regularly exceed 40°C, the absence of thermal regulation poses significant risks to vaccine potency, drug stability, and diagnostic integrity.

The facility has no doctors and is working with 2 community health extension workers, without doctor-level coverage or specialist depth. At a rate of around 420 weekly patients, this leads to an overall number of 210 patients per clinical staff. When interpreted relative to the service scope, the pressure becomes more pronounced and constrains clinical complexity and surge capacity.

Vaccines are sourced from a neighboring facility, creating reliance on uninterrupted transport and external storage. This dependency transforms what would otherwise be a manageable infrastructure limitation into a systemic vulnerability. Any disruption in road access, fuel availability, or inter-facility coordination directly affects immunization continuity.

Emergency preparedness is similarly limited. The absence of an ambulance, formal emergency response plan, or structured contingency protocol reduces the facility's ability to respond under compound shock conditions. Referral is possible under normal circumstances, but it is not insulated against hazard-related disruption.

From a system-of-systems perspective, Illah demonstrates high dependency on external infrastructure systems: transport networks, secondary-level facilities, and pharmaceutical supply chains. Because no redundancy mechanisms are present on-site, failure in any of these external systems translates rapidly into service degradation. In this sense, Illah functions as a node with high exposure to indirect and cascading disruption pathways.

4.3.1.3. Hazard-specific disruption pathways

Flooding

Flooding represents the most immediate and operationally disruptive hazard. The primary impact pathway is indirect: road inaccessibility limits patient access and delays referral to higher-level care (see chapter 4.4.1. for further details). However, cascading effects are relevant too and include that emergency obstetric cases may be delayed beyond safe intervention windows. pharmaceutical resupply may be interrupted, and the PHC becomes both overloaded and under-equipped simultaneously.

Flood-induced disruption is therefore not confined to physical inundation of the facility itself; rather, it emerges through breakdowns in functional connectivity. The risk lies less in structural damage to buildings and more in interruption of system linkages.

Extreme Heat

Extreme heat introduces both direct and indirect failure mechanisms. Directly, high ambient temperatures threaten the integrity of drugs and vaccines stored at room temperature. Indirectly, heat increases disease burden and may reduce staff productivity and working conditions. Without backup energy systems or cooling infrastructure, IHC lacks buffering capacity against prolonged heatwaves. Unlike facilities with solar or grid redundancy, this PHC's service quality is directly exposed to climatic stress.

Wildfire

Wildfire has less direct impact on facility access and operations compared with flooding and heat but may still produce indirect effects. Smoke-related respiratory illnesses could increase outpatient visits, while road disruption or environmental degradation could limit accessibility.

4.3.2. Tudun Faila PHC, Sarkin Adar Gidan Igwai

Tudun Faila PHC presents a demand score of 2.0 (moderate) and a capacity score of 2 (moderate), placing it in an intermediate position within the assessed hotspot set. As the only urban primary healthcare facility identified in the multi-hazard hotspot analysis, its disruption profile differs qualitatively from the rural primary facility. Its more compact catchment, stable road access, and functional infrastructure provide a baseline operational resilience that is absent in more rural hotspots. However, its sole dependence on grid electricity for cold chain operations, combined with the absence of functional backup power, represents a specific and foreseeable structural vulnerability in a context of projected extreme heat intensification. Its disruption risk is therefore not one of broad infrastructural fragility but of a targeted single-point dependency that, if unaddressed, could translate climate stress directly into service interruption for a concentrated urban population.

4.3.2.1. Demand pressure dynamics

The following table summarises the demand pressure assessment for Tudun Faila PHC across five indicators. The results reflect moderate overall demand pressure, shaped primarily by sustained maternal service utilisation and a gradually increasing climate-sensitive disease burden, moderated by the facility's more compact urban catchment and relatively stable access conditions.

Table 11: Demand Pressure Assessment of Tudun Faila PHC, Sarkin Adar Gidan Igawi ward, Sokoto North LGA

Indicator	Basis from Data	Score
Patient load	610 patients/week in urban PHC	2
Patient vulnerability	Mostly women and children, strong maternal focus	3
Climate-sensitive disease burden	Malaria increasing	2
Service disruptions	No major disruptions reported	1
Average demand score		*2 (Moderate)*

Tudun Faila PHC manages approximately 610 patients per week across three communities within an approximately 8 km catchment radius. Unlike the dispersed rural coverage that defines facilities such as Illah Health Clinic, the catchment here is more compact and predominantly urban, which reduces structural travel delays and improves physical accessibility under normal conditions. In absolute terms, this patient volume is moderate relative to the secondary and tertiary facilities assessed, yet it remains substantial when interpreted against the facility's staffing structure, which relies on community health workers without doctor-level coverage.

The composition of the patient population is a defining pressure driver. The facility's utilization profile is heavily maternal, with antenatal care attendance, immunization, and family planning services forming the core of service demand. Women and children constitute the dominant user group, indicating sustained and recurring need for preventive and reproductive health services that are highly sensitive to any interruption. Unlike episodic or emergency-driven demand, this pattern generates consistent weekly throughput that is not easily deferred or redistributed.

The facility reports increasing malaria incidence associated with climate variability. While no large-scale outbreaks or acute demand surges have been documented, the gradual upward trend in climate-sensitive disease burden signals an expanding and ongoing pressure that, under projected increases in heat and rainfall variability, is likely to intensify further. This expansion does not manifest as sharp spikes but as cumulative incremental pressure on an already constrained service environment.

Importantly, Tudun Faila PHC has not reported major service disruptions due to flooding or climate hazards, and referral linkages to Specialist Hospital Sokoto and Maryam Abacha Women and Children's Hospital remain operational under current conditions. Its urban location and relatively stable road access moderate the overall demand pressure level compared to rural hotspots. Nevertheless, its position as an urban first-contact facility within a densely populated ward means that any service degradation would affect a concentrated population with limited nearby alternatives at the same service tier.

4.3.2.2. Capacity and structural fragility

The following table presents the capacity assessment for Tudun Faila PHC across six indicators. The results reflect a facility with a functional operational baseline but limited redundancy, where the absence of backup power represents the most critical structural vulnerability in a context of projected extreme heat intensification and chronic grid unreliability.

Table 12: Capacity Pressure Assessment of Tudun Faila PHC, Sarkin Adar Gidan Igawi ward, Sokoto North LGA

Indicator	Basis from Data	Score
Human resources	Nurse, midwife, CHEW mix, no doctor	2
Workforce pressure	24.4 patients/clinical staff/day	2
Scope of services	ANC, delivery, immunization, family planning	2
Infrastructure & utilities	Electricity + borehole (solar not working)	2
Cold chain & temperature control	Functional cold chain but grid dependent	2
Emergency & referral readiness	Referral pathways functional, but no ambulance, no emergency plan	2
Average Capacity Score		*2.0 (moderate)*

Tudun Faila PHC demonstrates a noticeably stronger operational capacity than Illah Health Clinic, though important structural vulnerabilities remain. The facility has electricity supply and maintains a functional cold chain, structured pharmaceutical storage system, and a borehole water system. Heat-sensitive drugs and vaccines are stored under appropriate cooling conditions, which represents a significant advantage in Sokoto's extreme heat environment and provides a level of baseline infrastructure stability that is absent in more rural hotspot facilities.

However, this resilience carries a critical single-point vulnerability: the solar power system, which was intended to provide backup capacity, is no longer functional. The cold chain and general operations therefore depend entirely on grid electricity supply. In Sokoto's context, where grid electricity is chronically unreliable and outages are frequent even for connected facilities, this dependence on a single power source constitutes a meaningful structural risk. During peak heat periods, which are projected to intensify under all future climate scenarios, any sustained power interruption would directly threaten vaccine potency, compromise the storage of temperature-sensitive ANC drugs, and potentially interrupt immunization services without a backup system to absorb the failure.

Human resources are adequate for primary health care delivery but do not extend into specialist-level care. The service scope covers essential outpatient, maternal, and preventive health functions. Emergency referral pathways to higher-level facilities are functional, and road access remains reliable, which strengthens the facility's transfer capacity compared to rural counterparts. There is a total of 5 clinical staff working at the facility, which leads to a patient load of around 120 patients per clinical staff (at an estimated 610 weekly patients). Nevertheless, critical gaps persist, there is no doctor at the facility, the facility has no on-site ambulance, no formal emergency response plan, and no backup power redundancy. Day-to-day operations are stable, but the system has not been stress-tested under compound shocks, such as simultaneous grid failure during a heatwave, or concurrent demand surge during a climate-sensitive disease outbreak.

From a system-of-systems perspective, Tudun Faila PHC occupies a position of moderate resilience with limited redundancy. Its functional infrastructure provides absorptive capacity under routine conditions, but its dependence on a single, unreliable power source and the absence of formalized contingency protocols mean that compound climate stress could translate rapidly into service disruption. In comparative terms, it represents a more buffered profile than Illah Health Clinic, yet it is not insulated against climate-driven failure.

4.3.2.3. Hazard-specific disruption pathways

Extreme Heat

Extreme heat is the most structurally significant hazard for this facility given its sole dependence on grid electricity for cold chain operations. With no functional solar backup, any power outage during peak heat periods, which are projected to intensify across all scenarios, creates a direct risk of cold chain failure, vaccine temperature excursions, and interruption of immunisation services. Staff working conditions and patient comfort are also directly exposed to ambient heat, as the facility lacks cooling or climate-adaptive ventilation infrastructure.

Flooding

This facility is exposed to pluvial flooding, making rainfall-driven inundation the primary flood-related hazard for this facility. The principal disruption pathway is indirect: intense rainfall events can affect local drainage and access routes within the urban ward, potentially disrupting patient movement and pharmaceutical resupply. Under SSP5 mid-term projections, pluvial flood hazard increases, and the road accessibility analysis indicates the need for alternative routes to secondary and tertiary facilities (see chapter 4.4.2 for further details). While the facility's urban location provides more stable road infrastructure than rural hotspots, urban drainage capacity in Sokoto is limited, meaning that high-intensity rainfall bursts can still produce localized disruption to access and supply chains even without direct facility inundation.

Wildfire

Wildfire represents a secondary hazard. Smoke-related respiratory conditions may incrementally increase outpatient demand during fire season, but given the urban location and available data, wildfire is not assessed as a primary disruption driver for this facility.

4.3.3. Illela General Hospital, Illela

Illela General Hospital occupies a distinct position among the four assessed hotspots as the only secondary-level facility in the disruption analysis. With a demand score of 2 (moderate) and a capacity score of 2.7 (high), it does not present the acute structural imbalance that characterises the primary health facilities. However, its role as the principal referral destination for a large network of primary facilities across Illela LGA and cross-border communities in Niger Republic means that its disruption risk cannot be assessed in isolation. Climate hazards that degrade the functionality of feeder PHCs, or that constrain referral pathway accessibility, translate directly into elevated pressure at this facility, even when the hospital itself remains physically operational. Its disruption profile is therefore characterised less by internal fragility and more by system-level exposure through its referral network dependencies.

4.3.3.1. Demand pressure dynamics

The following table summarises the demand pressure assessment for Illela General Hospital across five indicators. The results reflect moderate demand pressure, driven by high patient volumes, a geographically extensive catchment that includes cross-border communities, and the facility's role as the principal referral destination for a wide network of primary facilities whose own climate vulnerability is significant.

Table 13: Demand Pressure Assessment of Illela General Hospital, Illela ward, Illela LGA

Indicator	Basis from Data	Score
Patient load	2047 patients/week	3
Patient vulnerability	All population groups with moderate vulnerability	2
Climate-sensitive disease burden	Limited reported climate-related illnesses	2
Service disruptions	No significant service disruptions reported	1
Average demand score		*2 (Moderate)*

Illela General Hospital serves approximately 2,047 patients per week, placing it among the highest-volume facilities assessed. Its catchment extends beyond Illela ward to include border communities and cross-border patients from Niger Republic, which adds a layer of demand that is both geographically expansive and difficult to predict or manage during climate-related disruptions. Referral inflows from surrounding primary facilities further amplify patient volumes, particularly during outbreak periods or when lower-level facilities are constrained by flooding or heat-related service interruptions.

The population served includes women and children alongside mixed socioeconomic groups, with maternal and child health services constituting a significant share of service utilization. Cross-border patients, who may arrive with more advanced presentations due to longer travel distances, add clinical complexity to the caseload. This combination of high volume, wide geographic reach, and population diversity places sustained operational pressure on staffing, pharmacy supply, laboratory services, and emergency response capacity.

Extreme heat has been reported to occasionally affect working conditions at the facility, though no major service shutdowns have been documented. The facility reports no large-scale climate-sensitive disease outbreaks to date, though Sokoto's broader disease burden (including seasonal meningitis, malaria, and recently emerging dengue) means that outbreak-driven demand surges remain a realistic and increasing future risk. Referral pressure from primary facilities during climate events represents the most probable pathway through which climate-related demand escalation would manifest at this facility.

4.3.3.2. Capacity risk drivers

The following table presents the capacity assessment for Illela General Hospital across six indicators. The results reflect strong operational capacity overall, with skilled staffing, functional referral systems, and reliable water supply, though a single-point dependence on solar power and the absence of formalised climate contingency protocols represent the facility's primary structural vulnerabilities.

Table 14: Capacity Pressure Assessment of Illela General Hospital, Illela ward, Illela LGA

Indicator	Description / basis for scoring	Score
Human resources	Full mix of skilled and specialist health personnel, 3 doctors	3
Workforce pressure	15.2 patients/clinical staff/day	2
Scope of services	Comprehensive services including specialized care	3
Infrastructure and utilities	Reliable water, power, and functional health infrastructure	2
Cold chain and temperature control	Robust and well-maintained temperature control systems	3
Emergency and referral readiness	Functional ambulance, referral pathways, and response plans	3
Average capacity score		*2.8 (high)*

Illela General Hospital demonstrates better operational capacity relative to the primary facilities in the hotspot set. The facility maintains skilled clinical staff, including three doctors, capable of managing secondary-level services including emergency obstetric care, surgical interventions, inpatient services, and laboratory diagnostics. Nevertheless, with an overall patient load of almost 700 patients per week per doctor (based on a total number of 2,047 total patients per week), the facility is considered to be congested. Also it was reported that equipment is outdated and more complex equipment for diagnostics is not available.

Water supply is reliable, and ambulance and referral systems are functional, supporting emergency transfer capacity both within the LGA and to higher-level facilities.

The facility's principal infrastructure vulnerability lies in its power supply. Operations and cold chain functions rely entirely on solar energy, with no grid connection or generator backup. Under normal conditions, the solar system performs adequately. However, prolonged cloudy periods (which can occur during the rainy season) may compromise power availability, introducing intermittent risk to cold chain integrity and general facility operations. In Sokoto's projected climate trajectory, where extreme heat intensifies and seasonal rainfall patterns shift, the reliability of solar output may face increasing variability. A single-source power dependency, even where that source is renewable, introduces a structural fragility that is not offset by any backup redundancy.

Emergency readiness is functional at the facility level, with referral pathways active and response mechanisms in place. However, structured contingency protocols for compound climate events, such as simultaneous heatwave conditions and surge referral demand from flood-affected primary facilities, are not formally institutionalized. The facility's capacity to absorb sudden increases in referral inflow during climate disruption events has not been formally stress-tested.

From a system-of-systems perspective, Illela General Hospital's capacity profile is one of operational strength with specific, addressable vulnerabilities. The power supply dependency and the absence of formalized climate contingency planning represent the primary risk drivers within the capacity dimension.

4.3.3.3. Hazard-specific disruption pathways

Extreme Heat

Extreme heat and heatwave hazard are projected at uniformly high to very high levels across Illela ward under all future scenarios. The most direct disruption pathway runs through the facility's sole dependence on solar power: prolonged heatwave conditions or periods of reduced solar irradiance could compromise cold chain integrity and general operations. Staff endurance and working conditions are also directly exposed, increasing the risk of reduced operational efficiency during peak heat periods. A secondary and system-level pathway operates through referral inflow: when feeder primary facilities across the LGA experience heat-induced service degradation, referral pressure at Illela General Hospital increases, absorbing cases that would ordinarily be managed at lower levels.

Flooding

Illela ward is not directly exposed to pluvial or fluvial flooding in the hotspot analysis. However, the referral pathway accessibility analysis shows that travel time delays to Illela General Hospital from feeder primary facilities increase substantially under SSP5 2050 and 2080 scenarios. Flood-induced road disruption at the primary level constrains timely referral, delays emergency cases, and may generate surges of more advanced presentations once access is restored undermining the hospital's functional role as a referral node without directly affecting the facility itself.

Wildfire

Illela ward is projected to experience high to very high wildfire hazard, consistent with the state-wide pattern. Smoke-related respiratory conditions during fire season may incrementally increase outpatient demand, compounding staff pressure during periods that already coincide with peak heat conditions.

4.3.4. Federal Neuro Psychiatric Hospital, Kware

The Federal Neuro-Psychiatric Hospital (FNPH) in Kware represents a fundamentally different disruption profile from the other three hotspots. As the only tertiary-level facility in the analysis, it combines the highest patient volume, the broadest catchment area, and the strongest internal capacity of the four assessed facilities, reflected in a demand score of 1.75 (moderate) and a capacity score of 3.0 (high). Its inclusion in the disruption analysis is driven by its critical and largely irreplaceable role as a specialist referral node serving Sokoto State and neighboring Kebbi and Zamfara. Disruption at this facility carries system-level consequences that extend well beyond the ward or LGA level.

4.3.4.1. Demand pressure dynamics

The following table summarises the demand pressure assessment for the Federal Neuro-Psychiatric Hospital (FNPH) across five indicators. The results reflect moderate overall demand pressure in scoring terms, though the facility's exceptionally high patient volume, state-wide and inter-state catchment, and the clinical complexity of its psychiatric patient population give this score a distinct character compared to the other assessed facilities.

Table 15: Demand Pressure Assessment of Federal Neuro Psychiatric Hospital, Kware ward, Kware LGA

Indicator	Basis from Data	Score
Patient load	2500 patients/week	3
Patient vulnerability	All population groups, including with high vulnerability	2
Climate-sensitive disease burden	No reported climate-related illnesses	1
Service disruptions	No significant service disruptions reported	1
Average demand score		*1.75 (Moderate)*

FNPH serves approximately 2,500 patients per week, the highest volume among the assessed facilities. Its catchment is state-wide and inter-state, drawing patients from Sokoto, Kebbi, and Zamfara. This scale of coverage means that any service disruption affects a large and geographically dispersed population that has no comparable alternative facility within reachable distance for specialist mental health care.

The facility serves all population groups, including highly vulnerable patients offering primary, secondary and tertiary health care services. Additionally, it covers those requiring specialist psychiatric services, inpatient care, and emergency psychiatric management. These patient groups are particularly sensitive to service interruption: continuity of psychiatric medication, consistent clinical oversight, and stable inpatient conditions. They do not reffer patients in the way that routine outpatient appointments might be. Disruption to medication supply chains or inpatient conditions therefore carries direct and potentially severe clinical consequences.

No climate-related disease outbreaks or major service disruptions have been reported to date. The facility's urban location in Kware reduces exposure to the road inaccessibility that characterizes rural hotspots. Demand pressure is driven principally by patient volume, catchment breadth, and the clinical complexity of the population served rather than by climate-sensitive disease burden or access disruption.

4.3.4.2. Capacity risk drivers

The following table presents the capacity assessment for the Federal Neuro-Psychiatric Hospital across six indicators. The results reflect the strongest capacity profile among the four assessed facilities, with full specialist staffing, comprehensive service coverage, reliable infrastructure with multiple power sources, and robust cold chain and emergency systems, though the clinical sensitivity of psychiatric care means that even well-buffered disruptions carry disproportionate consequences.

Table 16: Capacity Pressure Assessment of Federal Neuro Psychiatric Hospital, Kware ward, Kware LGA

Indicator	Description / basis for scoring	Score
Human resources	Full mix of skilled and specialist health personnel, 114 doctors	3
Workforce pressure	1.1 patients/clinical staff/day	3
Scope of services	Comprehensive services including specialized care	3
Infrastructure and utilities	Reliable water, power, and functional health infrastructure	3
Cold chain and temperature control	Robust and well-maintained temperature control systems	3
Emergency and referral readiness	Functional ambulance, referral pathways, and response plans	3
Average capacity score		*3.0 (high)*

FNPH demonstrates the strongest operational capacity among the four assessed hotspots. The facility maintains a full complement of specialist and skilled clinical staff, comprehensive service coverage including inpatient psychiatric care and emergency services, reliable infrastructure, multiple power sources, a functional and robust cold chain, and formal emergency and referral systems including ambulances and electronic medical records. Redundancy mechanisms are in place across key operational dimensions, providing a meaningful buffer against routine disruptions.

The facility's capacity profile is therefore one of structural strength rather than fragility. However, two specific vulnerabilities are worth noting. First, the facility's psychiatric medication supply chain is highly sensitive to temperature and continuity. Heat-sensitive medications, including certain mood stabilisers and injectable antipsychotics, require stable cold storage conditions. While the cold chain is currently robust, any sustained failure in power supply during extreme heat periods would have direct clinical implications for inpatient care that are more acute than in general health facilities. Second, the facility serves a population whose care cannot easily be transferred or deferred. Unlike general outpatient services, inpatient psychiatric care depends on uninterrupted physical access, staffing continuity, and medication availability. Compound disruptions affecting any of these dimensions simultaneously would carry disproportionate clinical risk.

4.3.4.3. Hazard-specific disruption pathways

Extreme Heat

Extreme heat and heatwave hazard levels are projected to be uniformly high to extreme across Kware ward under all future scenarios, consistent with the state-wide pattern. The most relevant disruption pathway for FNPH runs through its psychiatric medication supply chain: sustained high temperatures increase the risk of cold chain stress, and heat-sensitive medications require uninterrupted temperature control. While the facility's multiple power sources provide meaningful redundancy, prolonged heatwave episodes represent a cumulative stress on cooling infrastructure. Staff endurance and working conditions are also affected, particularly in non-air-conditioned areas of the facility.

Flooding

The hospital does not appear in the flood hotspot set, and the primary disruption pathway is indirect: because of its wider catchment, flood-induced road disruption, even if not in the vicinity of the facility, could constrain patient access and inter-facility transfer for a population that is already geographically dispersed and dependent on long-distance travel.

Wildfire

Wildfire hazard is projected at high to extreme levels across Sokoto State under long-term scenarios, including Kware ward. Smoke-related conditions may affect vulnerable patients with respiratory sensitivities, and coincidence with peak heat conditions compounds stress on facility operations. Wildfire remains a secondary disruption driver relative to heat and flood.

4.4. Road network disruption analysis (referral pathway accessability)

Transport disruptions related to flooding are an important hazard documented throughout the disruption analysis at the four facilities. The following chapter focuses on an analysis of disruption along referral pathways specific for the four facilities. They include referral pathways from the primary health care centers as well as referral pathways to the secondary and tertiary health care centers analysed. Changes in travel time were quantified under projected pluvial flood scenarios relative to baseline (no-flood) conditions. The assessment considered 100-year return period pluvial flood depth for future climate scenarios (SSP2 and SSP5) and the time horizons 2050 and 2080.

Flood depth values were intersected with the road network. Each road segment was assigned a flood depth and road speeds were modified using threshold-based reductions reflecting vehicle operability under different water depths. The speed adjustments are detailed in the following table:

Table 11 Speed multipliers applied to road segments according to flood depth thresholds to represent reduced vehicle operability during flood conditions.

Flood depth	*Speed multiplier*
0 (no flood)	1
1 - 10	0.8
11 - 20	0.5
21 - 30	0.3
>30	Near-impassable (1km/h speed)*

To avoid complete network disconnection and artificial isolation of health facilities within the model, a minimum speed of 1 km/h was assigned to segments exceeding 30 cm flood depth.

Using the adjusted speed, travel time was recalculated for each road segment. A shortest-path analysis was then performed using travel time as the focused variable. This was repeated for each climate scenario and time horizon. To quantify disruption, travel times under each flood scenario were compared to baseline (no-flood) conditions using a relative travel time ratio:

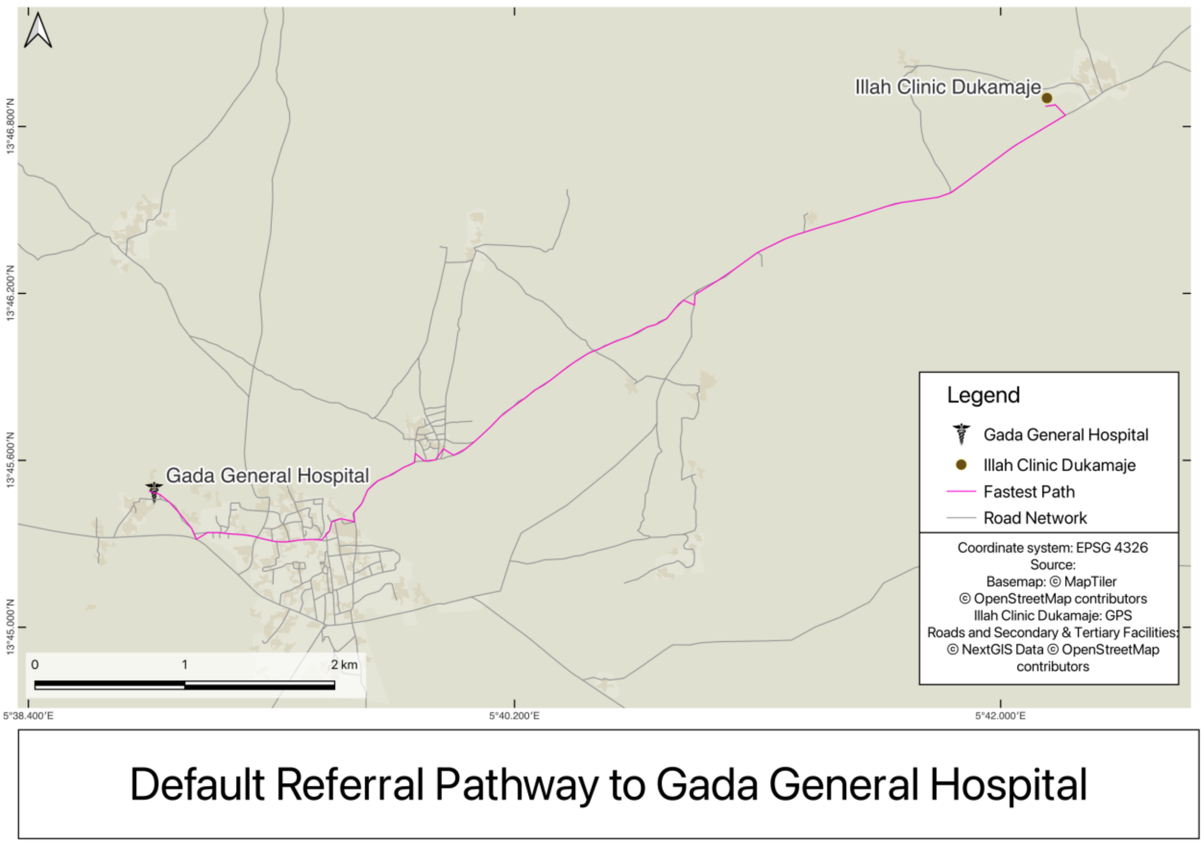
$$Travel\ Time\ Ratio = \frac{Travel\ Time_{scenario}}{Travel\ Time_{no\ flood}}$$

Values greater than 1 indicate increased travel time and therefore reduced accessibility under flood conditions.

4.4.1. **Pathway** 1: Referral Pathway from Illah Clinic Dukamaje to Gada General Hospital

This pathway represents referrals from Illah Clinic Dukamaje, a primary health facility, to Gada General Hospital, which is the main secondary referral facility for this area. The default referral pathway under baseline (no-flood) conditions is shown in Figure 20.

Figure 20: Default referral pathway from Illah Health Clinic, Dukamaje, to Gada General Hospital



Under the SSP5-2.5 and the SSP-5 scenario for 2050 pluvial flooding is projected to significantly affect accessibility along this referral pathway (

Figure 21 and Figure 22). The road conditions result in a substantial increase in travel time, with a travel ratio of approximately 7.8 (under SSP 2.5.) and 10,3 (under SSP 5) to baseline conditions.

Figure 21: Referral pathway from Illah Health Clinic, Dukamaje, to Gada General Hospital SSP2- 2050

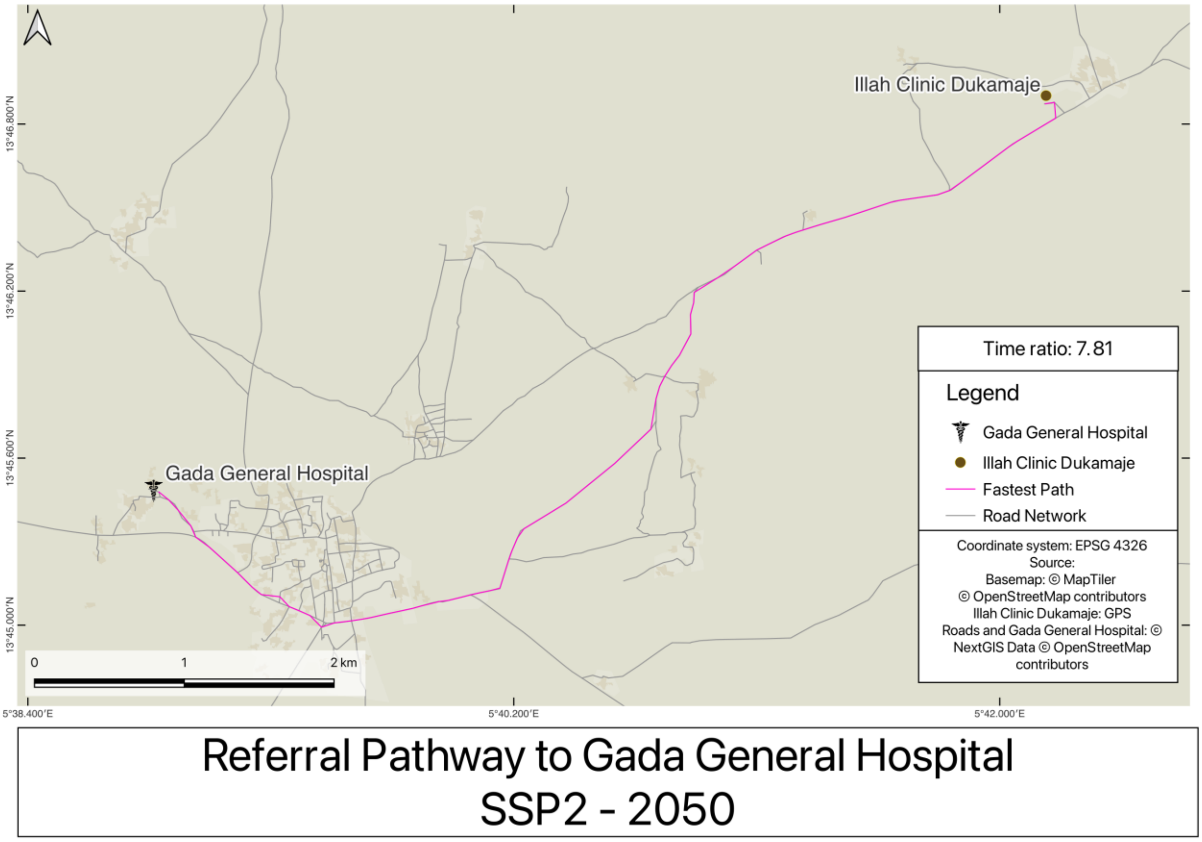
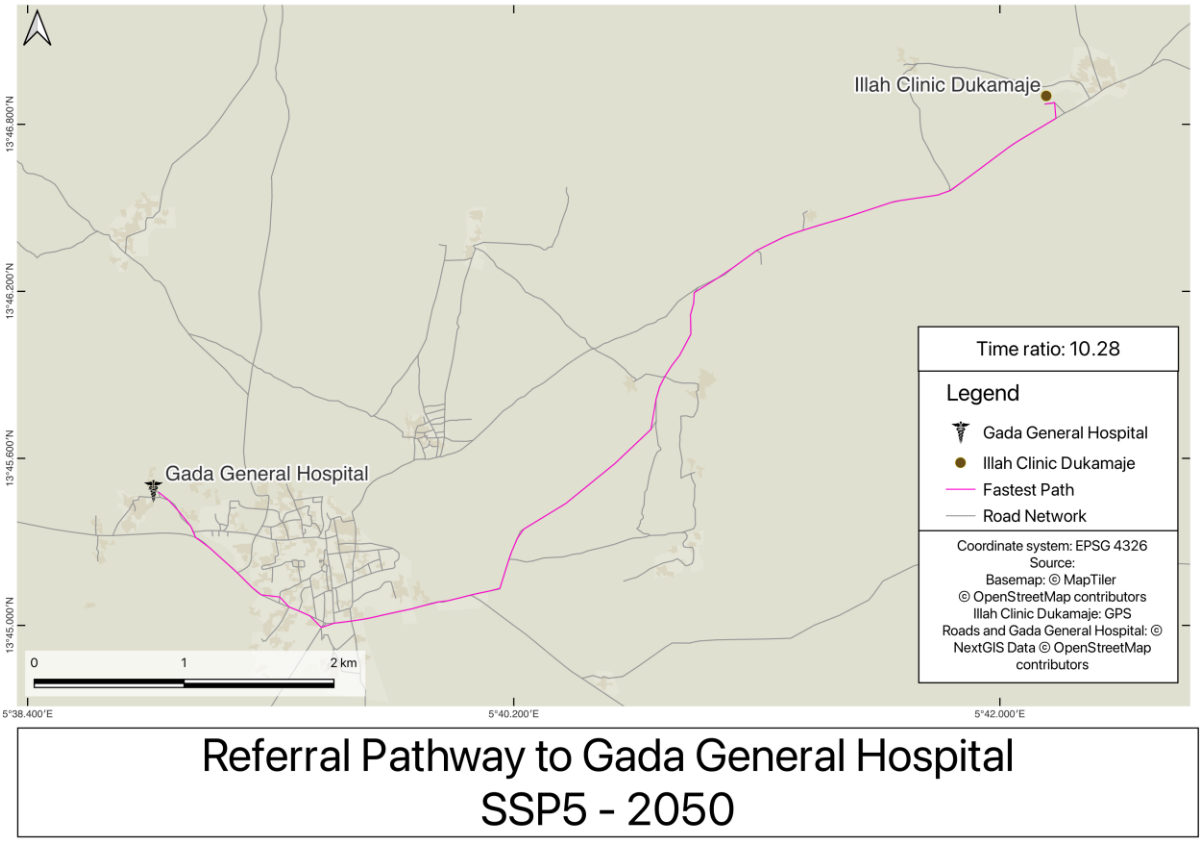


Figure 22 Referral pathway from Illah Health Clinic, Dukamaje, to Gada General Hospital: SSP5- 2050



Disruptions are even worse under the SSP2.5 and the SSP5 scenario for 2080, with an increase in travel time to approximately 10.3 times and 11.4 times compared to baseline conditions.

Figure 23 Referral pathway from Illah Health Clinic, Dukamaje, to Gada General Hospital: SSP 2-2080

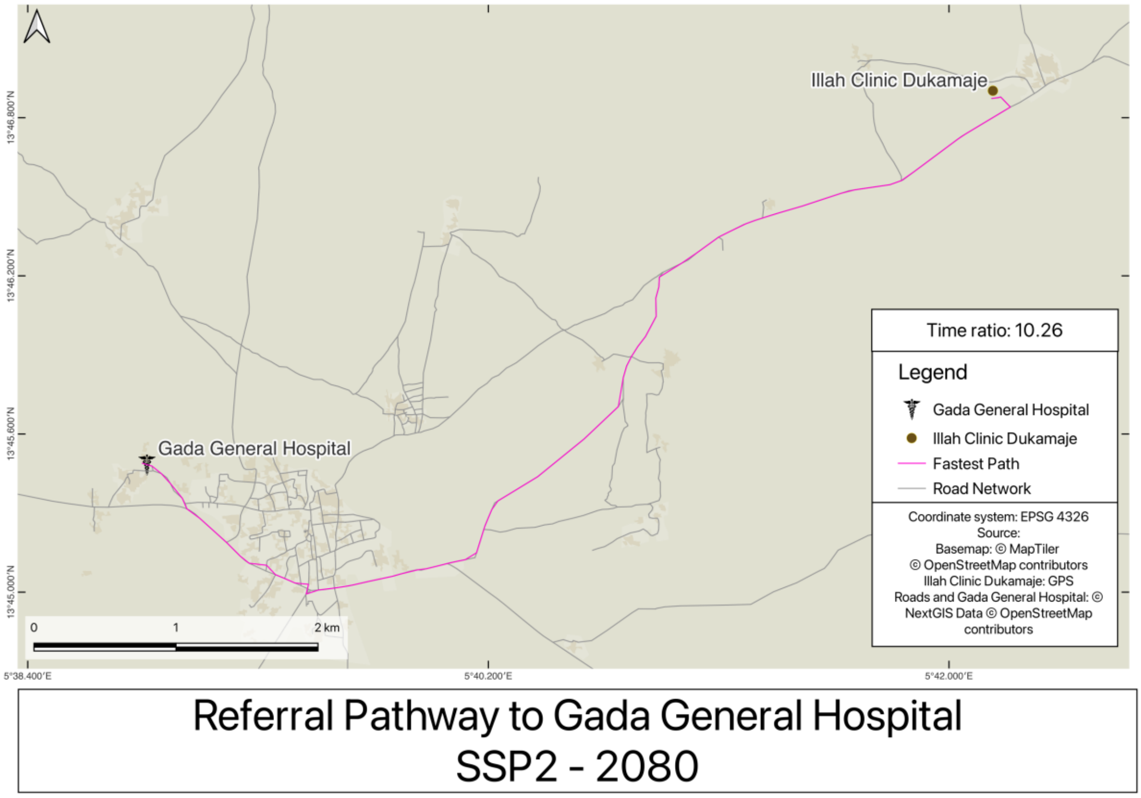
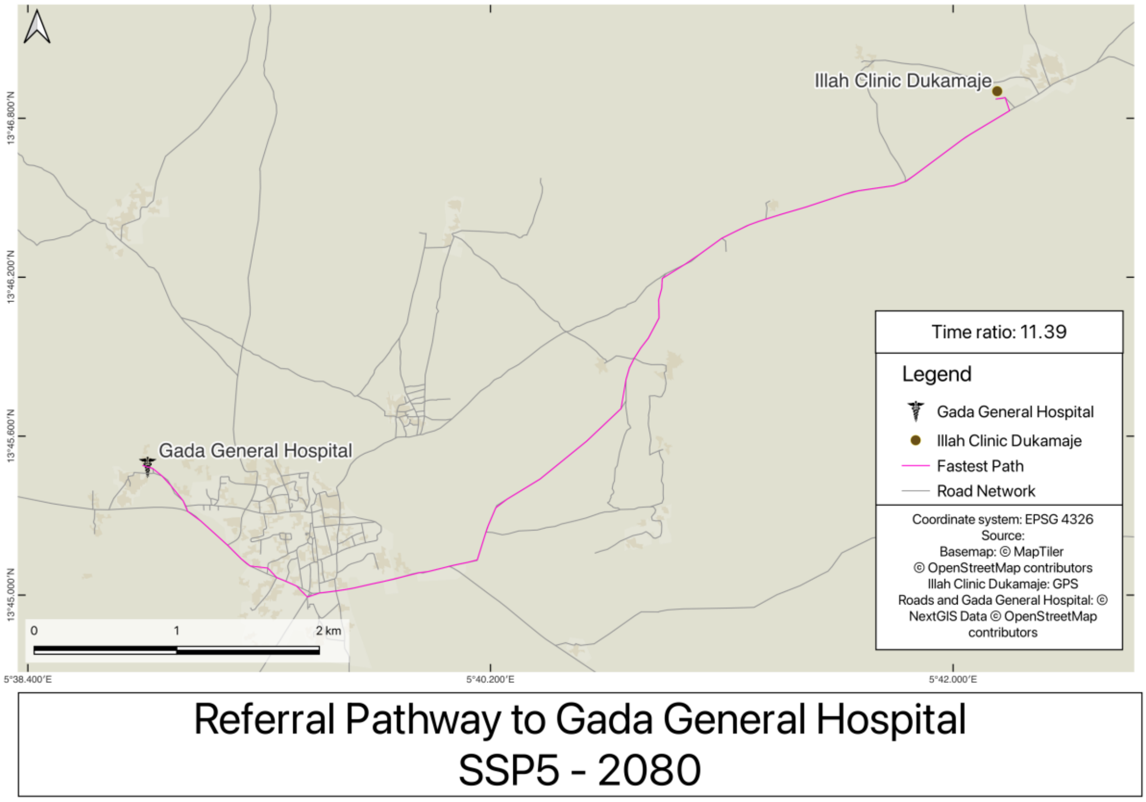


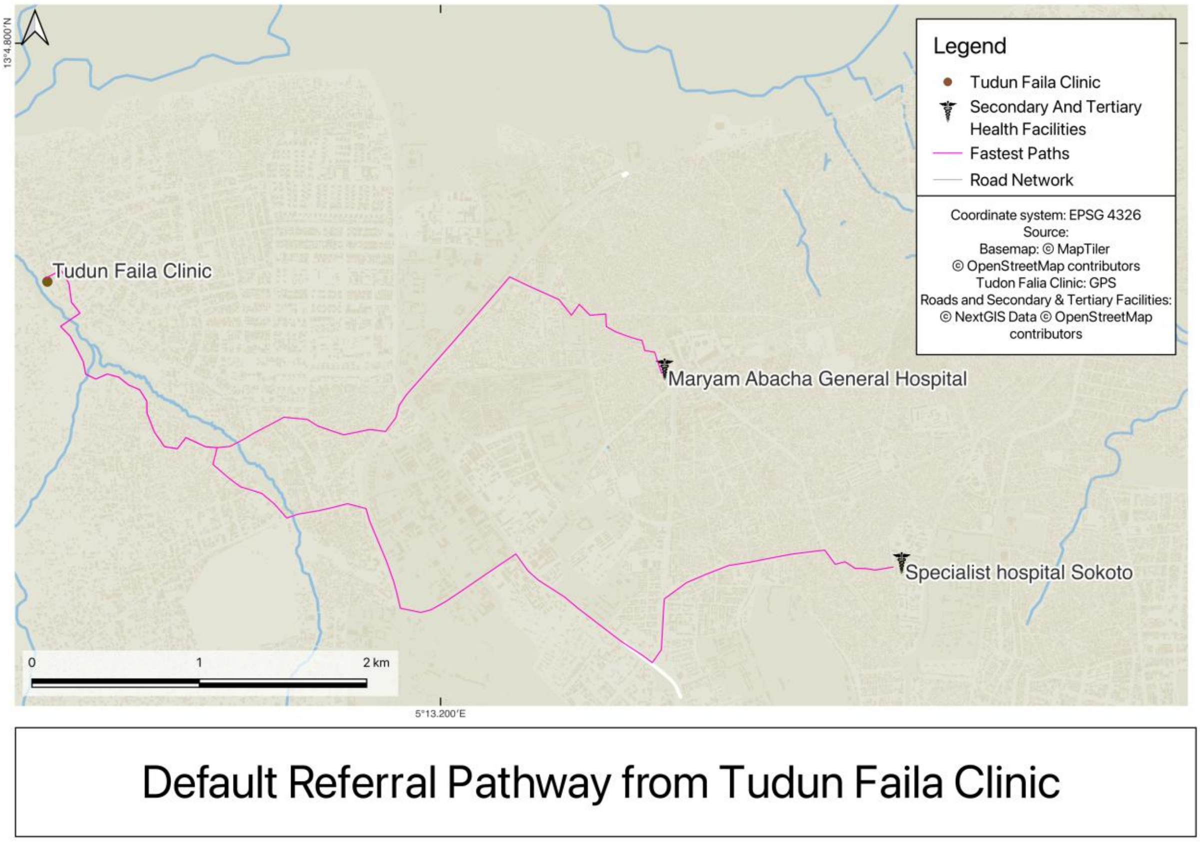
Figure 24 Referral pathway from Illah Health Clinic, Dukamaje, to Gada General Hospital: SSP5 – 2080.



4.4.2. Pathway 2: Pathway from Tudun Falia PHC

Patients from Tudun Faila Clinic requiring referral to secondary or tertiary care are typically referred to Maryam Abacha General Hospital or Specialist Hospital Sokoto. The default referral pathway (fastest route based under baseline conditions) is shown in Figure 25.

Figure 25: Default referral pathway from Tudun Faila PHC to Maryam Abacha General Hospital and Specialist Hospital Sokoto under baseline (no-flood) pathway.



Under the SSP2-4.5 scenario for 2050, pluvial flooding is expected to alter the road network, resulting in a different route, which does not require river crossings, to reach the referred hospitals (

Figure 26). This alternative route results in a travel time approximately 1.6 times longer compared to the baseline (no-flood) pathway. Under the SSP5-8.5 scenario for 2050, the disruption is expected to be smaller, with a travel ratio time of approximately 1.2, indicating that travel times are less affected under this scenario (Figure 27).

Figure 26 Referral pathway from Tudun Faila PHC to Maryam Abacha General Hospital and Specialist Hospital Sokoto: scenario SSP2 – 2050.

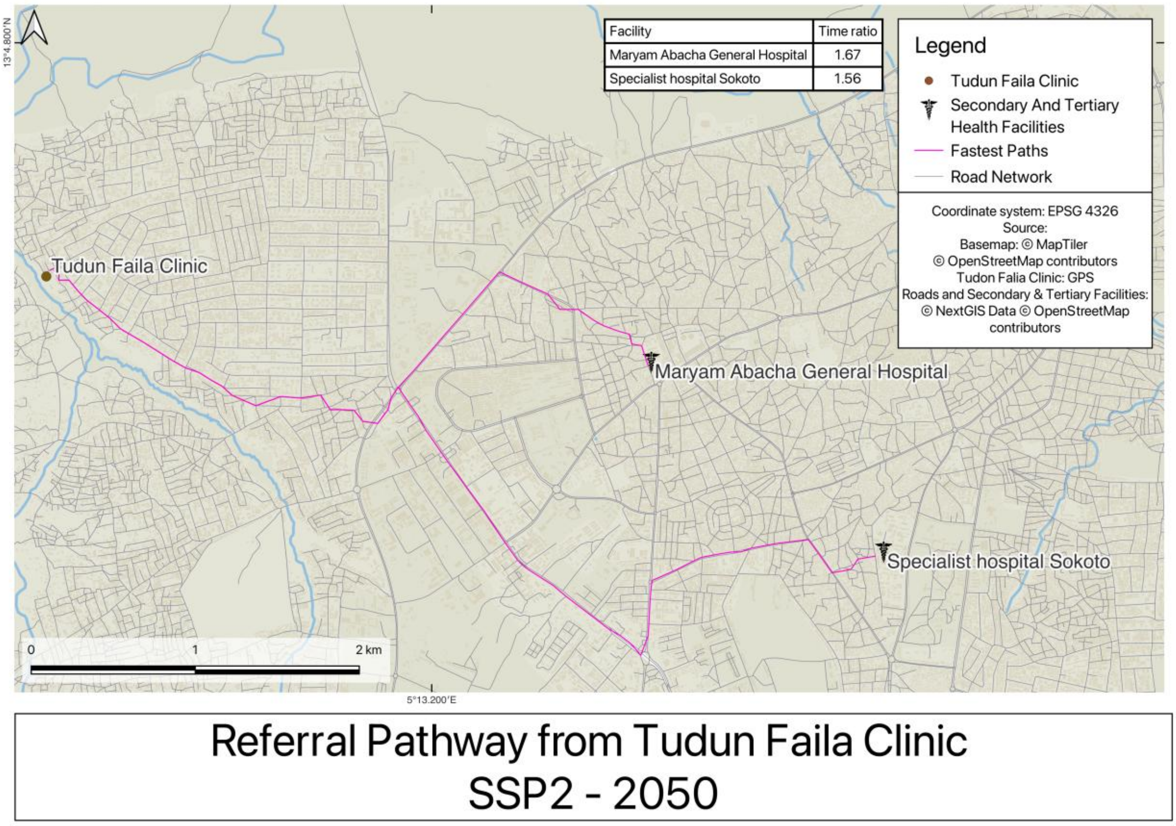
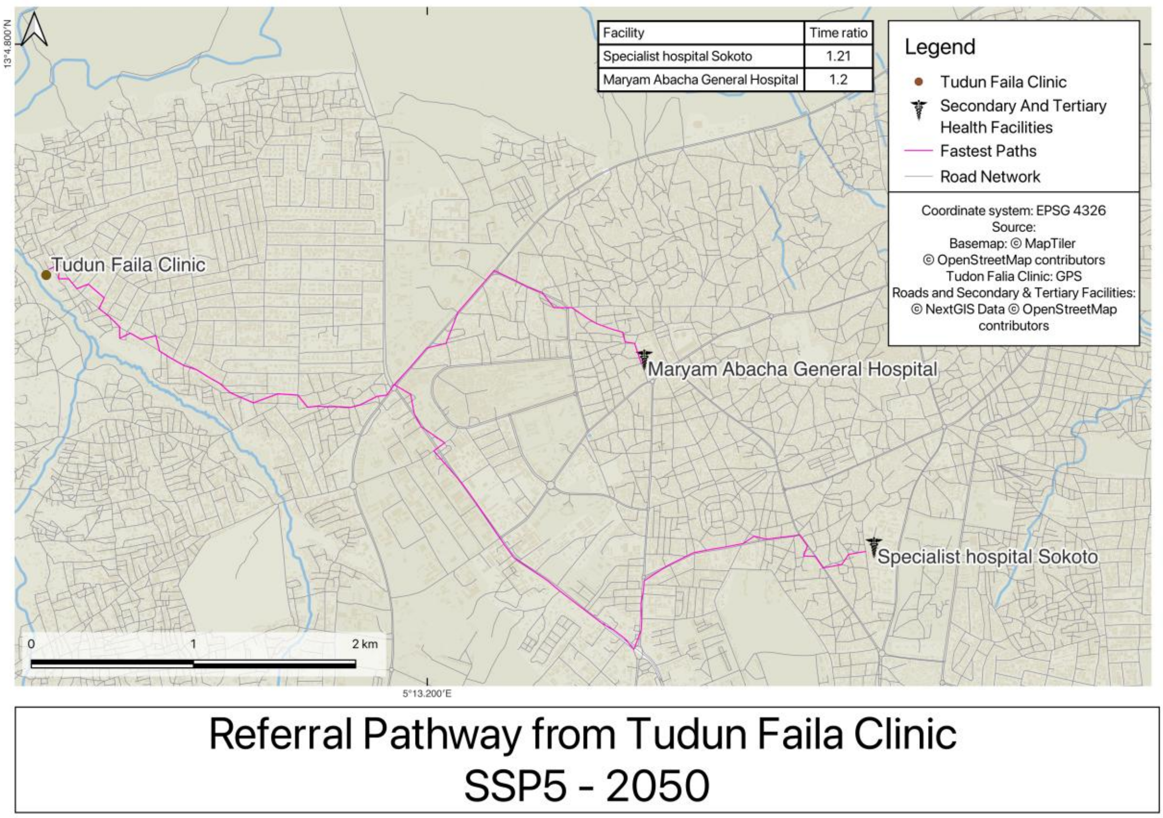


Figure 27 Referral pathway from Tudun Faila PHC to Maryam Abacha General Hospital and Specialist Hospital Sokoto: scenario SSP5 – 2050.



For 2080, under the SSP2-4.5 scenario the alternative referral route is expected to be approximately 1.2 times longer than the baseline (no-flood) pathway (Figure 28). Under the SSP5-8.5 scenario, travel time is projected to increase approximately 1.3 times the baseline route. While the overall time required will be similar to other scenarios, the route that is to be used then follows a path away from the river to the north, leading to a change in the overall route in comparison to the other projected scenarios (

Figure 29). The direct route to specialist hospital Sokoto would then be through the Maryam Abacha General Hospital instead of using a southern access road to the hospital.

Figure 28 Referral pathway from Tudun Faila PHC to Maryam Abacha General Hospital and Specialist Hospital Sokoto: scenario SSP2 – 2080.

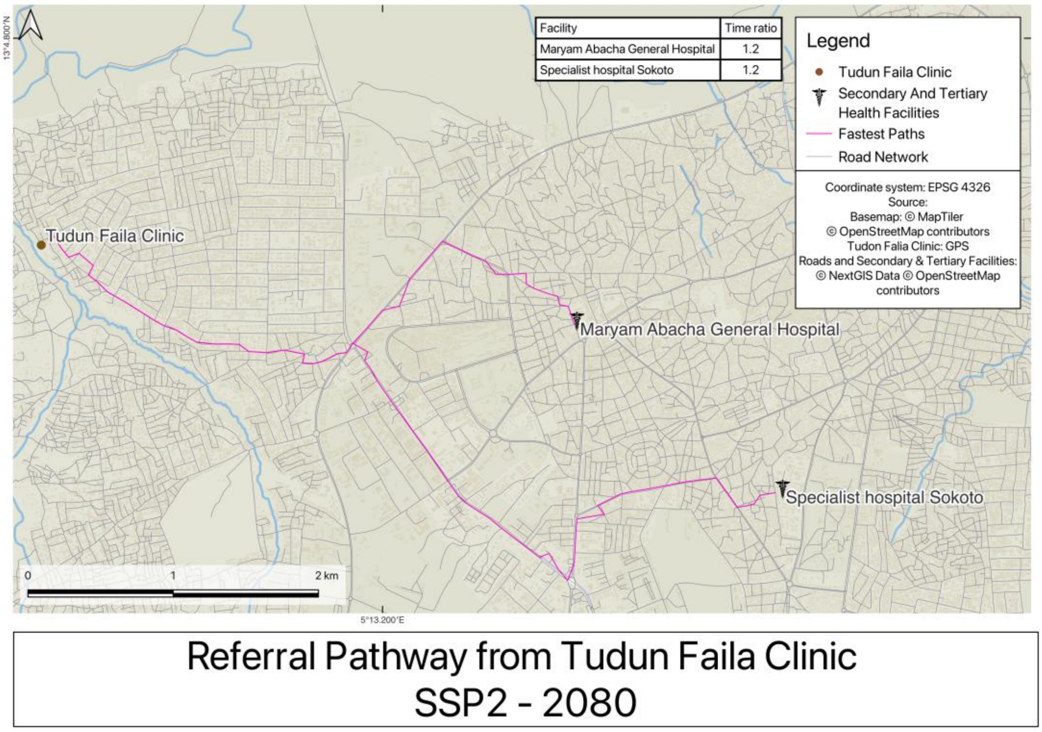
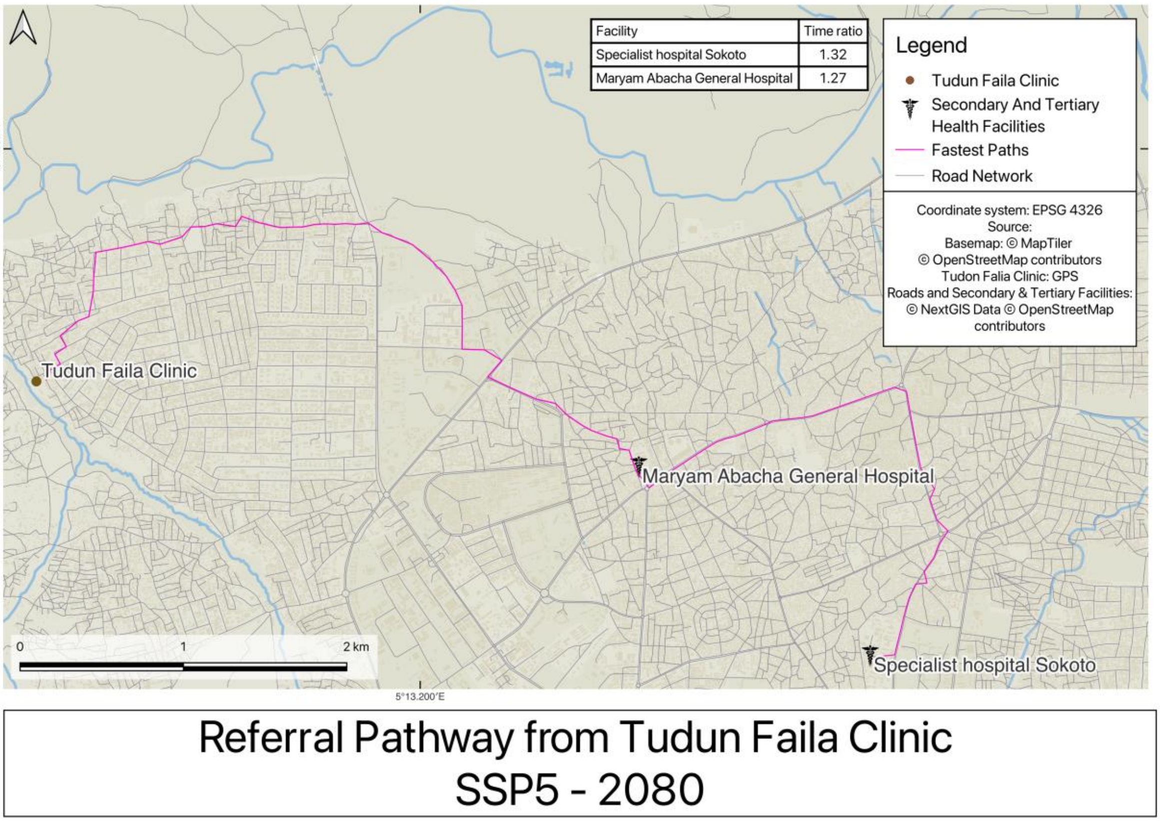


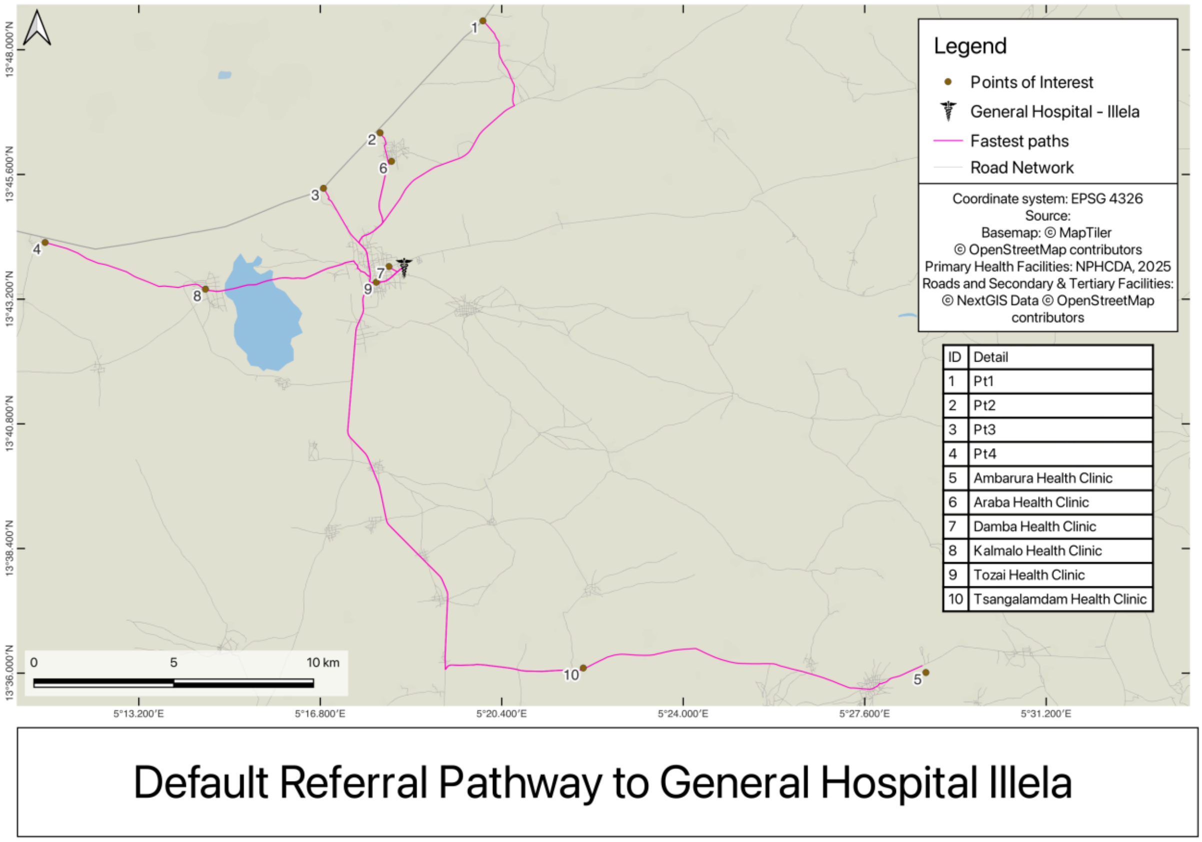
Figure 29 Referral pathway from Tudun Faila PHC to Maryam Abacha General Hospital and Specialist Hospital Sokoto: scenario SSP2 – 2080.



4.4.3. Pathway 3: Referral Pathway to Illela General Hospital

This pathway includes referrals from surrounding primary health facilities and cross-border points of contact to General Hospital Illela, which works as the main secondary referral facility for this area. Points 1 to 4 represent cross-border referral entry points from neighboring areas outside the national boundary. The baseline (no-flood) pathway is shown in Figure 30.

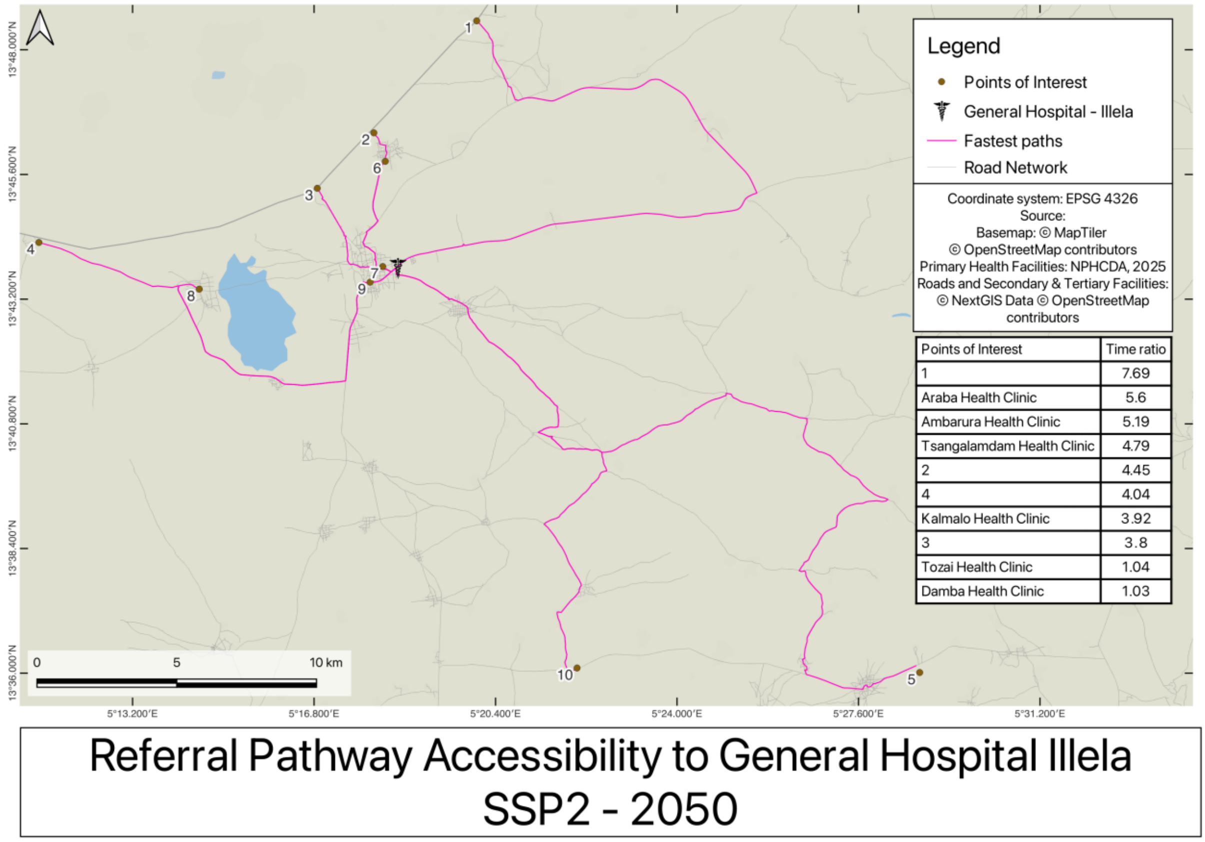
Figure 30 Default referral pathway to General Hospital Illela under baseline (no-flood) pathway.



Under the SSP2-4.5 scenario for 2050, pluvial flooding is expected to significantly affect accessibility along several referral routes (Figure 31). Travel time ratios vary depending on the origin of location. The most affected referral pathway corresponds to Point 1, where travel time is expected to increase to approximately 8 times the baseline (no-flood). Other locations, such as Araba Health Clinic and Ambarura Health Clinic are also projected to experience substantial increases in travel time, with ratios of 5.6 and 5.2, respectively.

Moderate disruptions are observed for Tsangalambam Health Clinic, Kalmaro Health Clinic, and Point 4, where travel time ratios range between approximately 4.8 and 4. In contrast, some locations, closer to the referral hospital, such as Tozai Health Clinic and Damba Health Clinic, show minimal changes in travel time, indicating that accessibility to General Hospital Illela remains largely unaffected for these areas.

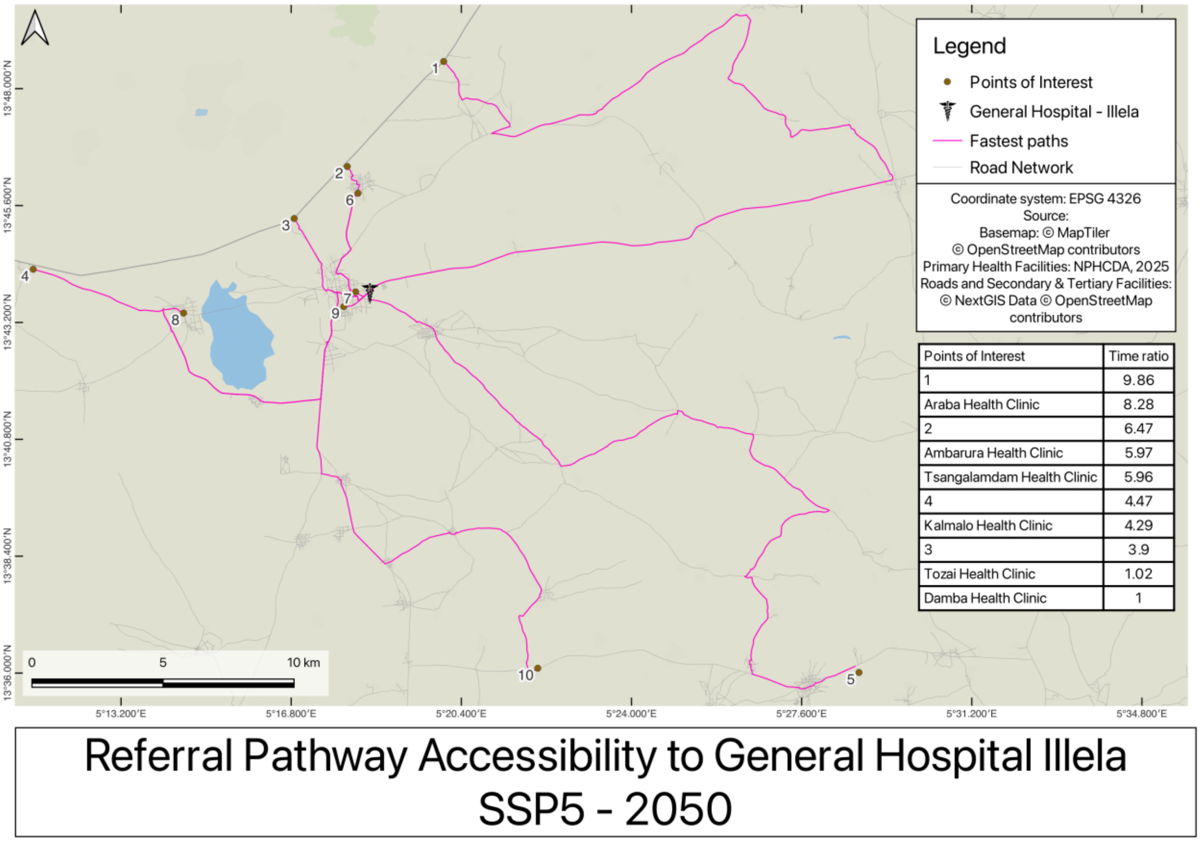
Figure 31 Referral pathway to General Hospital Illela: scenario SSP2 – 2050.



Under the SSP5-8.5 scenario for 2050, pluvial flooding is expected to significantly disrupt accessibility along several referral routes to General Hospital Illela (Figure 32). Travel time ratios vary considerably depending on the location of origin. The most severe disruption is expected to be for Point 1, where travel time is projected to increase to approximately 9.9 times the baseline. Similarly, Araba Health Clinic and Point 2 are expected to experience substantial accessibility reductions, with travel time ratios of approximately 8.3 and 6.5, respectively.

Other facilities, including Ambarura Health Clinic and Tsangalambam Health Clinic, also show significant increases in travel time, with ratios close to 6. Moderate disruptions are observed for Kalmalo Health Clinic, Point 4, and Point 3, where travel time ratios range between approximately 3.9 to 4.5.

Figure 32 Referral pathway to General Hospital Illela: scenario SSP5 – 2050.

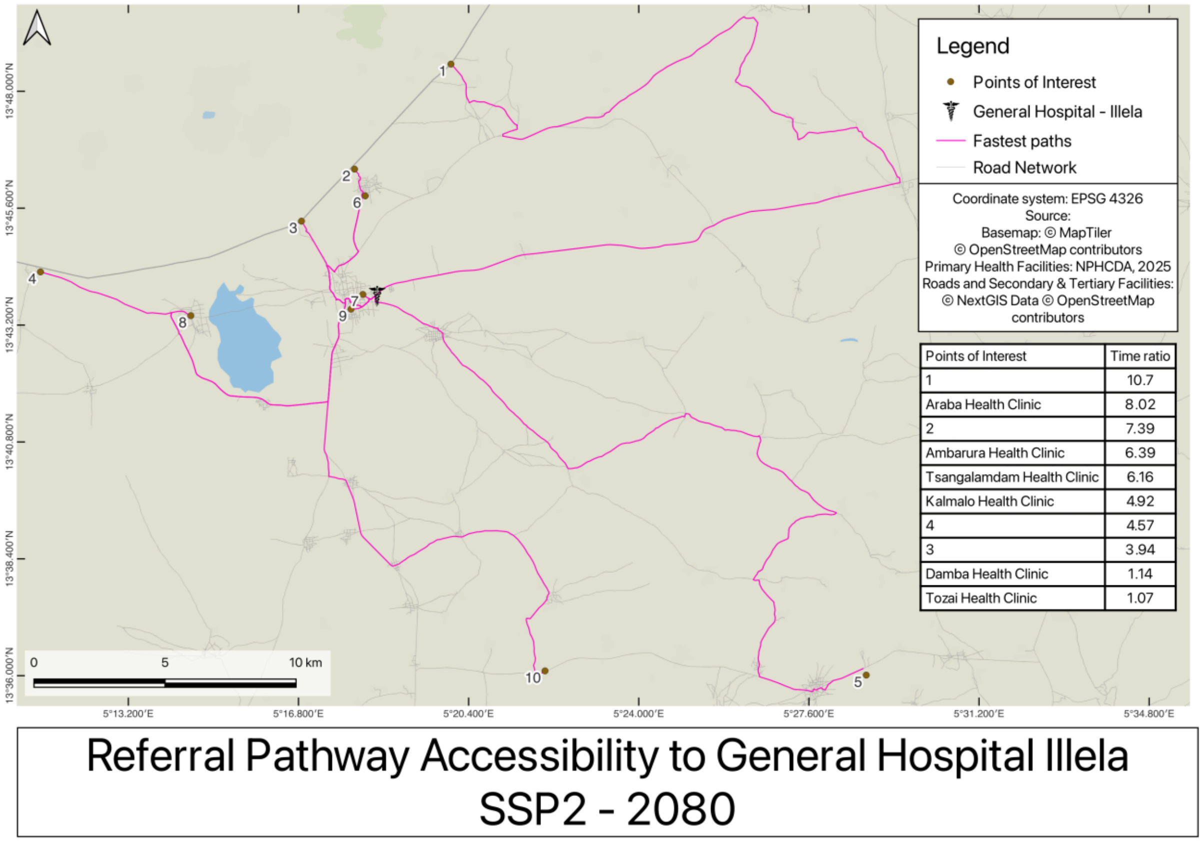


Points of Interest	Time ratio
1	9.86
Araba Health Clinic	8.28
2	6.47
Ambarura Health Clinic	5.97
Tsangalamdam Health Clinic	5.96
4	4.47
Kalmalo Health Clinic	4.29
3	3.9
Tozai Health Clinic	1.02
Damba Health Clinic	1

Under the SSP2-4.5 scenario for 2080, pluvial flooding is expected to significantly disrupt accessibility along several referral routes to General Hospital Illela (Figure 40). Travel time ratios vary significantly depending on the origin location. The most severe disruption is projected for Point 1, where travel times is expected to increase almost 11 times the baseline (no-flood). Similarly, Araba Health Clinic and Point 2 show major accessibility reductions, with travel time ratios of approximately 8.0 to 7.4, respectively.

Other facilities such as Ambarura Health Clinic and Tsangalambam Health Clinic are also expected to experience significant increases in travel time, with rations of approximately 6.4 and 6.2. Moderate disruptions are projected for Kalmalo Health Clinic, Point 4, and Point 3, where travel time ratios range between 3.9 and 4.9.

Figure 33 Referral pathway to General Hospital Illela: scenario SSP2 – 2080.

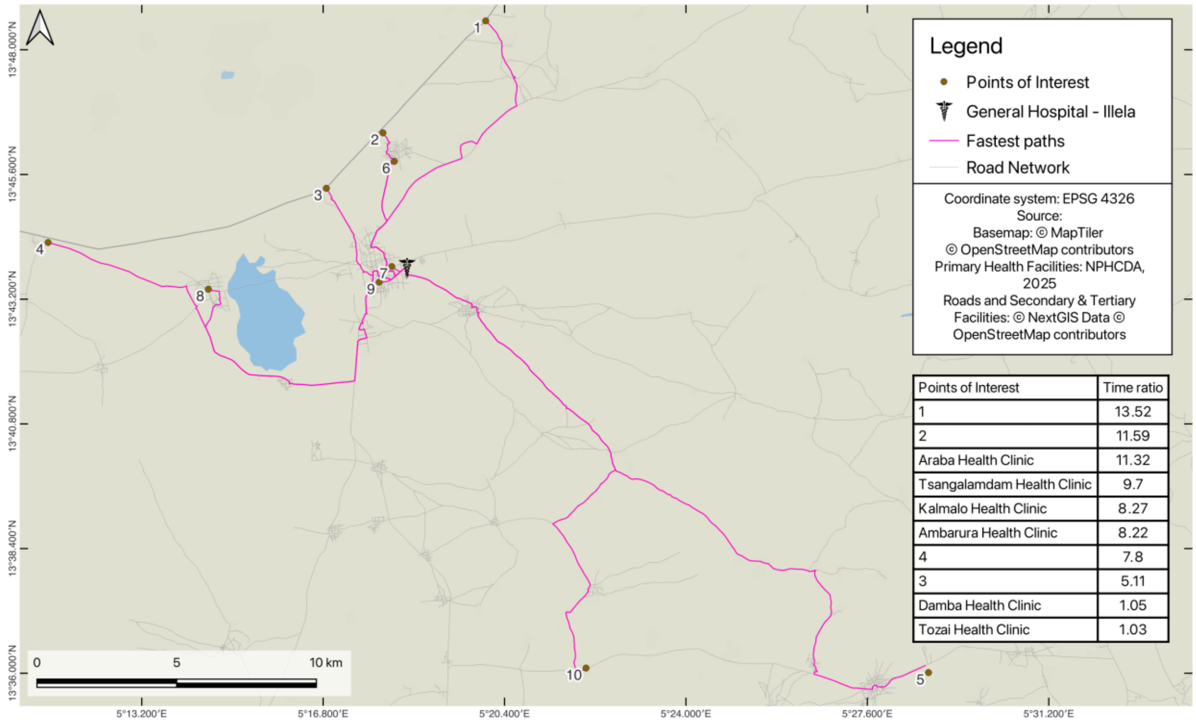


Under the SSP5-8.5 scenario for 2080, pluvial flooding is projected to severely disrupt accessibility along several referral routes to General Hospital Illela (

Figure 34). Travel time ratios increase considerably compared with baseline conditions, with the highest disruption observed for Point 1, where travel time is projected to increase to approximately 13.5 times the baseline (no-flood) travel time. Similarly, Point 2, and Araba Health Clinic show major accessibility reductions, with travel time ratios of approximately 11.6 and 11.3, respectively.

Other facilities such as Tsangalamdam Health Clinic, Kalmalo Health Clinic, and Ambarura Health Clinic are also projected to experience severe increases in travel time, with ratios ranging between 8.2 and 9.7. Moderate disruptions are observed for Point 4 and 3, where travel time ratios reach 7.8 and 5.1, respectively.

Figure 34 Referral pathway to General Hospital Illela: scenario SSP5 – 2080.



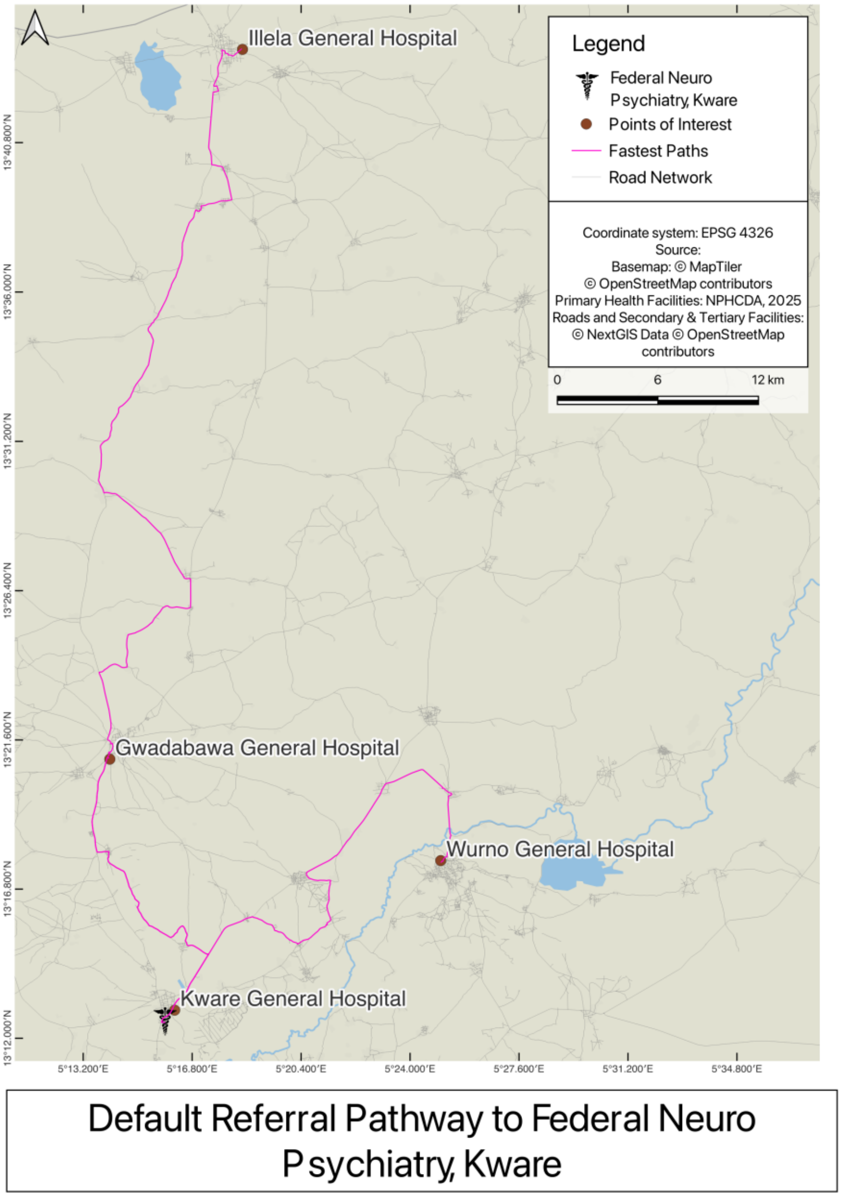
Points of Interest	Time ratio
1	13.52
2	11.59
Araba Health Clinic	11.32
Tsangalamdam Health Clinic	9.7
Kalmalo Health Clinic	8.27
Ambarura Health Clinic	8.22
4	7.8
3	5.11
Damba Health Clinic	1.05
Tozai Health Clinic	1.03

Referral Pathway Accessibility to General Hospital Illela
SSP5 - 2080

4.4.4. Pathway 4: Referral Pathway to Federal Neuro Psychiatry, Kware

This pathway represents referrals from surrounding secondary health facilities, including Gwadabawa General Hospital, Illela General Hospital, Kware General Hospital and Wurno General Hospital, to the Federal Neuropsychiatric Hospital, Kware, which works as a specialist tertiary referral facility for this area. The baseline referral pathway is shown in Figure 35.

Figure 35 Default referral pathway to Federal Neuro Psychiatry, Kware.



Under the SSP2-4.5 scenario for 2050, pluvial flooding is projected to affect accessibility along several of the referral pathways (Figure 36). Travel time ratios vary depending on the origin locations. The greatest disruption is observed for Gwadabawa General Hospital, where travel time is projected to increase to approximately 6.4 (SSP2) and 7.9 (SSP5) times the baseline (no-flood) travel time. Similarly, referrals from Illela General Hospital and Wurno General Hospital are expected to experience substantial increase in travel time, with ratios of approximately 6.2 (SSP2) and 7 (SSP5) and around 5 (for both scenarios), respectively. In contrast, referrals from Kware General Hospital, which is located close to the specialised facility, show minor changes in accessibility.

Figure 36 . Referral pathway to Federal Neuro Psychiatry, Kware: SSP2 – 2050

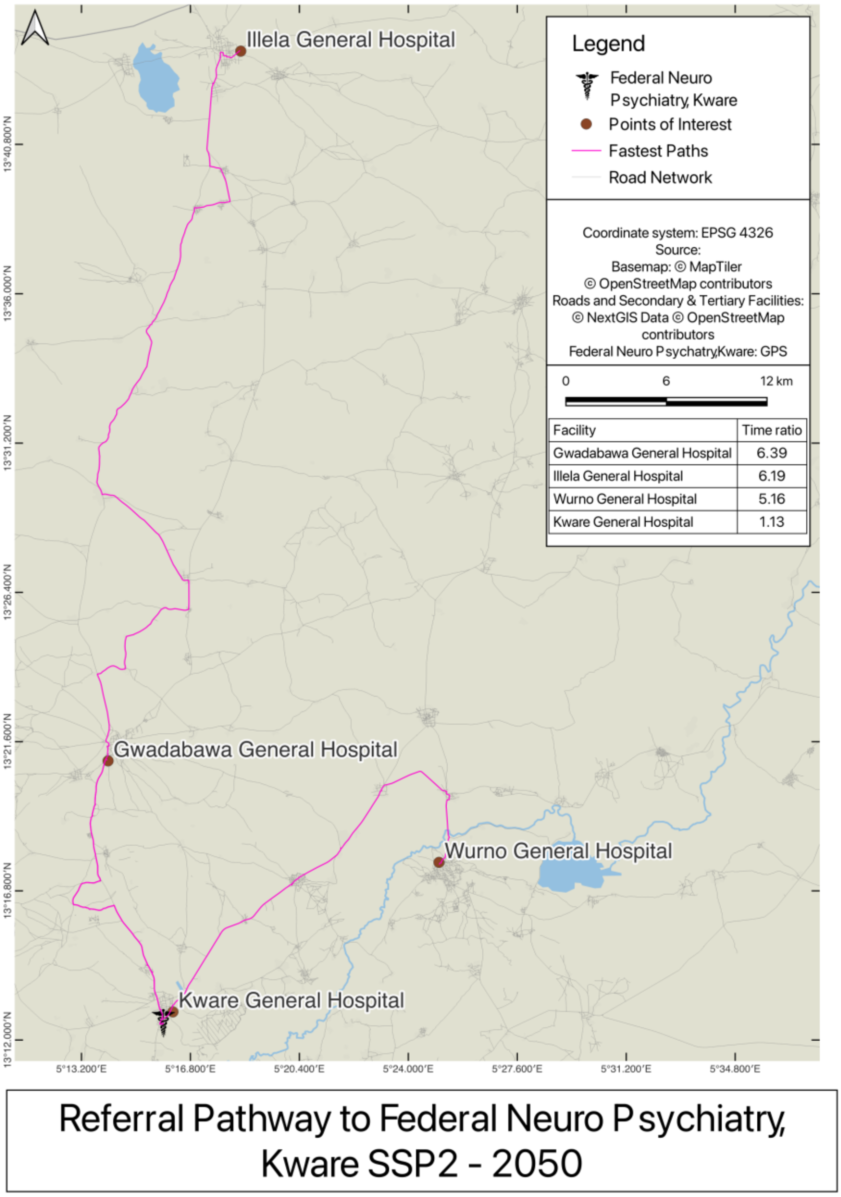
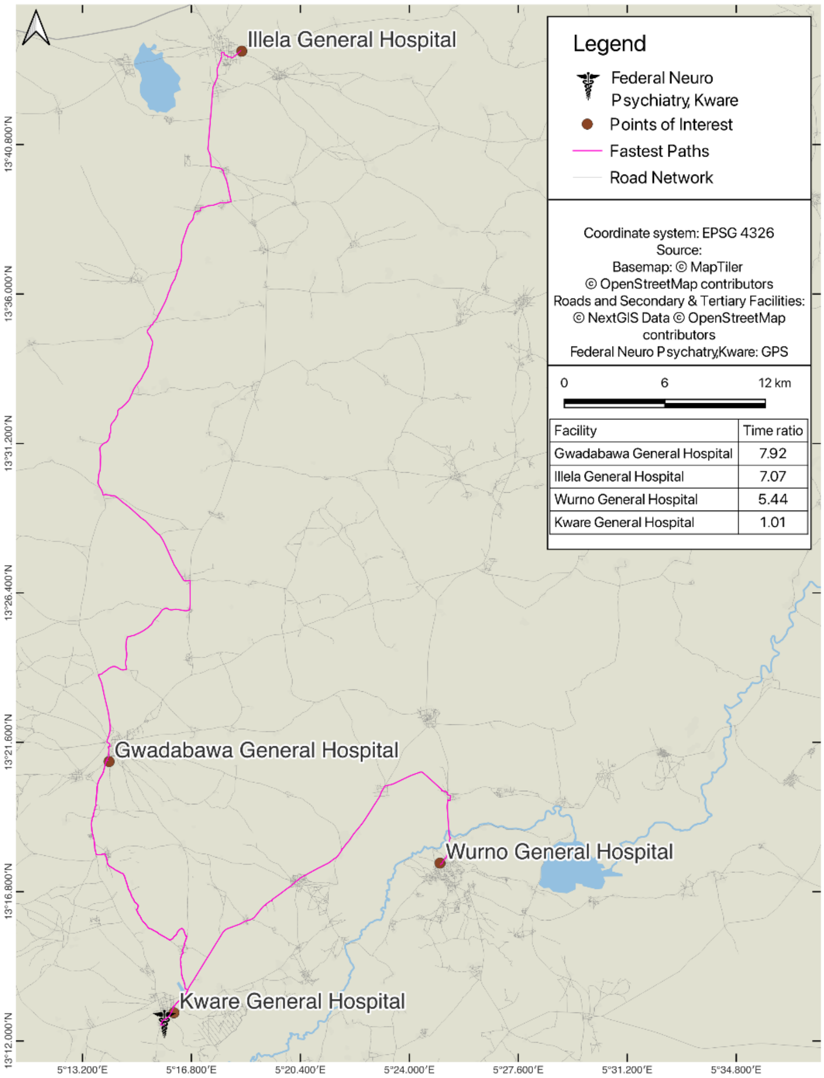


Figure 37 Referral pathway to Federal Neuro Psychiatry, Kware: SSP5 – 2050

Under the SSP2-4.5 and the SSP 5 scenario for 2080, pluvial flooding is projected to affect accessibility along several of the referral pathways (

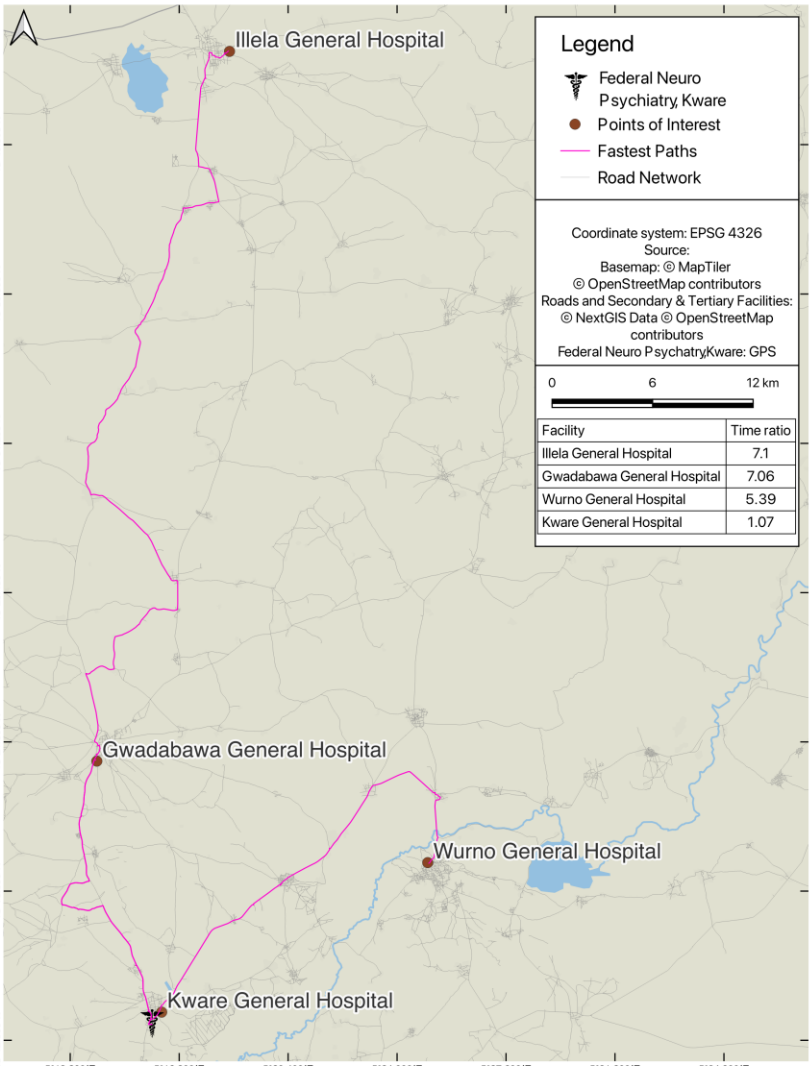
Figure 38 and

Figure 39) Travel time ratios vary depending on the origin location. The greatest disruption is observed for Illela General Hospital, where travel time is projected to increase to approximately 7.1 (SSP 2.5) and 8.9 (SSP 5) times the baseline (no-flood) travel time. Similarly, referrals from Gwadabawa General Hospital and Wurno General Hospital are expected to experience significant increases in travel time, with ratios of approximately 7 (SSP 2.5) and 8.9 (SSP 5) and 5 (SSP 2.5) and 7.2 (SSP 5), respectively. In contrast, referrals from Kware General Hospital, which is located close to the specialised facility shows minimal changes in accessibility.



Referral Pathway to Federal Neuro Psychiatry, Kware SSP5 - 2050

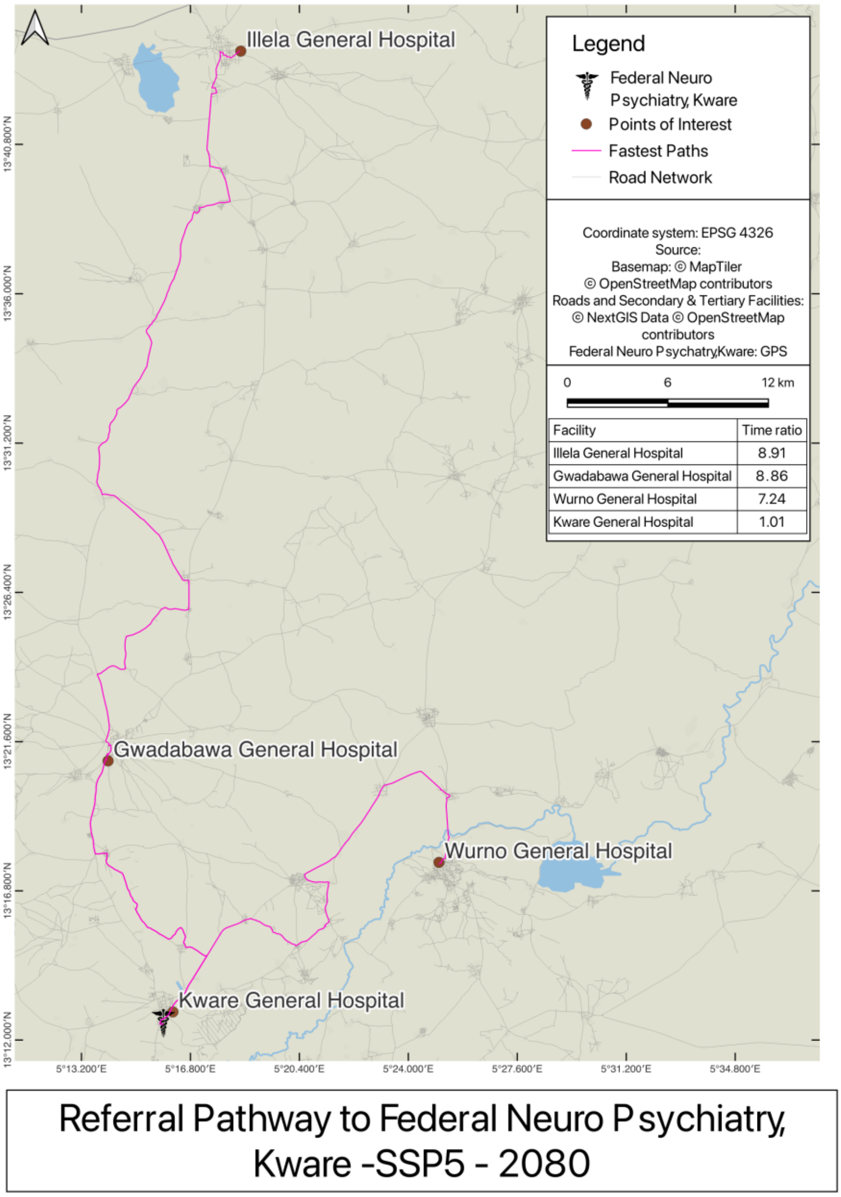
Figure 38 Referral pathway to Federal Neuro Psychiatry, Kware: SSP2 – 2080



Facility	Time ratio
Illela General Hospital	7.1
Gwadabawa General Hospital	7.06
Wurno General Hospital	5.39
Kware General Hospital	1.07

Referral Pathway to Federal Neuro Psychiatry, Kware SSP2 - 2080

Figure 39 Referral pathway to Federal Neuro Psychiatry, Kware SSP5- 2080



4.5. Comparative disruption assessment

After analysing the disruption drivers affecting each of the selected facilities, as well as the hazard-specific disruption pathways and the flood related disruptions with regards to referral pathways, this chapter provides a comparative perspective showing how these factors interact across the assessed sites. This section therefore synthesizes the facility-level findings by comparing the underlying demand and capacity drivers across the four cases and derive strategic implications for each facility. In addition to the facility-level disruption pathways discussed in section 4.3, the above road network disruption analysis (section 4.4) highlights how flood-related transport disruption can substantially affect referral accessibility across several of the assessed pathways. These results provide additional context for understanding how infrastructure connectivity influences disruption sensitivity across the facilities.

4.5.1. Disruption synthesis

Table 12 and Table 13 and Table 13 summarize the key indicators used to derive the demand pressure and service capacity scores presented in the previous chapter. By consolidating these indicators in a single table, a transparent basis for comparing how service pressure and adaptive capacity vary between facilities is provided.

Demand pressure comparison

These indicators capture both the scale of service utilization and the vulnerability profile of the populations served (Table 12). Patient load provides an indication of overall service demand relative to facility level, while the vulnerability profile of service users reflects the prevalence of population groups with elevated health-care needs. Climate-sensitive disease burden and reported service disruptions further indicate the extent to which climate stressors already shape service demand.

Table 12: Demand pressure indicators and scores across selected health system disruption hotspots

Indicator	Illah health clinic (score)	Tudun faila health clinic (score)	Illela general hospital (score)	Federal neuro psychiatry (score)
Patient load/ week	420 (1)	610 (2)	2047 (3)	2500 (3)
Patient vulnerability	Patients mostly women, children, vulnerable farmers (3)	Women and children, strong maternal focus (3)	All population groups with moderate vulnerability (2)	All population groups, including with high vulnerability (2)
Climate-sensitive diseases	Malaria and typhoid increasing (3)	Malaria increasing (2)	Limited reported climate-related illnesses (2)	No reported climate-related illnesses (1)
Service disruptions	Flooding + insecurity affecting referrals (3)	No major disruptions reported (1)	No significant service disruptions reported (1)	No significant service disruptions reported (1)
Demand pressure rating (score)	*High (2.5)*	*Moderate (2)*	*Moderate (2)*	*Moderate (1.75)*

The comparison reveals notable differences in demand pressure across the facilities. Illah Health Clinic exhibits the highest demand pressure rating, reflecting the combination of increasing climate-sensitive disease incidence and disruptions affecting referral pathways and access. The remaining facilities show moderate demand pressure overall, although absolute patient volumes vary considerably between facility levels. These differences highlight how service pressure is distributed across the selected hotspots.

Service capacity comparison

Table 13 summarizes the indicators used to assess service capacity across the four facilities. These indicators reflect the structural and operational characteristics that determine a facility's ability to maintain service delivery under stress conditions. Human resource availability and workforce pressure capture staffing adequacy, while scope of services indicates the breadth of clinical functions provided. Infrastructure reliability, cold chain systems, and emergency or referral readiness further reflect the presence of operational redundancy and contingency mechanisms.

Table 13: Service capacity indicators and scores across selected health system disruption hotspots

Indicator	Illah health clinic (score)	Tudun faila health clinic (score)	Illela general hospital (score)	Federal neuro psychiatry (score)
Human resources (skill mix)	CHEW/JCHEW only, no doctor, limited skills (1)	Nurse, midwife, CHEW mix, no doctor (2)	Full mix of skilled and specialist health personnel, 3 medical doctors (3)	Full mix of skilled and specialist health personnel, 114 medical doctors (3)
Workforce pressure (patients per clinical staff/day)	42 (1)	24.4 (2)	15.2 (2)	1.1 (3)
Scope of services	Basic PHC services only (1)	ANC, delivery, immunization, family planning (2)	Comprehensive services including specialized care (3)	Comprehensive services including specialized care (3)
Infrastructure and utilities	No electricity, limited storage (1)	Electricity + borehole; solar not working (2)	Reliable water, power, and functional health infrastructure, medical equipment outdated (2)	Reliable water, power, and functional health infrastructure (3)
Cold chain and temperature control	No cold chain, room temperature storage (1)	Functional cold chain but dependent	Robust and well-maintained	Robust and well-maintained

		on unstable grid / no redundancy (2)	temperature control systems (3)	temperature control systems (3)
Emergency and referral readiness	No ambulance, no response plan, disrupted referrals (1)	Referral pathways functional, but no ambulance, no emergency plan (2)	Functional ambulance, referral pathways, and response plans (3)	Functional ambulance, referral pathways, and response plans (3)
Capacity rating (score)	*Low (1)*	*Moderate (2)*	*High (2.7)*	*High (3)*

The comparison shows substantial variation in service capacity across the facilities. The Federal Neuro Psychiatric Hospital and Illela General Hospital exhibit the strongest capacity profiles, reflecting skilled personnel, reliable infrastructure systems, and functional referral mechanisms. Tudun Faila Health Clinic takes an intermediate position, with moderate staffing and service scope but some infrastructure limitations. Illah Health Clinic shows the weakest capacity profile, characterized by limited staffing, unreliable infrastructure, and constrained referral readiness. These differences are central to understanding the varying disruption sensitivity identified in the comparative matrix presented below (Figure 40).

Combined comparison demand pressure and service capacity

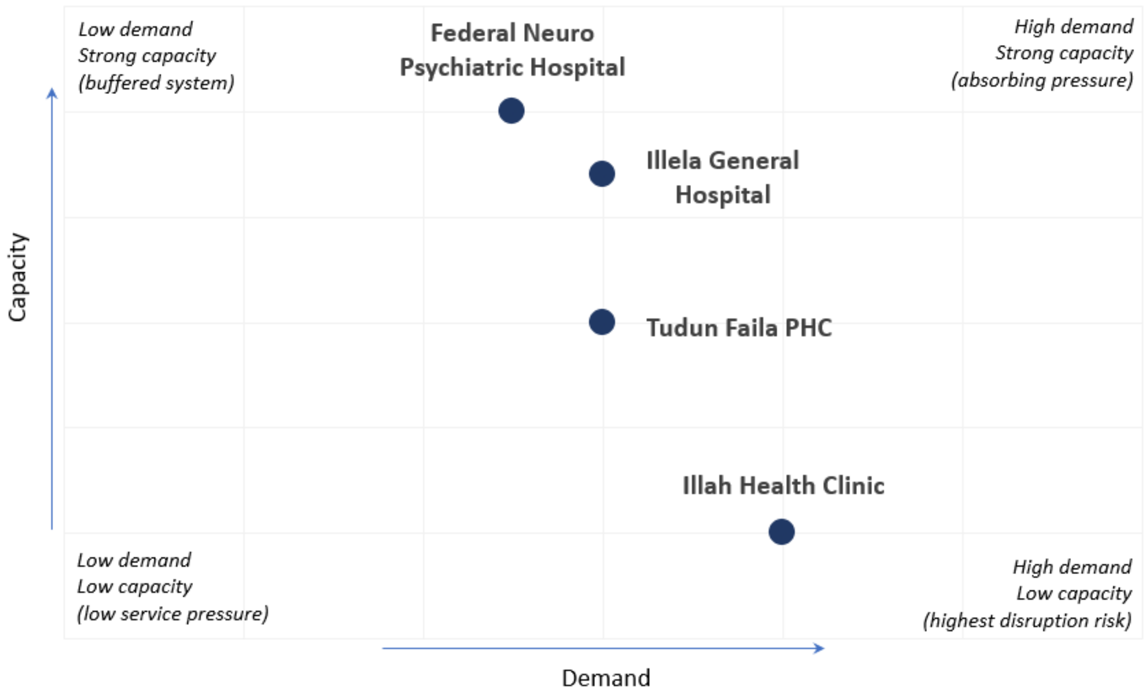
Combining demand and capacity indicators reveals a clear gradient across the facilities. Higher-level hospitals experience substantial service demand but retain stronger buffering capacity due to greater staffing depth, infrastructure reliability, and functional referral systems. In contrast, rural primary health facilities operate under significant service pressure while possessing far more limited adaptive capacity. As a result, structural imbalances between demand and capacity are most pronounced at the primary care level. Table 14 summarizes the composite demand pressure and service capacity scores derived from the preceding indicator analysis. Comparing these scores highlights how the balance between service demand and facility capacity varies across the selected sites. Facilities where demand pressure substantially exceeds available capacity are more sensitive to disruption when climate hazards affect service delivery, while facilities with stronger capacity buffers are better positioned to absorb such shocks.

Table 14: Facility Scores (Demand vs Capacity)

Facility	Demand score (level)	Capacity score (level)	Demand-capacity relationship	Disruption interpretation
FNPH KWARE	1.75 (moderate)	3.0 (high)	Capacity exceeds demand	Strong buffering
GH ILLELA	2.0 (moderate)	2.7 (high)	Capacity exceeds demand	Relatively resilient
ILLAH CLINIC	2.5 (high)	1.0 (low)	Demand exceeds capacity	High disruption sensitivity
TUDUN FAILA	2.0 (moderate)	2.0 (moderate)	Demand ≈ capacity	Moderate disruption sensitivity

The demand–capacity matrix below (Figure 40) highlights differences in the balance between service pressure and buffering capacity across the selected facilities. Facilities are positioned according to their composite demand pressure and service capacity scores (scale 1–3). The figure illustrates relative positioning rather than strict quadrant classification. Note that the matrix does not explicitly incorporate hazard exposure. Climate hazards act as external triggers that may disrupt service delivery, while the position of a facility in the matrix reflects its relative ability to absorb or amplify resulting disruptions. Hazard exposure is therefore analyzed separately through the hazard-specific disruption pathways discussed in the facility profiles above.

Figure 40: Demand–capacity positioning of selected health system disruption hotspots



The Federal Neuro Psychiatric Hospital occupies the strongest capacity position relative to demand, while Illah Health Clinic lies closest to the higher-demand / lower-capacity end of the spectrum, indicating the greatest disruption sensitivity among the four cases. Illela General Hospital occupies an intermediate position with relatively strong capacity despite high demand, while Tudun Faila PHC is positioned closer to the center, reflecting a more balanced demand-capacity profile.

Taken together, the matrix synthesizes the facility-level findings by illustrating how differences in demand pressure and service capacity shape relative disruption sensitivity across the selected sites. This comparative perspective helps visualize and identify where resilience strengthening is most critical.

4.5.2. Strategic implications

Illah Health Clinic

Illah Health Clinic can be characterized as a high-demand, low-capacity disruption archetype. Its vulnerability emerges not from extreme hazard exposure alone, but from the interaction between elevated service dependence and minimal adaptive infrastructure. Under projected increases in flood variability and extreme heat intensity, the probability of compound stress, where demand increases while referral and supply pathways degrade, is likely to rise.

In comparative terms, IHC represents the clearest example of structural fragility among the assessed hotspots. Strengthening resilience at this facility therefore requires addressing the basic infrastructure and operational constraints that currently limit its ability to absorb external shocks. Improvements in areas such as energy reliability, cold chain stabilization, and referral contingency planning would significantly alter its disruption trajectory. Without such adjustments, even moderate hazard events may result in disproportionate service interruption relative to other facilities. This vulnerability is reinforced by the road network disruption analysis, which indicates that flood conditions could substantially increase travel times along the referral route from Illah Clinic Dukamaje to Gada General Hospital under several projected scenarios. Areas where resilience strengthening would be particularly relevant include:

- Improving access to reliable power supply and basic cooling infrastructure to protect vaccine storage and pharmaceutical integrity under extreme heat conditions.
- Strengthening on-site vaccine refrigeration and temperature monitoring to reduce reliance on external facilities.
- Enhancing referral coordination and transport arrangements to maintain access to higher-level care during flood-related road disruptions.

- Improving storage capacity, utilities, and essential facility infrastructure to reduce operational fragility.
- Strengthening staffing arrangements and outreach coordination to manage fluctuations in patient demand during disruption periods.

Improvements in these areas would help shift Illah Health Clinic from a structurally fragile node within the health system toward a more resilient primary care facility capable of maintaining essential services under climate-related stress.

Tudun Faila PHC

Tudun Faila PHC can be characterized as a moderate-demand, moderate-capacity facility operating with meaningful but fragile infrastructure. Its disruption risk profile differs qualitatively from that of Illah Health Clinic: whereas Illah operates without foundational infrastructure and is exposed to both direct and cascading failure pathways simultaneously, Tudun Faila has functional systems in place but lacks the redundancy needed to absorb compound stress.

The critical vulnerability is its single-point dependence on grid electricity in an environment of projected extreme heat intensification. This represents a foreseeable and addressable failure point. Unlike structural deficits that would require substantial investment to resolve, restoring reliable solar backup capacity would significantly improve the facility's resilience against its most likely disruption pathway.

The road network disruption analysis indicates comparatively smaller increases in travel times along referral routes from Tudun Faila under projected flood scenarios. While transport disruption may still affect accessibility during extreme events, the analysis suggests that in urban areas, alternative routes are available and infrastructure reliability within the facility itself represents the more immediate resilience constraint.

In comparative terms, Tudun Faila PHC occupies an intermediate position wialthin the assessed hotspot set—more buffered than Illah, yet less resilient than the secondary and tertiary facilities. Strengthening resilience at this site would therefore primarily involve improving the reliability of existing infrastructure systems rather than addressing fundamental service gaps. Areas where resilience strengthening would be particularly relevant include:

- Improving backup energy capacity to reduce dependence on grid electricity and maintain service continuity during extreme heat events and power outages.
- Strengthening temperature control systems and ensuring stable operation of refrigeration and diagnostic equipment during power interruptions.
- Strengthening contingency planning and communication procedures to maintain functional referral pathways during disruption events.
- Ensuring that existing water, power, and facility systems operate consistently under climate stress conditions.

Addressing these areas would help consolidate Tudun Faila's role as a moderately resilient primary care facility, reducing the likelihood that localized infrastructure failures translate into broader service disruptions.

Illela General Hospital

Illela General Hospital is best characterized as a system-stressed node rather than a structurally fragile facility. Its internal capacity is the strongest among the primary and secondary hotspot facilities assessed, and routine operations are stable. Its disruption risk derives principally from two sources: a single-point power dependency that exposes cold chain and general operations to power system failure, and its position as the referral anchor for a network of primary facilities whose own climate vulnerability is high. This system-level vulnerability is also reflected in the road network disruption analysis, which indicates substantial increases in travel times along several referral routes to General Hospital Illela under projected flood scenarios.

Under compound stress scenarios such as simultaneous heatwave conditions, flood-related road disruption across feeder LGAs, and surge referral demand, the hospital's absorptive capacity may be tested in ways that current contingency arrangements may not fully address. In this sense, Illela General

Hospital represents a case where disruption risk is shaped less by internal structural fragility and more by the interaction between facility capacity and system-wide demand dynamics.

Among the four hotspots, Illela therefore represents the facility where health system network resilience, rather than internal infrastructure strengthening alone, becomes particularly relevant for maintaining service continuity during climate-related disruptions. Areas where resilience strengthening would be particularly relevant include:

- Improving redundancy in power supply to reduce operational risks associated with single-point energy dependence and to safeguard cold chain and medical equipment during extreme heat conditions.
- Strengthening preparedness for temporary increases in patient inflow resulting from disruptions affecting surrounding primary facilities.
- Enhancing coordination mechanisms with surrounding PHCs to maintain effective referral flows during flood-related transport disruption.
- Improving coordination between facility operations, transport systems, and emergency response arrangements to reduce cascading disruption across the wider service network.

Strengthening these aspects of system coordination and infrastructure reliability would help reinforce Illela General Hospital's role as a stable referral hub within the regional health system, capable of maintaining service continuity during compound climate-related stress events.

Federal Neuro Psychiatric Hospital

Among the four hotspots, the Federal Neuro-Psychiatric Hospital (FNPH) presents the strongest internal capacity and the lowest structural fragility under current and near-term conditions. Its disruption risk is not driven by infrastructure deficit but by the irreplaceable nature of its service function and the clinical sensitivity of its patient population. A disruption that would represent a manageable setback at a general facility, such as a temporary cold chain failure, a period of reduced access, or a medication resupply delay, carries disproportionately severe consequences at a specialist psychiatric hospital where continuity of care is clinically non-negotiable.

As flood exposure along selected referral pathways materializes, and as extreme heat intensifies across all projections, maintaining operational continuity at FNPH becomes particularly important. Disruption at this facility would have implications extending well beyond Sokoto State, given its role as a regional specialist referral center. The road network disruption analysis similarly indicates that several referral pathways from surrounding secondary facilities to the Federal Neuro-Psychiatric Hospital may experience significant travel time increases under projected flood conditions.

In comparative terms, FNPH therefore represents a case where resilience considerations focus less on addressing structural deficits and more on safeguarding continuity in a facility with high system criticality. Areas where resilience strengthening would be particularly relevant include:

- Maintaining reliable backup energy systems and operational redundancy to ensure uninterrupted functioning of clinical infrastructure during extreme heat or grid disruptions.
- Strengthening supply chain reliability and contingency planning to safeguard uninterrupted access to essential psychiatric medications.
- Ensuring that referral pathways and transport access remain functional during flood-related disruptions affecting key transport corridors.
- Strengthening institutional preparedness for maintaining continuity of care during compound climate-related disruptions.

Taken together, strengthening these aspects of operational redundancy and contingency planning would help safeguard the continuity of specialized mental health services provided by FNPH, thereby protecting a facility whose disruption would have consequences extending well beyond the immediate local health system.

5. Synthesis and foundations for adaptation planning

The analyses presented in this report span climate hazard projections, health system exposure, socio-economic vulnerability, facility-level disruption assessment, and road network accessibility. Collectively, they characterize how climate change is likely to affect healthcare delivery across Sokoto State, and where the consequences will be most acutely felt. This concluding chapter synthesises those findings into a coherent basis for adaptation planning. It identifies the dominant risk patterns, the most critical failure pathways, and the priority areas where intervention would most effectively reduce disruption risk — providing the analytical foundation for the long list of adaptation options developed in a companion document. It also reflects on the boundaries of the analysis and identifies directions for future work that would strengthen the evidence base over time.

5.1. Dominant hazard profiles and their system-level implications

The climate hazard analysis establishes two hazards as structurally dominant for health system continuity in Sokoto State: extreme heat and flooding. Their system-level implications are distinct and in many respects compounding.

Extreme heat operates as a near-universal, chronic stressor. Under both moderate (SSP2) and high-emission (SSP5) scenarios, the analysis projects that all health facilities across Sokoto State will face high to extreme hazard levels by mid-century, with intensification continuing through 2080–2100. This uniformity means that heat does not differentiate spatial priorities between wards or facilities — it is a baseline condition that all parts of the health system will need to adapt to. Its primary effects on health infrastructure run through three interconnected channels:

- cold chain and pharmaceutical storage integrity, where unstable or absent electricity creates direct risks of temperature excursion under sustained high ambient temperatures;
- staff performance and endurance, where prolonged heatwaves reduce clinical capacity in facilities that lack cooling infrastructure; and
- disease burden amplification, particularly for climate-sensitive conditions such as malaria, meningitis, and diarrhoeal disease, which increase outpatient demand precisely when facility conditions are most constrained.

Heatwaves compound all three pathways simultaneously and are projected to become more frequent and persistent across all scenarios. Flooding, by contrast, operates as a spatially differentiated, episodic stressor with cascading effects that extend well beyond direct facility inundation. Direct pluvial flood exposure affects a meaningful subset of primary facilities under 100-year return period projections, with hazard levels escalating significantly under SSP5 by 2080. However, the more pervasive impact of flooding is indirect: the road network disruption analysis demonstrates that pluvial flooding can increase travel times to referral facilities by 7 to 14 times baseline conditions along several key pathways under mid- and long-term scenarios. In a health system that is already structurally dependent on linear referral chains and is largely without ambulance coverage or alternative routing options, these travel time increases are not administrative inconveniences — they represent disruptions to the ability of pregnant women, acutely ill children, and psychiatric patients to reach time-sensitive care. Wildfire functions as a secondary hazard, compounding heat-related stress and generating incremental increases in respiratory outpatient demand, but does not drive primary disruption pathways at the facility level under current projections.

5.2. Priority disruption profiles across the health system

The facility disruption analysis, combined with the socio-economic vulnerability assessment, identifies a differentiated set of priority profiles across the health system tier structure. These profiles are not interchangeable: each describes a distinct combination of risk drivers, and effective adaptation requires tailored responses to each type.

Primary care: structural fragility under compound stress. Illah Health Clinic in Dukamaje represents the archetype of primary-level structural vulnerability in the hotspot set — a facility with high demand pressure from a predominantly maternal and child population, operating without electricity, without a functional cold chain, without a doctor, and without any formal emergency preparedness. The road network analysis projects travel time increases of 7.8 to 11.4 times baseline for the referral pathway to Gada General Hospital under projected flood scenarios, meaning that the facility cannot reliably offload cases it cannot manage on-site. This combination — high demand, minimal on-site capacity, and severely degraded referral access under climate stress — represents the most acute disruption risk among the assessed facilities. Tudun Faila PHC in the only urban hotspot ward presents a more contained but real vulnerability: it is otherwise functionally adequate, but its sole dependence on an unreliable electricity grid for cold chain operations, combined with a non-functional solar backup, creates a targeted single-point failure risk that extreme heat intensification will increasingly exploit.

Secondary care: system-level exposure through referral network dependencies. Illela General Hospital presents a fundamentally different risk profile: internal capacity is adequate, but the facility functions as the referral anchor for a wide primary care network whose own climate vulnerability is high — including cross-border communities from Niger Republic. The road network analysis projects travel time ratios reaching up to 13.5 times baseline for its feeder pathways under SSP5 2080, meaning that flood-induced primary care degradation will generate surge pressure at Illela General Hospital even when the hospital itself is physically operational. A single-source solar power dependency — without grid or generator backup — represents an addressable but unresolved infrastructure vulnerability at a facility that cannot afford power failures during referral surges.

Tertiary care: irreplaceability as the primary risk driver. The Federal Neuro-Psychiatric Hospital in Kware carries the strongest capacity profile of the four assessed facilities, yet also the most consequential disruption risk in systemic terms. Its psychiatric patient population cannot defer care, its medication supply chain is temperature-sensitive in ways that have direct clinical consequences, and it serves as the only regional specialist facility for psychiatric care for Sokoto, Kebbi, and Zamfara States. Flood-induced travel time increases of up to 8.9 times baseline along referral pathways from surrounding secondary hospitals further constrain the access of an already geographically dispersed patient population. At this facility, resilience investment is justified not by internal fragility but by the irreversible consequences of any disruption to care continuity.

Socio-economic vulnerability and compound exposure. Across the 17 multi-hazard hotspot wards, the socio-economic vulnerability analysis identifies Gandi 1 (Rabah) and Makuwana (Sabon Birni) as the highest-priority locations from a population impact perspective. Both wards are combining large concentrations of infants, young children, women of reproductive age, and older adults with structurally fragile access conditions and, in Makuwana, elevated comorbidity burden. A second-tier of wards, namely Dukamaje, Kaura, and Darna Sabon Gari, carries substantial dependent populations whose scale alone implies severe societal impact from any service disruption. These findings directly inform where facility-level investments and system strengthening measures will have the greatest community benefit.

5.3. Cross-cutting priorities for adaptation

Taken together, the analyses converge on a set of cross-cutting priorities that should inform the selection, sequencing, and design of adaptation options across the system.

Energy reliability and cold chain protection emerge as the single most consistent system-wide vulnerability. Across all four assessed facilities, the cold chain (and the broader set of operations that depend on stable power supply) represents a critical point of exposure to heat-related disruption. At Illah Health Clinic, there is no power and no cold chain whatsoever. At Tudun Faila, the cold chain depends on a single unreliable grid source. At Illela General Hospital, operations depend on solar power with no backup. Even at FNPH, where infrastructure is robust, psychiatric medication storage adds a layer of heat sensitivity that demands sustained vigilance. Adaptation measures that improve energy reliability, introduce backup redundancy, and strengthen thermal protection for pharmaceutical storage are therefore relevant across all facility tiers and represent the broadest systemic return on investment.

Referral system resilience is the second major cross-cutting priority. The road network analysis makes clear that flood-induced travel time degradation along key referral pathways is not a marginal disruption. Rather, it represents a systemic failure risk for the linear referral architecture on which Sokoto's health system depends. Adaptation responses in this domain will need to combine engineering measures (road and drainage improvements on critical feeder routes), contingency planning (flood-safe routing protocols, pre-positioned transport options), and facility-level interventions that reduce the time-sensitivity of care transfers (enhanced stabilization capacity at primary level). For border wards and cross-border referral pathways, coordination mechanisms with Niger Republic, Kebbi, and Zamfara State are an additional requirement that adaptation planning should explicitly address.

Primary care infrastructure uplift is a precondition for system-wide resilience. The disruption analysis consistently finds that structural vulnerabilities at the primary care level, including insufficient staffing, absent utilities, no cold chain, no emergency preparedness, are the weakest links in the system under climate stress. These are not climate-specific problems; they pre-date climate change. But they represent the points at which climate hazards most efficiently convert into service failures, especially for the maternal and child populations that depend most heavily on continuous primary care access. Adaptation at higher system levels cannot substitute for baseline functionality at the primary tier.

Security and cross-border dynamics as compound risk multipliers. The analyses consistently identify heightened insecurity in Sabon Birni, Rabah, and Goronyo LGAs, and cross-border population movements across six hotspot wards, as factors that amplify climate-related disruption risks in ways the health system is not formally equipped to absorb. These dynamics do not fall within the technical remit of health infrastructure adaptation alone, but they are integral to realistic disruption scenarios. Adaptation planning should explicitly account for compound risk configurations (climate disruption combined with insecurity or displacement), particularly in the design of contingency protocols and in inter-sectoral coordination arrangements.

5.4. Data gaps and directions for future work

The analyses in this report were conducted against a backdrop of significant data constraints, several of which limited the depth and precision of specific findings. Identifying these gaps is important both for interpreting the current results and for prioritizing future data collection and analytical work.

The socio-economic vulnerability assessment was originally designed to span a broader range of dimensions, including income, livelihood, poverty, and health status, that would allow a more complete characterization of the indirect societal impacts of health system disruption. The absence of spatially differentiated ward-level data on these dimensions ultimately constrained the analysis to healthcare-relevant population groups and structural access indicators. Future work that integrates ward-level poverty and livelihood data, spatial nutrition and baseline health status information, and empirical referral flow and facility utilization data would substantially deepen the vulnerability analysis and improve the precision of priority setting.

The road network disruption analysis was conducted for pluvial flooding only, as insufficient data on bridge locations and river-crossing infrastructure precluded a reliable assessment of fluvial impacts on road connectivity. Given that fluvial flooding along the Sokoto–Rima river system is a historically documented and operationally significant hazard for transport links in the state, closing this data gap would meaningfully improve the comprehensiveness of the accessibility analysis. Similarly, the pharmaceutical supply chain assessment was constrained by the absence of facility-level data on distribution routes, storage capacities, and resupply schedules; a structured supply chain mapping exercise would allow disruption risks to be traced more precisely from production and storage through to last-mile delivery.

Beyond data collection, future analytical work would benefit from the incorporation of an explicit compound risk assessment, one that systematically models how combinations of climate hazards, insecurity, and cross-border population dynamics interact to shape disruption risk in the border ward cluster. The current analysis addresses these factors qualitatively, but quantitative integration would strengthen the basis for contingency planning and inter-sectoral coordination. Finally, as the adaptation options in the companion document move toward prioritisation and implementation, monitoring and evaluation frameworks will be needed to track the effectiveness of resilience investments over time, particularly as climate conditions evolve.

ANNEX

All annexes can be found in a separate document.

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