Field Guide to Assessing Critical Infrastructure and Public Health in Post-Conflict Recovery

TARGETING FECAL-ORAL DISEASE RISK IN WATER AND SANITATION

JAYDEN KUDZAK, ALEXANDER HAY, DAVID MEYER, BRYAN KARNEY

Southern Harbour
FUTURE READY

Civil & Mineral Engineering
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UTP

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FOREWORD

For the past 22 years, while I was working for the International Committee of the Red Cross (ICRC) as a public health engineer, I've been confronted with the ravaging effects of protracted conflicts and crises on the systems providing essential services to the population. These systems are complex and, following the cessation of hostilities – or rather reduction considering that today's conflicts tend to have no end – require rapid action to ensure that the people have access to a minimum level of services for prolonged periods of time, as unfortunately structural interventions rarely follow rapidly or at the desired scale. Most of the humanitarian workers, as I used to be, are not equipped to understand how these systems function and consequently what is the best course of action to take. Even after years of working in such situations, I've often felt ill-prepared even if, at the ICRC, we had the chance to work with the service providers, who often had a great knowledge of their infrastructure and organization, which helped us to provide some useful responses.

We tried many different methods, including almost 10 years ago with Alec Hay when he came with his team in support of our operations in Gaza. We learned a lot by trying to model these complex and deteriorated systems, but it still took a lot of time to be able to define tools that could be of help to more junior humanitarian practitioners, who never faced such conditions beforehand. I'm confident that this *Field Guide to Assessing Critical Infrastructure and Public Health in Post-Conflict Recovery* is a great step in this direction. When Alec shared it with me, I thought that this was indeed far too simple, but I realized that what they are proposing here is indeed what I was applying intuitively in my practice … except that it took me more than 20 years to reach this level. Consequently, if this framework can help young engineers to find solutions to safeguard public health in conflict settings, then it will definitely allow the humanitarian community to be stronger and make sure the right choices are made when prioritizing the infrastructure works that can be done with the largely insufficient resources – considering the extent of needs in the conflict settings of today – that are allocated to humanitarian organizations. And this will hopefully help victims of armed conflict to regain a bit of dignity and hope to go back to a normal life.

Guillaume Pierrehumbert

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PREFACE

The breakdown of essential services in conflict-affected communities often leads to additional public health crises, such as the spread of waterborne diseases, which remains a leading cause of indirect civilian harm (Marou et al., 2024; Talhami & Zeitoun, 2020). In April 2024, the civilian population of Gaza was projected to suffer more than 85,000 "excess deaths" if epidemic-prone diseases like cholera were introduced, due to the widespread damage of water and wastewater infrastructure (Geneva Water Hub, 2024). Mitigating these potential secondary crises in the post-conflict phase requires an accurate and timely understanding of current infrastructure carrying capacity and local demand, particularly in water and sanitation infrastructure.

This white paper provides a step-by-step procedural framework to assess and interpret critical infrastructure carrying capacity to deliver essential services (e.g., water, sanitation, energy), in situations where preferred data sources – namely very high-resolution satellite imagery and local infrastructure experts – are unavailable. It is written for humanitarian and development actors engaged in providing stabilization and rehabilitation solutions for conflict-affected communities during the transition phase of a crisis. Beyond alleviating the suffering of those affected by armed conflict, a major objective of this framework is to align emergency response and development planning operations by taking advantage of humanitarian field workers' opportunities to observe and collect the community-level infrastructure data needed to design and deliver rehabilitation solutions that are appropriate to the local needs. With little technological resources, assessors can generate actionable insights to address critical essential service needs, reduce duplication of data collection efforts, and enhance cross-sector coordination.

The framework relates essential service delivery to the context-specific public health outcomes, allowing assessors to identify and prioritize areas for interventions that stabilize community health while simultaneously establishing a broader situational understanding needed to guide long-term infrastructure planning. It describes a first-principles approach that is applicable to many public health risks associated with essential service delivery. In this document, the approach is illustrated using fecal-oral disease (FOD) – a relevant risk in many crises around the world. Consequently, it provides an immediately practicable solution to assessing infrastructure in contexts where FOD is the public health risk of greatest concern. In crisis situations where other risks predominate, the field guide guides the production of a comparable assessment by drawing on professional and academic experts in public health and civil engineering.

REMARKS

Throughout my career, I have participated in one role or another in many post-conflict/post-disaster reconstruction and development projects. Often, the project was successful, but the outcome was less so. The stated beneficiary, the local population, didn't seem to benefit quite as intended. As I investigated what might have led to these observations, I concluded two potential causes: an overly rigid approach and a chronic lack of situational awareness. When we deconstruct our (international community) approach to regions emerging from conflict and natural catastrophe, it is clear that there is no consistent regional need and that the rehabilitation paradigm of aid, reconstruction, and development is concurrent, not consecutive.

I had the privilege of investigating this at the University of Toronto with advice and guidance from Professors Bryan Karney, Janice Stein, Brenda McCabe, and Adonis Yatchew, and from Michael Talhami and Doctor Federico Sittaro from the Water and Habitat division of the International Committee of the Red Cross (ICRC). This work concluded with an improved understanding of the new needs across the region and how to deliver them without compromising subsequent sustainable development. However, the tools that enhance the situational awareness of infrastructure are generally adaptations of earth observation. Earth observation requires ground truthing to calibrate interpretation. It is also often denied by one side or another in the conflict, so its value is limited to historical data. We concluded that there remains a pressing need to enhance our situational awareness of infrastructure and essential services, typically through observations by non-engineers.

Southern Harbour decided to sponsor further research into this issue at the University of Toronto. With a matching grant by Mitacs, Jayden Kuzdak investigated possible approaches to deliver a workable solution, albeit with particular applications and conditions. Professor David Meyer supervised the research, and Professor Bryan Karney and I provided advice. Many others supported us, and it was most heartening to receive enthusiastic yet critical advice and commentary from experienced field delegates from the ICRC and Médecins sans frontières (MSF). This field guide is the result. It is not a universal model and does challenge some of the received wisdom of the humanitarian community. However, it works when applied correctly and represents a small step towards a more efficient and sustainable response to post-conflict rehabilitation. My sincerest thanks to all who have helped on this journey.

A.H. Hay
Principal, Southern Harbour Ltd

EXECUTIVE SUMMARY

This field guide describes a versatile approach to understanding the ability of critical infrastructure[1] to satisfy community health needs during the transition phase of an armed conflict, where preferrable technologies and methods (e.g., satellite imagery, spatial data analysis) are not available. After providing a background on infrastructure rehabilitation and the context of armed conflict, an assessment approach is presented in nine detailed steps that are demonstrated for a hypothetical conflict in which fecal-oral disease (FOD) is the greatest public health concern.[2]

Steps 1–6 guide *humanitarian field actors* through identifying priority community health risks,[3] defining geographic units of analysis that correspond to existing public health systems, modeling relationships between priority health risks and essential services, and assessing the performance of essential services against international standards. These steps leverage humanitarian actors' ability to conduct field surveys in unstable environments and rapidly collect information at a community level.

Steps 7–9 translate field observations into essential service risk profiles by public health unit and infrastructure dependency maps that can be used to analyze infrastructure capacity and service-based risks across the entire area of operations. This guidance is intended for *development actors* engaged at the transition from post-crisis to recovery phase of conflict who are equipped to generate such evidence-based insights to drive funding/investment in projects, shape recovery timelines, and align reconstruction activities with the most urgent and enduring community needs. This includes urban planners, infrastructure engineers, development banks, and environmental scientists.

Ultimately, the approach presented in this field guide provides *humanitarian field actors* with an immediately practicable solution for rapidly assessing the capacity of critical infrastructure systems to mitigate FOD risk. The knowledge gained from rapid assessment can be used by *humanitarian agencies* to prioritize emergency response efforts and by *development actors* to inform sustainable strategies for infrastructure rehabilitation.

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[1] *Critical infrastructure:* Systems like water, electricity, and health services that communities rely on to survive.

[2] Illness spread through water or food contaminated by human feces (Bartram & Hunter, 2015).

[3] *Health risk:* A hazard with potential to cause harm to a population's physical health (e.g., contaminated drinking water).

INTRODUCTION

Essential Services during Armed Conflict

Critical infrastructure (CI) is the collective system of components that function to deliver essential services and support the continued health, safety, and well-being of communities. When infrastructure systems are damaged, essential services may perform inadequately, making it difficult for communities to satisfy basic survival needs. Keeping these essential services functional requires infrastructure that can adapt to rapid changes.

Physical components (i.e., equipment, buildings, materials) are just one aspect of CI that make essential services function. CI also comprises natural, virtual, and human aspects that together determine the unique structure and behavior of infrastructure in each community. Figure 1 reflects this concept, providing a model of infrastructure consisting of components from four fundamental categories that interact to produce a desired outcome (e.g., water to users).[4] These fundamental categories are not independent, nor are the components within them. In fact, CI systems are highly *interdependent* – they depend on each other to function effectively. When change occurs in one component

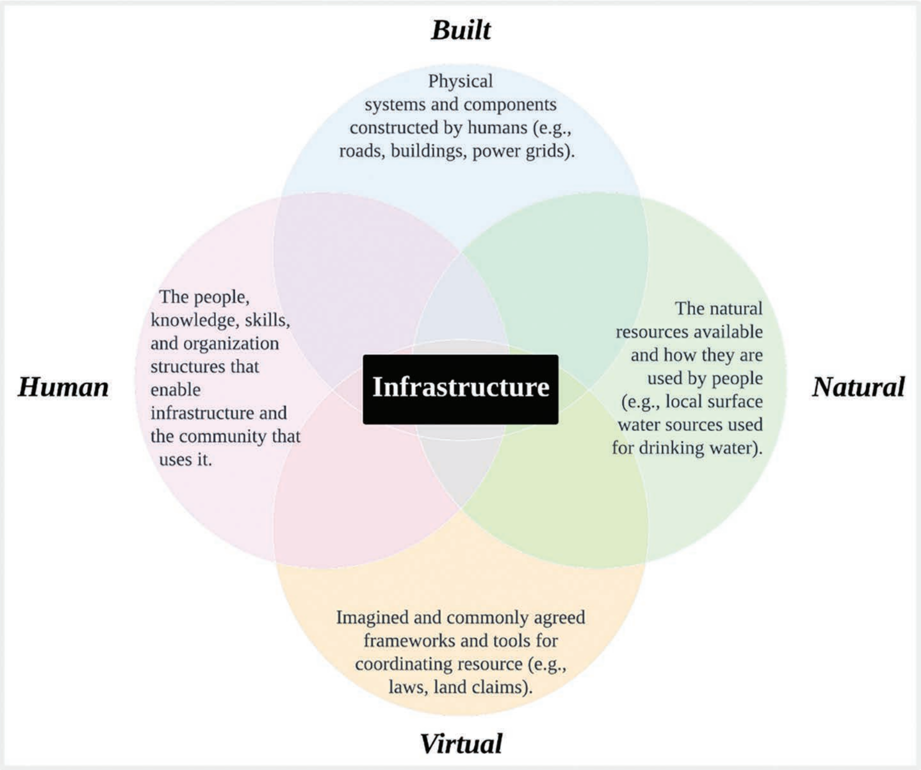

Figure 1. Infrastructure domains, as described by Hay et al. (2019). The domains, which together support the functioning of infrastructure systems, are dynamic and may be fundamentally changed during and after armed conflict.

[4] The natural domain is what exists naturally but is utilized by society. The built domain is everything that has been constructed by humans. The human domain is how people live in and use the world around them. The virtual domain is the shared set of imagined rules, frameworks, and currency used to operate society (Hay et al., 2019).

or system of components (e.g., oil embargo), it can directly affect the performance of other systems (e.g., cold storage for food). As CI systems scale and become more interconnected, these cascading consequences from one subsystem to another become more likely amidst the impacts of armed conflict.

Armed conflicts stress CI systems in countless ways. Bridges and generating stations are destroyed by explosive weapons, skilled workers permanently flee their homeland, and international blockades disrupt critical supply chains. As war progresses and such war-time stressors reduce infrastructure *carrying capacity*,[5] community well-being suffers – most commonly in the form of preventable communicable disease (Hay et al., 2019). **Figure 2** illustrates the causal pathway from war-time impacts (i.e., explosive attack) to public health deterioration.

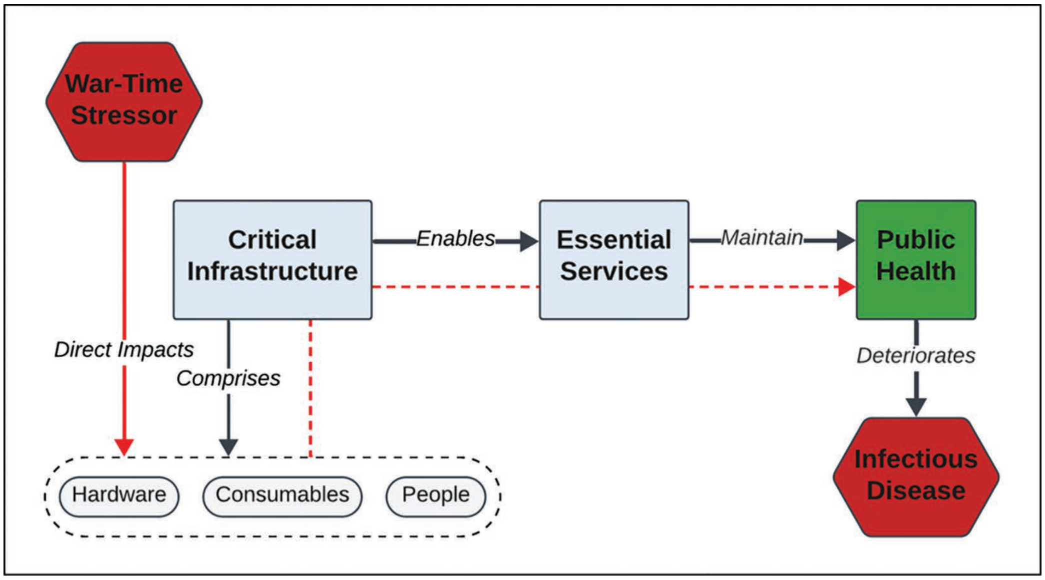

Figure 2. Depicts a version of the consequential chain model as described by Talhami and Zeitoun (2020). Effects of explosive weapon attacks reverberate along the consequential chain, degrading essential services and increasing public health risks.

The Role of Humanitarian and Development Actors in Crisis Situations

Crisis situations – such as natural disasters, armed conflicts, and industrial accidents – vary considerably in their impact, community responses, and humanitarian involvement. These crises typically evolve through four distinct phases – acute, chronic, transition, and recovery – characterized by the level of disruption to socioeconomic activities, the persistence of violence, and the local governance structure and functionality (UNFPA, 2010). **Figure 3** illustrates the timeline of these crisis phases, highlighting key transitions. As the crisis evolves

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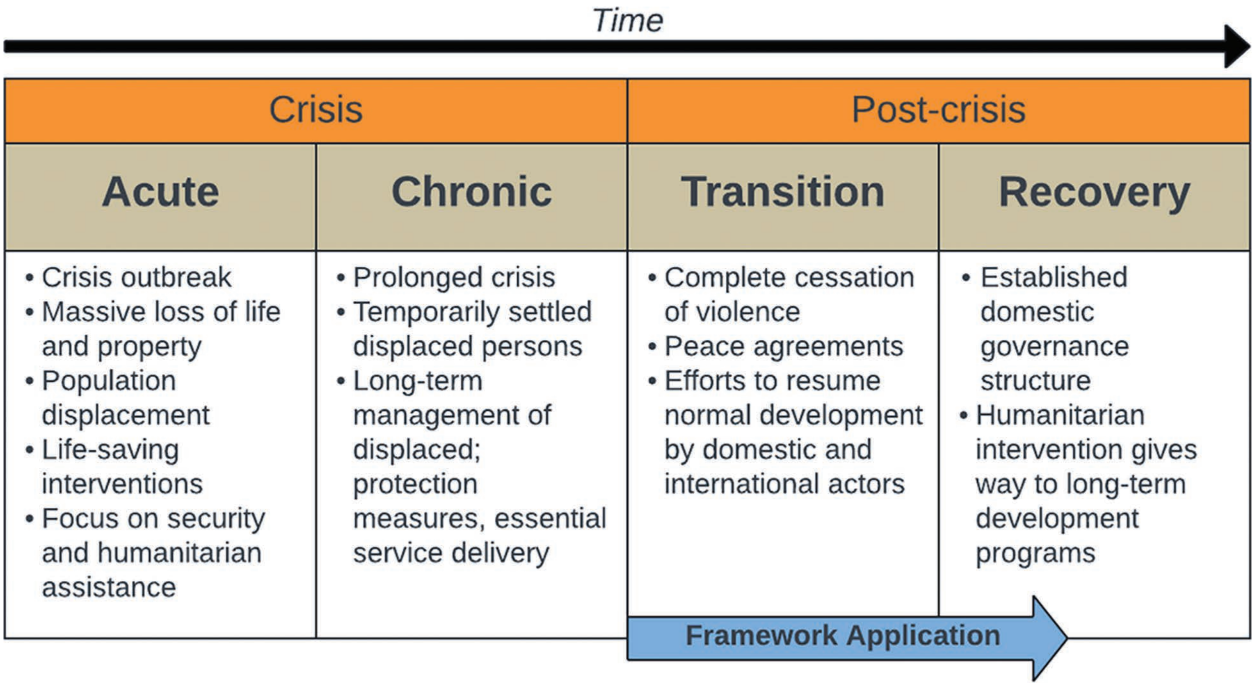
[5] *Carrying capacity:* The maximum amount of people or usage a service (e.g., water, electricity) can support under the current operating conditions.



Crisis		Post-crisis	
Acute	**Chronic**	**Transition**	**Recovery**
• Crisis outbreak • Massive loss of life and property • Population displacement • Life-saving interventions • Focus on security and humanitarian assistance	• Prolonged crisis • Temporarily settled displaced persons • Long-term management of displaced; protection measures, essential service delivery	• Complete cessation of violence • Peace agreements • Efforts to resume normal development by domestic and international actors	• Established domestic governance structure • Humanitarian intervention gives way to long-term development programs

Figure 3. Phases of a crisis situation, including characteristics and strategic considerations (UNFPA, 2010). This field guide is designed for implementation during the transition phase and supplementary use during recovery phase in a post-conflict situation.

through phases, it changes strategic planning requirements, the actors involved, and the types of data needed for response efforts. In particular, the post-crisis phase marks a crucial transition, where violence subsides and *humanitarian* efforts shift from emergency response to long-term recovery led by *development actors* (UNFPA, 2010).

Historically, rehabilitation of conflict-affected areas has focused on rebuilding infrastructure to its pre-crisis state (Hay et al., 2019). However, this approach overlooks the fundamental and lasting changes to the local socioeconomic conditions caused by conflict. During both the acute and chronic phases, population displacement, supply chain disruption, and asset destruction reshapes the affected area. Out of necessity, communities and CI systems develop interim solutions and alternative service modes to cope with these shocks and stresses (Abi Ghanem, 2018; Al-Saidi et al., 2020; Hay et al., 2019). Because of these changes, pre-crisis data on population and infrastructure no longer reflects current conditions, including population dynamics and new essential service solutions. **If rehabilitation efforts rely on unreliable pre-crisis data, they risk providing solutions that do not align with communities' actual needs or their ability to sustain services over the long term**.

Consequently, a major challenge during the transition phase of crisis response is the lack of reliable data. Without accurate, up-to-date information, *humanitarian* and *development* actors struggle to assess priorities, leading to inefficient resource allocation and ineffective recovery efforts. To address this, post-conflict rehabilitation actors require a real-time understanding of the local infrastructure carrying capacity and locally available resources (e.g., social capital, materials) to support service delivery (Hay et al., 2019; ICRC, 2022). This ensures that rehabilitation strategies align with current needs rather than restoring infrastructure to pre-conflict conditions, which may no longer be suitable.

Humanitarian and *development* actors play complementary but distinct roles in crisis recovery, each aligning their approach with different phases of the crisis timeline. *Humanitarian* organizations focus on immediate relief, addressing urgent needs such as food, shelter, and medical care, while *development* actors work towards long-term stability by rebuilding governance and infrastructure (Mason et al., 2017). Although both aim to improve the well-being of the affected population, their operational differences can lead to disjointed recovery efforts where *humanitarian* actions might not align with systematic *development* plans, and vice versa (Mason et al., 2017). Additionally, when these actors collect data separately, it can result in redundant efforts and inefficient resource use, as they often require similar information (UNFPA, 2010). Overcoming these challenges requires a coordinated approach to data collection and sharing, ensuring recovery efforts are informed by real-time, reliable information and are responsive to the evolving needs of affected communities.

Assessing Critical Infrastructure in Crisis Transition

Organizations working to stabilize and rehabilitate conflict-affected communities have developed and practiced effective methods for assessing post-crisis CI conditions and the immediate needs of vulnerable populations (ICRC, 2015, 2022). Existing approaches typically rely on two key data sources: *local infrastructure experts*, who provide insights into infrastructure behavior and interdependencies[6]; and *remote sensing technologies* (e.g., satellite imagery, aerial photography), which help to identify infrastructure presence, function, and operating context (Hay et al., 2019). Remote sensing is particularly valuable to *humanitarian actors* during active conflict when on-the-ground assessments are prohibited or unsafe.

However, these preferrable data sources are not always available. Advanced remote sensing may be restricted due to combatants' concern over foreign intervention (e.g., government space agencies) or the *humanitarian* imperative to maintain neutrality (Mason et al., 2017; UNFPA, 2010). Additionally, armed conflicts often lead to the displacement or loss of skilled personnel, reducing access to expert insights crucial for reconstruction planning (UNFPA, 2010). These challenges expose a critical gap in existing assessment approaches that rely on local experts and remote sensing. **When such data is unavailable, crisis response and recovery efforts require another way to rapidly produce a systems understanding of CI in real time that aligns with the needs of humanitarian and development actors.**

Objective

The objective of this framework is to equip humanitarian and development actors in the *post-crisis transition phase* with practical methods to assess the capacity of critical infrastructure to support public health needs, in situations where preferred data sources

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[6] *Interdependencies:* Instances where two or more individuals, systems, organizations, or processes rely on one another for support, resources, or functionality (e.g., electricity powering water pumps).

and local expertise are unavailable. It aims to generate accurate, relevant, and timely infrastructure data that informs immediate relief and longer-term rehabilitation planning. This is achieved through two integrated approaches:

1. **Catchment-based public health risk mapping**. Linking observed patterns of disease burden to essential service performance within the areas served by local health clinics (catchments).
2. **Dependency mapping of essential services**. Documenting how infrastructure components rely on one another.

The utility of this guidebook is the integration of catchment-based public health risk mapping and essential service dependency mapping. By evaluating public health risk levels by area (e.g., neighborhoods, communities), this approach enables humanitarian organizations to prioritize urgent risks and focus interventions where they will most effectively reduce public health risks. Moreover, dependency mapping provides *development actors* with an integrated view of CI systems that supports intelligent rehabilitation planning. The result is a single assessment that uncovers the essential service pathways for public health risks and describes the dependency relationships that reveal the root causes of service deficiencies.

To illustrate the framework application in context, this paper focuses on fecal-oral disease (FOD) as a priority hazard requiring mitigation (Geneva Water Hub, 2024; Levy & Sidel, 2007; Marou et al., 2024; Talhami & Zeitoun, 2020). The proposed methodology is designed to be adaptable to diverse post-conflict contexts while also offering an immediately applicable CI assessment tool for crises where FOD represents the greatest threat to public health.

Constraints

To maintain relevance across diverse conflict-affected contexts, the framework was developed within the following design constraints and boundary conditions[7]:

1. **Minimal technology requirements:** *Humanitarian field actors* only need a cell phone and a GPS-enabled device. They do not require advanced tools like ground-penetrating radar or water quality testing kits.
2. **No infrastructure expert consultations:** The framework can be implemented independently, even without access to infrastructure specialists.
3. **On-foot mobility:** *Humanitarian field actors* conduct assessments by foot, making the framework suitable for areas with restricted transportation accessibility.
4. **No advanced spatial analytics:** The framework does not rely on sophisticated remote sensing datasets (e.g., very high-resolution satellite imagery, hyperspectral imagery) or advanced spatial data processing. Instead, it uses only basic mapping techniques which can be managed with basic analog or digital tools.

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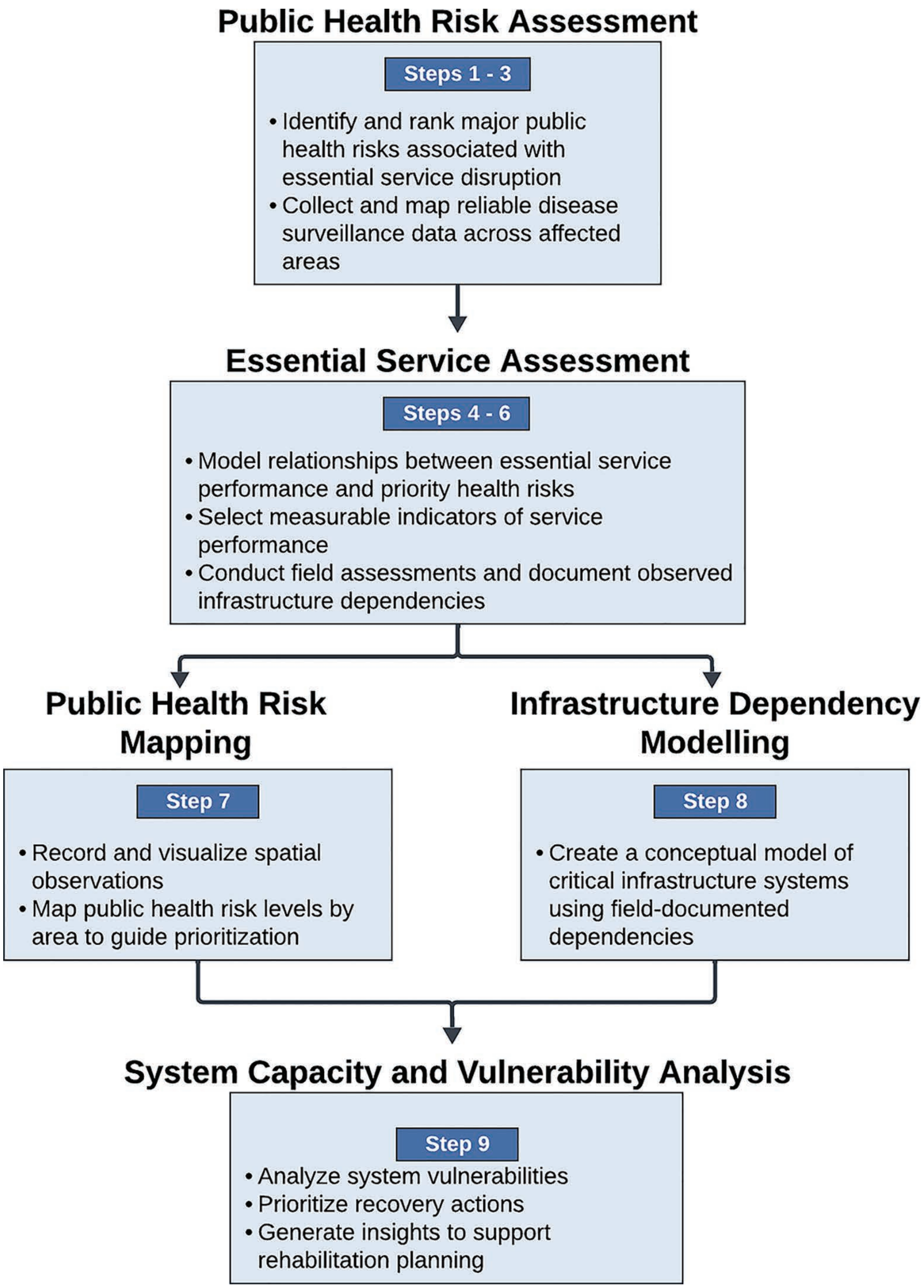
[7] All remaining assumptions and limitations of the framework are explicitly described where appropriate.

ASSESSMENT METHODS

This field guide presents a structured approach to assessing CI functionality and essential service needs in conflict-affected urban areas. Figure 4 outlines the assessment steps, which emphasize the interdependence of infrastructure systems – encouraging assessors to observe and document connections between water, sanitation, energy, and other



Public Health Risk Assessment

Steps 1 - 3

- Identify and rank major public health risks associated with essential service disruption
- Collect and map reliable disease surveillance data across affected areas

Essential Service Assessment

Steps 4 - 6

- Model relationships between essential service performance and priority health risks
- Select measurable indicators of service performance
- Conduct field assessments and document observed infrastructure dependencies

Public Health Risk Mapping

Step 7

- Record and visualize spatial observations
- Map public health risk levels by area to guide prioritization

Infrastructure Dependency Modelling

Step 8

- Create a conceptual model of critical infrastructure systems using field-documented dependencies

System Capacity and Vulnerability Analysis

Step 9

- Analyze system vulnerabilities
- Prioritize recovery actions
- Generate insights to support rehabilitation planning

Figure 4. A summary of assessment steps. The logic of the framework reflects the "consequential chain" model in reverse, which relates public health risks to essential service performance and infrastructure functionality by building a georeferenced chain.

essential services. The methodology provides *humanitarian actors* with a systematic way to assess real-time infrastructure conditions and guides *development actors* through analyzing collected data to prioritize reconstruction and inform resilient infrastructure development.

To demonstrate the adaptability of this approach, this section includes *applied scenario boxes* that illustrate key assessment steps across different post-conflict contexts. These examples show how the framework can be tailored to diverse field conditions and provide practical guidance for *humanitarian* and *development actors* conducting real-world assessments. While not exhaustive, the scenarios offer practical guidance to *humanitarian* and *development* actors navigating real-world assessments.

Step 1: Identify the greatest public health risks associated with essential service delivery

Focused User: Humanitarian Field Actors

Humanitarian field actors operating in conflict-affected areas during the crisis transition phase are well-positioned to conduct rapid assessments of evolving public health risks. In this step, field actors identify the most pressing threats to public health affected by essential service provision, such as water, sanitation, and energy. These risks often include waterborne diseases from inadequate waste management and electricity disruptions that compromise health care facilities and routine domestic activities. Ask: What foreseeable public health consequences are most important to mitigate in this crisis?

Each conflict-affected area will experience different public health risks, determined by the unique impacts on essential services and the underlying CI systems. To determine which risks are most important to mitigate, establish a basic understanding of local infrastructure conditions and hazards. Utilize news coverage, humanitarian journalism, conversations with affected civilians, government reports, and first-hand observations during transit (air and terrestrial) to develop a broad awareness of the situation including existing public health challenges and the status of essential services.[8] Use this process to build a broad understanding of local hazard dynamics and their relationship to essential service performance.

This field guide illustrates the approach using a hazard that is often of immediate concern to public health in crisis situations – waterborne disease. Humanitarian and academic literature indicate that waterborne disease, specifically FOD, is a significant public health risk in conflict situations when essential services are disrupted (Geneva Water Hub, 2024; Levy & Sidel, 2007; Marou et al., 2024; Talhami & Zeitoun, 2020).

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[8] It is assumed that a high-level understanding of the situation is available to field workers at deployment or can be rapidly achieved once on location.

Scenario 1

Prioritizing Health Risks

Scenario: Spring Thaw in an Eastern European Conflict Zone

In a conflict-affected Eastern European city, repeated disruptions to the natural gas supply have left urban households without reliable heating. During winter, the lack of indoor warmth increases the risk of hypothermia and cold-related illness, especially among vulnerable groups. At the same time, sewerage systems – damaged by shelling – remain out of service. Many households have resorted to storing excreta in shallow outdoor pits where it freezes through the winter.

As spring approaches and temperatures begin to rise, the thaw will mobilize this waste, increasing the risk of fecal contamination in open water sources. However, that risk is still weeks – perhaps months – away. The more immediate concern is cold exposure and respiratory illness due to prolonged heating outages.

Procedure: Applying Step 1, the assessment team begins by identifying and ranking the greatest public health risks associated with current infrastructure failures. Visual observations and conversations with local health staff indicate a clear, present threat: insufficient heating during cold temperatures is causing increased respiratory illness and cold-related admissions. This is prioritized as the most urgent health risk.

Meanwhile, the team also identifies a delayed but significant hazard. They document the locations of frozen sanitation pits using GPS and note their proximity to homes and known water sources. While the threat of fecal-oral disease is not yet active, it is foreseeable and potentially severe once the thaw accelerates.

Step 2: Collect authoritative public health data and map disease burden across the affected area

Focused User: Humanitarian Field Actors

Collect the best-available public health data from health clinics, delineate the area of access for each reporting health clinic, and visualize the distribution of disease burden across the area. Prioritize areas with the greatest disease burden for rapid assessment.

Although armed conflict may disrupt routine disease monitoring, organizations like Médecins Sans Frontières (MSF) and the World Health Organization (WHO) have developed Early Warning, Alert, and Response Systems (EWARS) to detect and respond to infectious disease outbreaks at community, regional, and national levels during the acute phase of crises (Cordes et al., 2017; Karo et al., 2018; World Health Organization, 2022). These monitoring systems gather real-time data on syndromes, confirmed disease cases, incidence rates, demographics, mortality, and vaccination coverage from participating clinics – such as hospitals and urgent care facilities (World Health Organization, 2022). EWARS have been implemented effectively in crisis-affected regions, representing an important data source for humanitarian and development actors (Karo et al., 2018). Accessing EWARS or comparable real-time public health data is the first step in understanding how disease is distributed across the conflict-affected population. If no public health surveillance system is available, the remaining assessment steps can be completed, but because assessors will lack awareness of disease patterns, they may be unable to effectively prioritize areas for intervention, and they will require a different geographic unit of analysis for the subsequent essential service assessment.

Operational guidance for EWARS published by the WHO requires participating clinics to define their unique clinic catchment area (CA), which represents the geographic area from which patients typically travel to access care (World Health Organization, 2022). CAs provide a practical way to spatially relate public health outcomes to essential service performance. When CI is damaged and essential services are disrupted, the exposure to public health hazards increases (e.g., cholera from contaminated water). Conversely, functional and adequate services reduce these risks (e.g., handwashing stations preventing disease transmission). In data- and resource-limited areas where rapid assessments are needed, the disease burden within a CA serves as a key indicator of infrastructure or service inadequacy (Freeman et al., 2017; Speich et al., 2016; Ziegelbauer et al., 2012).

Alongside weekly disease reporting, assessors should obtain the geographic boundaries of each reporting clinic's CA from EWARS or other public health monitoring systems in operation. Use these CAs as the primary geographic unit of analysis for the remainder of the essential service assessment. If CAs are not already defined, work with local health authorities (e.g., doctors, nurses, administrators) to delineate boundaries based on their understanding of patient access patterns. In stable environments, healthcare access is typically determined by travel distance – individuals use facilities nearest to their homes (McGrail, 2012). However, in conflict settings, healthcare access may be shaped by geography, cultural practices, and religious and political divides. To ensure accuracy, engage local authorities in their native language and confirm place names to avoid misinterpretation during data collection.

An example of how disease reporting data can be visualized spatially by clinic catchment areas is shown in Figure 5. To produce this map, clinic case counts are linked to their corresponding catchment boundaries in GIS software. Each catchment is then symbolized by disease incidence or case density, creating a choropleth map that highlights areas with the highest reported illness. Base maps can be derived from pre-conflict satellite imagery (e.g., Google Earth) or administrative files to ensure local landmarks and boundaries are clearly visible.

This spatial approach reflects a core principle of epidemiology: That geographic patterns in health outcomes can reveal underlying systemic infrastructure failures. A well-known example is John Snow's investigation of a cholera outbreak in 1850s London. With no laboratory testing, limited data, and only rudimentary mapping tools, Snow combined direct observation and interviews with a waterborne theory he had developed years earlier to argue that a public water pump on Broad Street was the likely source of infection. He later prepared a hand-drawn map that illustrated the clustering of cases near the pump (Tulchinsky, 2018). Although the map served more to communicate his findings than to generate the original insight, it demonstrates that even in conditions of limited information, disrupted systems, and constrained resources, well-applied spatial reasoning can reveal potential drivers of disease. In humanitarian crises, where high-tech tools and quality data are unavailable or fragmented, this kind of low-resource, field-driven analysis remains not just relevant but essential for protecting health and allocating resources wisely.

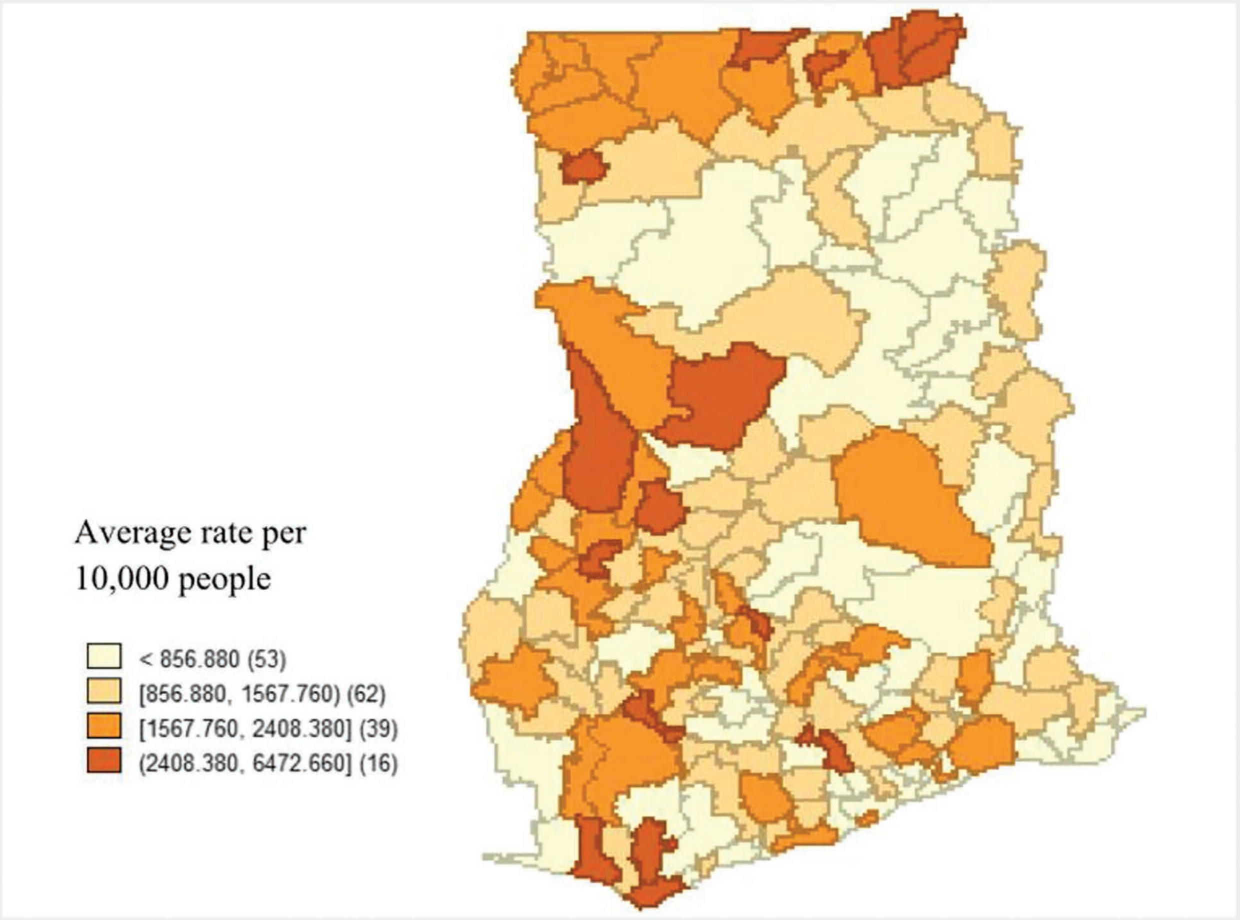

Figure 5. Example choropleth map of malaria incidence across districts in Ghana. Numbers in the brackets indicate the number of districts within that rate range (Nyadanu et al., 2019).

Scenario 2

Acquiring and Using Disease Surveillance Data

Scenario: Mapping Disease Burden in an Informal Settlement

In a dense, underserved settlement on the outskirts of a conflict-affected city, medical clinics are reporting a surge in respiratory infections and fever-related illnesses such as influenza and pneumonia. Winter temperatures are near freezing, yet households face long daily power outages and unreliable fuel supplies. Many families burn debris or use small stoves indoors for warmth, while others endure unheated shelters with broken windows and leaking roofs. Humanitarian actors want to determine how these energy and shelter failures are influencing the rise in illness – and where assistance should be prioritized.

Procedure: To apply **Step 2**, the team first compiles weekly case data from clinics operating in and around the settlement. Working directly with clinic staff, they outline each facility's *catchment area* on a printed or digital base map, identifying the clusters of homes and shelters from which patients typically arrive. Staff confirm neighborhood names, main access roads, and recognizable landmarks to ensure accuracy. The number of respiratory cases is visualized for each catchment, providing an initial visual pattern of disease burden.

Field teams then visit the mapped catchments to document exposure conditions: duration of power outages, availability and type of heating fuel, structural condition of shelters, and household crowding. Short interviews identify how families manage cold temperatures and whether they experience recurring smoke-related symptoms or fuel scarcity.

When mapped together, the data reveal that the highest illness rates occur in catchments where outages exceed eight hours per day, wood fuel is unavailable, and household crowding is common. By linking mapped health data with observed energy and housing conditions, responders are able to confidently pinpoint where essential-service breakdowns are directly driving community illness and prioritize recovery actions that most effectively reduce respiratory disease risk.

Step 3: Determine how the priority health risk(s) is related to essential services, model the relationships

Focused User: Humanitarian Field Actors

Draw on existing models of public health risks to determine possible root causes and visualize the cause-and-effect pathway with a conceptual model. For each pathway, identify how essential services affect the likelihood or consequences of the risk(s). Use the conceptual model to estimate essential service performance requirements to mitigate the risk.

The performance of essential services in emergency conditions must be assessed relative to their relationship with the public health risk of concern. This is not just a matter of identifying what is broken – it is the foundation for aligning short-term humanitarian response with long-term development planning. Humanitarians are trained to act quickly and practically to protect health and reduce suffering. Yet to scale these responses and ensure their relevance beyond the immediate crisis, they must also interpret public health needs in relation to the systems that are meant to prevent or mitigate them.

This requires a clearer understanding of the potential causes that could lead to a risk event. Each situation will be different, so ask: **What might cause the health risk of concern to occur?** Trace the relationships between hazard conditions, service breakdowns, and the health risk in question. Representing these cause-and-effect pathways – however simply – creates clarity. The models do not need to be technical or precise, but they do need to be accurate enough to highlight which services are failing, which components are most critical, and how failure contributes to human exposure.

When done well, this conceptual modeling provides a shared frame of reference. It establishes continuity between humanitarian field evidence and development-oriented planning. By mapping observed risks to the infrastructure systems responsible for managing them, it becomes possible to guide near-term mitigation while also shaping durable, locally grounded recovery strategies.

This field guide demonstrates the assessment procedures using fecal-oral disease (FOD) as the example priority health risk. FOD is particularly well suited for this purpose because it has a popular transmission model that clearly illustrates how essential service performance influences public health outcomes. Assessors may choose to apply this model directly in contexts where FOD is a priority concern, or they may adapt the same principles to construct a comparable model for another health risk.

FOD transmission occurs when individuals are exposed to water, food, or surfaces contaminated by fecal pathogens such as *Salmonella enterica* (typhoid), *Vibrio cholerae* (cholera), or Hepatitis A. Transmission can occur directly or indirectly through vectors like flies, fingers, and soil. The F-diagram – a simple but well-established tool in the water, sanitation, and hygiene (WASH) sector – visualizes these pathways and highlights how essential services act as barriers or enablers of transmission depending on their performance

(**Figure 6**) (WHO, 2018). Despite its simplicity, the F-diagram is an effective way to represent the relationship between infrastructure performance and disease exposure.

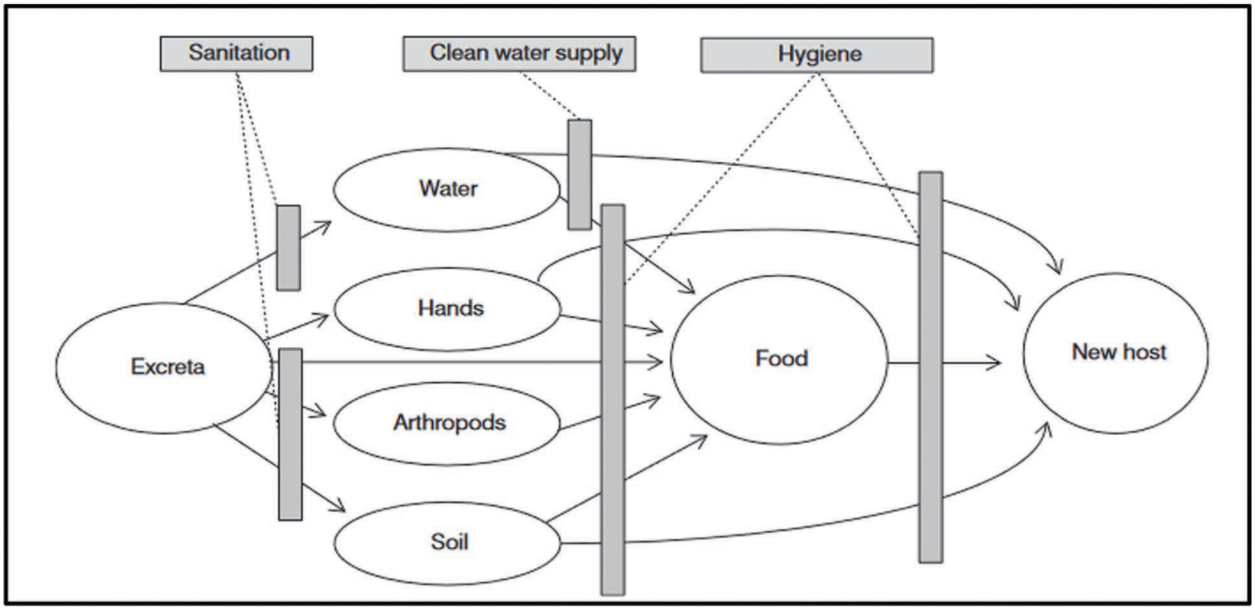

Figure 6. The F-diagram of fecal-oral disease transmission visualizes transmission pathways and highlights the role of essential services in preventing transmission (Bartram & Hunter, 2015).

However, the F-diagram – like many public health risk models – captures only first-order transmission pathways. It does not account for the interdependencies that underpin essential service delivery. For instance, a sanitation system may rely on continuous power supply to operate pumps and treatment facilities. The pumping and treatment processing *dependency* on the power source (electricity or fuel) is out-of-view to those who aren't directly involved in its management, but represents a point of vulnerability for sanitation services, where power is unreliable. A useful model of current infrastructure systems should go beyond assessing the primary health risk pathways (e.g., sanitation, hygiene, clean water supply) and also consider the resources that enable those essential services to function.

This field guide brings together catchment-based public health risk mapping and essential service dependency mapping in a single integrated framework. This integration begins in *Step 6*, which describes the dependency mapping method. To optimize the time and resources spent on *Steps 3-5*, assessors should be familiar with the dependency mapping process and therefore prime their contextual awareness to recognize and record dependencies throughout the entire process.

In summary, FOD offers a clear and familiar example for illustrating risk pathways in this guide. For other public health risks linked to essential service delivery, field actors should select or develop models that similarly make explicit the relationships between health outcomes, service performance, and system vulnerability. The usefulness of these models lies not in their technical complexity but in their ability to help assessors reason through cause and effect in ways that lead to more targeted, impactful decisions.

Scenario 3

Modelling Risk Pathways for Infrastructure-Linked Health Outcomes

Scenario: Modeling Exposure to Cold in a City Without Reliable Heating In a war-affected city facing its second winter since the collapse of public services, hospitals report a spike in respiratory illnesses and pneumonia, particularly among young children and the elderly. Although the health system is overwhelmed, it's clear that the rise in illness is not just medical – it's infrastructural. With the electricity grid and district heating systems only partially functional, many homes lack sufficient indoor warmth. Humanitarians need to determine how degraded energy and shelter systems are contributing to exposure, and where targeted support might reduce health risks.

Procedure: Applying Step 3, the assessment team builds a basic model to understand how infrastructure failure is driving cold exposure and related illness. Rather than looking at "heating" as a single system, they break it into critical subsystems: electricity supply, fuel distribution, building insulation, and indoor heating appliances. Each subsystem has specific requirements, such as fuel availability, functioning transformers, or intact window glazing.

Using available maps, engineering records, and field observations, the team traces how failures in these subsystems intersect. For instance, unrepaired transformer damage in one zone means no electricity; fuel shortages prevent alternative heating sources; and many homes have broken windows or thin roofs due to earlier shelling. The model links these failures to sustained indoor cold, weakened immune responses, and ultimately increased respiratory illness.

This conceptual diagram – based on a cause-effect chain similar to the F-diagram – provides a systems view of the problem. It shows not only which services are failing, but *how* those failures are converging to increase human vulnerability. The model guides later assessment efforts, helping the team target zones where multiple subsystems are non-functional and where interventions – like fuel drops, window repairs, or generator deployment – can quickly reduce health risk.

Step 4: Select measurable indicators of essential service performance and develop guidelines for field investigations

Focused User: Humanitarian Field Actors

Translate the relationships identified in the previous step into measurable indicators of essential service performance. Step 4 focuses on choosing indicators that can be observed or verified under field conditions and defining simple, reliable methods for data collection. These indicators provide a practical means to assess how essential services function in relation to public health risks and form the basis for consistent, comparable field investigations.

Although infrastructure failures that increase public health risks can occur at many points along an essential service chain,[9] not all of these points are accessible or measurable in the field. This step focuses on identifying which parts of each service chain can be directly observed and assessed under prevailing field conditions. For example, while a centralized water treatment plant's chlorination process may be critical for reducing waterborne disease risk, field assessors may not be able to verify treatment efficacy at the facility itself. However, they can test residual chlorine levels at household taps, observe water container conditions, or evaluate access to treated water at distribution points. These practical entry points allow assessors to diagnose service performance, even when upstream processes are uncertain or inaccessible.

The purpose of this step is to develop a clear, field-applicable set of indicators that describe how well essential services are performing in relation to the identified public health risk. Assessors can begin by reviewing each essential service chain and mapping how it currently operates under conflict conditions – from inputs and enabling resources (e.g., people, consumables, hardware) through to processes, outputs, and end use. For each step of the service chain, identify where breakdowns occur that would allow the public health risk to manifest. In this framework, these intersections between service function and health risk are called risk pathways. They represent points at which a disruption in service performance directly increases the likelihood of human exposure to the hazard.

Once these intersections are defined, assessors select measurable indicators that reveal whether a service is performing adequately or creating conditions that contribute to disease transmission. Indicators should be kept simple and field-relevant – qualitative or quantitative metrics that can be observed, estimated, or inferred using minimal resources. They function as diagnostic signals of whether essential services are safeguarding or exposing the population to harm.

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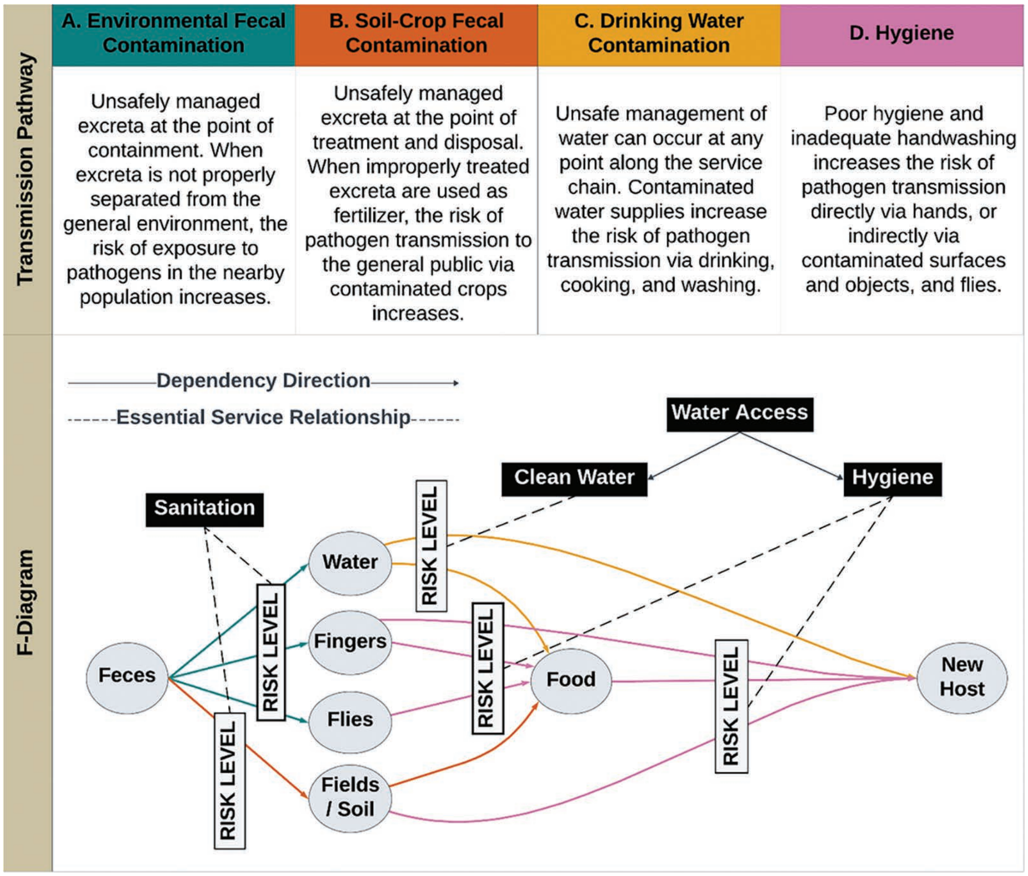
[9] ***Essential service chain:*** **The sequence of components and processes through which an essential service is delivered from source to end use. For example, the drinking water service chain includes source water, abstraction, treatment, transportation, distribution, and storage.**

When parts of a service chain are not observable, assessors should first prioritize those indicators that can be directly measured. Performance of unobservable segments may be inferred from evidence elsewhere in the chain – for instance, from downstream water quality or known material flows. If a critical process cannot be accessed, its importance should be noted and communicated to stakeholders who have access to broader or upstream system information.

The outcome of this step is a list of measurable indicators linked to specific points along each essential service chain, accompanied by a short description of what each indicator signifies about system performance. The modified F-diagram in **Figure 7** demonstrates a visual tool that supports this process by illustrating how essential services interact with the hazard and where indicators should be developed along the risk pathway.



	A. Environmental Fecal Contamination	B. Soil-Crop Fecal Contamination	C. Drinking Water Contamination	D. Hygiene
Transmission Pathway	Unsafely managed excreta at the point of containment. When excreta is not properly separated from the general environment, the risk of exposure to pathogens in the nearby population increases.	Unsafely managed excreta at the point of treatment and disposal. When improperly treated excreta are used as fertilizer, the risk of pathogen transmission to the general public via contaminated crops increases.	Unsafe management of water can occur at any point along the service chain. Contaminated water supplies increase the risk of pathogen transmission via drinking, cooking, and washing.	Poor hygiene and inadequate handwashing increases the risk of pathogen transmission directly via hands, or indirectly via contaminated surfaces and objects, and flies.

Figure 7. Adapted F-Diagram showing fecal–oral transmission pathways and associated service dependencies. Four primary pathways (A–D) illustrate how fecal contamination moves through environmental, soil-crop, drinking-water, and hygiene routes to reach a new host. Arrows depict dependency direction and essential-service relationships linking sanitation, water access, and hygiene. Risk levels are indicated along each pathway, emphasizing how service performance influences exposure potential

Transmission Pathway A: Environmental Fecal Contamination

This pathway assesses the performance of sanitation systems in containing and safely conveying excreta to treatment or disposal. Failures at this level result in direct exposure risks through contact with fecal matter, contamination of the environment, or mobilization of waste during rain/flood events. Indicators are selected to identify where containment and conveyance has failed and where excreta is entering the local environment:

1. Understand the proportion of sanitation facilities (toilets) that do not safely contain excreta.
2. Locate sanitary sewerage overflows.

A.1 Facilities Not Contained

This indicator measures the **proportion of sanitation facilities observed that do not safely contain excreta**. Excreta is considered "not contained" when it results in an elevated risk of fecal pathogen exposure in the nearby population (Peal et al., 2020). It reflects potential points where fecal matter can enter the environment through damaged, unlined, or overflowing containment systems, increasing the likelihood of human or environmental exposure. When these conditions are present, users may come in direct contact with excreta, flies may freely contact excreta and transport pathogens elsewhere, and groundwater may become contaminated, especially during rainfall events (Basheer & Elagib, 2024).

A.2 Average Users per Facility

This indicator describes the **average number of users per sanitation facility**. Facilities shared by many people can rapidly reach and exceed containment capacity if regular emptying services are inadequate. Therefore, this indicator reflects the pressure placed on available sanitation infrastructure and the likelihood of overuse, overflow, or maintenance failure that may compromise safe containment and therefore increase the risk of pathogen transmission.

A.3 Sanitation Hotspots; Visual and Olfactory Cues

This indicator **identifies locations where sanitation systems have failed on a large scale**, resulting in the accumulation or surface flow of untreated wastewater or excreta. It represents localized areas of environmental contamination and potential human exposure.

A.4 Surface Water Dumping

This indicator captures the **occurrence of untreated excreta or sewage discharged directly into surface water bodies** such as rivers, streams, or drainage channels. This type of practice may be employed where sanitation containment facilities are not adequately emptied into sewerage systems, or where centralized wastewater treatment is non-functional – forcing emptying service providers to find expedient alternatives. It indicates a potential exposure route, where contaminated water is used by people for domestic or recreational purpose.

TRANSMISSION PATHWAY B: SOIL-CROP FECAL CONTAMINATION

This pathway assesses the reuse of untreated excreta as crop fertilizer – either as a routine practice or an adaptive response to disrupted emptying and treatment services. It is most relevant in rural or peri-urban areas where households maintain small farms or garden plots on the property. When excreta is applied to soil without adequate treatment, fecal pathogens may contaminate crops and be ingested by consumers.

B.1 Facilities Fertilizing On-Site

In communities using on-site sanitation,[10] safe management depends on the regular emptying of containment systems and delivery to treatment. Where treatment operations are unavailable or nonfunctional, service providers may resort to alternatives – such as applying untreated excreta directly to fields. This indicator represents the **proportion of households or service providers applying untreated excreta to soil, either on-site or nearby, as fertilizer**. It reflects a direct exposure pathway linking human fecal waste to food crops and soil (Dureab et al., 2019; Katzenelson et al., 1976; Ziegelbauer et al., 2012). Washing produce can reduce risk but may be inconsistently practiced due to limited access to clean water.

Transmission Pathway C: Drinking Water Contamination

This pathway assesses the contamination of water sources used for drinking. Fecal pathogens may enter groundwater or surface water due to system failures such as uncontrolled dumping, leaching from unlined pits, or sewerage overflows. This risk increases when flooding or damaged containment infrastructure allows excreta to migrate into drinking water supplies. The indicators representing this pathway seek to evaluate the exposure of drinking water systems to priority contaminants (e.g., fecal pathogens, heavy metals, etc.) along the entire drinking water service chain and the risk of users consuming contaminated water. This pathway asserts that the risk of water contamination increases when:

1. Infrastructure has not been adequately designed and constructed to protect water sources.
2. Drinking water treatment processes are nonoperational or not appropriate for current source water qualities.
3. Transmission and/or distribution infrastructure (i.e., pipelines) is damaged or destroyed.

Water quality testing may be used to confirm contamination of drinking water sources, but it requires time, equipment, and technical capacity that may not be available in the immediate post-crisis setting. In these cases, a risk-based approach is applied to prioritize testing. Field teams assess the likelihood of contamination based on water type (e.g., surface water, groundwater, piped supply), source location, and proximity to known sanitation failures. This approach supports targeted testing in areas where the perceived risk to health is greatest.

C.1 Groundwater Pollution Risk Assessment (Microbiological)

This indicator estimates the **likelihood that contaminants from sanitation systems will reach groundwater** sources used for drinking or domestic purposes. In many crisis-affected areas, groundwater is a critical supply of water, yet it may be vulnerable

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[10] ***On-site sanitation:*** **Systems in which excreta (primarily fecal sludge) are collected and stored where they are generated (Peal et al., 2020)**

to contamination when co-located with dysfunctional or poorly constructed sanitation systems. This indicator draws on established, field-practiced guidance from the SFD Promotion Initiative and the British Geological Survey's Guidelines for Assessing the Risk to Groundwater from On-Site Sanitation (ARGOSS) to identify locations where sanitation and water supply systems interact unsafely, exposing groundwater sources to contamination and endangering public health (British Geological Survey, 2001; SFD-PI, 2025).

C.3 Unimproved Source

Unimproved drinking water sources by their nature are unable to ensure that the water collected is free from priority contaminants. This indicator measures the **proportion of households relying on unimproved water sources**, as defined by the Joint Monitoring Program (JMP). It reflects population dependence on sources that do not reliably protect water from contamination and therefore indicates a potential route of FOD transmission.

C.4 Point-of-Consumption Treatment

Point-of-consumption (POC) treatments refer to methods or technologies that render water safe for consumption by individual households or communities. Effective treatment ensures that water is made safe for human consumption, although it may also be used for other domestic purposes like washing, cooking, and bathing. Treatment options include chemical, physical, or biological processes including boiling, filtration, iodine tablets, and diluted bleach (Howard et al., 2020).

This indicator measures the **proportion of households or users applying effective POC water treatment** *and* whether water delivered/transported to households remains safe at the moment of consumption by identifying hygiene practices and household storage/container conditions that prevent contamination. It reflects the final barrier to protecting water quality at the household level. This indicator does not attempt to evaluate large, centralized water treatment processes and humanitarian-operated refugee camps, which already have standards of practice for treatment.

Transmission Pathway D: Hygiene Practices

This pathway assesses the risk of fecal pathogen transmission through inadequate hygiene practices. Handwashing with soap at critical times (e.g., after using the toilet, before handling food) is a core WASH intervention that is consistently linked with reducing the spread of waterborne diseases (Bartram & Hunter, 2015; Joos Van Den Noortgate & Peter Maes, 2010; WHO, 2018). It has been shown to reduce the incidence of diarrheal diseases by up to 40 per cent and respiratory infections by 25 per cent (WHO, 2018). Studies show that even when handwashing facilities exist, actual behavioral compliance may be low due to factors like cultural norms, awareness of its importance, and convenience (WHO, 2018). In this case, it is appropriate to combine indicators of physical access with users' self-reported handwashing behavior to assess whether handwashing is practiced, and if not, whether it is due to a behavioral or infrastructure limitation. Indicators in this pathway assess whether hygiene practices are in place and are likely to be effective at reducing exposure. Service availability and adequacy and user behaviors are examined to understand how people may be exposed to fecal pathogens through hands or food.

D.1 Handwashing Practice

This indicator measures (1) **the proportion (%) of observed or surveyed facilities with a functional handwashing setup containing water and soap**; and (2) **the proportion (%) of respondents who report regularly washing hands with soap at critical times**. It reflects the capacity of households and shared facilities to maintain effective hygiene barriers.

D.2 Food Hygiene

Poor food hygiene practices such as eating with unwashed hands or using dirty utensils are major contributors to the transmission of diarrheal disease. These practices reflect local customs, which in normal circumstances may not increase foodborne disease transmission. However, when a community's water access and quality are degraded by the effects of conflict, typical transmission controls (e.g., hand- and dishwashing) may not be effectively practiced.

This indicator measures the **proportion of observed eating practices that meet basic hygiene standards.**

E. Water Access[11]

Water access directly influences hygiene practices. When access is limited, households are assumed to prioritize basic needs such as drinking and cooking over hygiene behaviors like handwashing and washing food before cooking. Howard et al. (2020) identifies a strong inverse relationship between water collection time and daily per capita water use. Water use drops sharply when round-trip collection time exceeds 5 minutes (or approximately 100 meters travel distance), then plateaus between 5–30 minutes (100–1,000 meters) before declining further at longer distances (Cairncross & Cliff, 1987; Howard et al., 2020). These dynamics have direct implications for health, as reduced availability constrains hygiene and increases the risk of water-washed disease.[12]

This indicator attempts to **quantify the volume of water available per person per day**, expressed in litres per capita daily (LPCD). Specifically, the per capita volume of water that can be collected from improved off-premises sources, such as public taps, boreholes with handpumps, or protected dug wells. It reflects the adequacy of household or community access to safe water supply for basic drinking, cooking, and hygiene needs.

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[11] Collection time thresholds and associated water volumes collected (Howard et al., 2020).

[12] *Water-washed:* A class of diseases that arise due to inadequate personal hygiene stemming from insufficient water. In contrast to water-borne disease, the role of water is in prevention of disease transmission rather than as a vehicle for carriage of pathogens (Bartram & Hunter, 2015).

Scenario 4

Selecting Indicators of Service Performance

Scenario: Evaluating Sanitation Failures in an Overcrowded Neighborhood

A conflict-displaced population has overwhelmed an urban neighborhood, more than doubling the number of residents and placing extreme pressure on local sanitation infrastructure. Waste management services are irregular, and communal latrines – originally built for 30–40 people – are now used by more than 100. Overflow, odor, and open defecation have become commonplace. Local authorities, working under constrained resources, seek a way to focus interventions where the risk of disease transmission is highest.

Procedure: To support targeted decision-making, the assessment team applies **Step 4** by developing a structured set of performance indicators and practical guidelines for conducting field investigations. The goal is to describe the severity and spread of sanitation system strain using repeatable and context-relevant metrics.

Indicators are selected to capture both usage burden and system breakdown:

1. *Average number of users per communal facility*
2. *Percentage of facilities experiencing overflow or structural failure*
3. *Observed frequency of open defecation in shared spaces*
4. *Reported frequency of waste removal or desludging service*

Each indicator is paired with a simple field observation or interview method. For example, user counts are estimated through resident interviews and observational tallies during peak hours. Containment failure is assessed through visual inspection for overflow, physical damage, or signs of backflow. Open defecation is recorded using a presence/absence grid across public areas, and waste removal schedules are confirmed through conversations with local workers and service contractors.

These guidelines are compiled into a field protocol, enabling multiple teams to gather comparable data across neighborhoods. The resulting indicator set serves as a baseline for identifying priority zones, informing short-term interventions, and supporting future trend analysis as the crisis evolves.

Step 5: Link essential service performance to public health risk(s) and define scoring criteria

Focused User: Humanitarian Field Actors

To make sense of essential service observations, quantitatively relate essential service indices developed in the previous step to the public health risks. Develop scoring criteria to evaluate risk based on the service levels observed, using authoritative standards that explain or quantify how variations in service levels impact public health outcomes.

Observations of essential service performance must be interpreted in relation to the priority public health risk to understand infrastructure capacity. For each indicator (e.g., water access), risk scoring criteria are developed based on the best available data and existing standards. These criteria must reflect meaningful changes in public health risk resulting from changes in service performance.

Established frameworks – such as the Joint Monitoring Program (JMP) service ladder for water and sanitation – offer authoritative benchmarks that identify thresholds where changes in service levels affect the ability to meet essential needs like hygiene or laundry (UNICEF & WHO, 2020). Typically, a decline in service performance corresponds to a higher risk score when it increases the likelihood or severity of hazard exposure. Scoring thresholds help determine when users retain or lose the capacity to prevent disease and whether the level of service is adequate to protect public health at large.

To improve local relevance, assessors should use national or context-specific thresholds wherever possible. This ensures that assessments reflect the specific conditions and needs of the affected population. When applied consistently across the study area, this scoring system helps identify the greatest public health risks and supports the prioritization of interventions.

Table 1 presents a reference set of risk-scoring criteria for indicators of essential service performance associated with FOD. These criteria are derived from international standards on water, sanitation, and hygiene, and adapted for use in conflict-affected urban contexts.

Table 1. *Selected indicators of essential service and risk scoring criteria.*

Pathway and Service Outcome	Indicator[13]	LOW	MEDIUM	HIGH	CRITICAL	Notes
Environmental Fecal Contamination	Facilities Not Contained[14]	< 5% of sanitation facilities observed have containment failures (WHO, 2018).	5–15% of facilities show minor containment issues without widespread contamination.	15–30% of facilities are observed to have significant containment issues with leakage and nearby contamination.	Over 30% of facilities show severe containment failures, which significantly increases the likelihood of human exposure.	Use GPS-enabled device to record locations of failed containment facilities.
	Average Users per Household Facility[15]	1 household per toilet facility.	2–3 households.	4–5 households.	> 5 households.	Survey the community to gather demographic data on household sizes and access to sanitation facilities.
	Average Users per Communal Facility	< 20 people per communal facility (Sphere Project, 2018).	21–30 people per communal facility.	31–40 people per communal facility.	> 40 people per communal facility.	
	Surface Water Dumping					
Soil-Crop Fecal Contamination	Facilities Fertilizing On-Site	< 10% of households dispose of fecal sludge as fertilizer on premises.	10–25%	25–50%	> 50%	Interview households to determine disposal/reuse applications of on-site fecal sludge as fertilizer.

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[13] Unless noted, percentages refer to the percentage of the population.

[14] Includes unstructured facilities (e.g., shallow dug pits for open defecation). “Not contained” determined by using the containment system assessment table from SFD-PI (2018). Record the observed facility in the appropriate category in Table 2, found in the Appendix.

[15] Household on-site sanitation systems are assumed to be designed for individual household use. The risk scoring criteria reflects the effect of a linear increase in the number of households relying on a single containment facility.

Pathway and Service Outcome	Indicator[13]	LOW	MEDIUM	HIGH	CRITICAL	Notes
Clean Water	Groundwater Fecal Pollution Risk[16]	Report score from SFD Groundwater Pollution Risk Estimation Tool	-	-	-	Use observations from field surveys to satisfy the requirements of the SFD-PI groundwater pollution risk estimation tool.
	Unimproved Drinking-Water Source[17]	< 10% of households rely on unimproved sources.	10–25%	25–50%	> 50%	Use established definition and examples of “unimproved” from JMP to classify water sources.
	Point-of-Use Treatment	< 10% of users receive water that is treated at the POU.	10–25%	25–50%	> 50%	Occurrence/non-occurrence classification of observations and interview responses.
Hygiene	Handwashing	> 90% of households or facilities have a functional handwashing station and soap, and more than 90% of respondents report washing at critical times.	75–90%	50–75%	< 50%	
	Food Hygiene Practices	> 90% of observed eating practices use clean utensils or practice handwashing with soap before eating.	75–90%; some lapses are observed	50–74%; handwashing before meals is infrequent and utensil cleanliness is inconsistent	< 50%; most eating practices demonstrate infrequent or no handwashing before meals, and utensils are rarely cleaned with soap and water	Observations of eating practices and understanding of customs can be used to assign a risk level. Assess the use and cleanliness of utensils.
Water Access	Liters per Capita Daily (LPCD)	> 50 (optimal access, sufficient for most household needs) (Howard et al., 2020; Sphere Project, 2018).	15–50 (intermediate access, covering most essential needs).	7.5–15 (limited access, primarily for drinking and basic hygiene).	< 7.5 (survival-level access, minimal water for drinking and hygiene).	Observe improved, off-premises water collection points.Survey users queued for collection.

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[16] Use the groundwater pollution risk tool at https://sfdapp.susana.org/gw-helper.php. If internet is not available, refer to the (SFD-PI, 2018).

[17] (Howard et al., 2020; UNICEF & WHO, 2020).

Scenario 5

Establishing Risk Scoring Criteria

Scenario: Prioritizing Cold-Weather Response Through Fuel Risk Scoring

In a mountainous region affected by prolonged conflict, households have lost access to electricity, gas, and fuel markets. To stay warm and cook food, communities have turned to surrounding hillsides to harvest wood. As winter progresses, accessible trees are becoming scarce, and residents are walking further to gather firewood. Local clinics are already reporting an increase in respiratory illness, burns from unsafe stoves, and cold-related complications. With several weeks of freezing temperatures still ahead, humanitarian responders need to estimate how long households can maintain basic energy needs, and which areas are at highest risk of fuel exhaustion.

Procedure: Applying Step 5, the assessment team evaluates fuel availability as a time-sensitive determinant of public health risk. Field teams map community harvesting areas, estimate remaining standing wood, and calculate average household firewood consumption to determine the expected **time until depletion**.

They apply a time-based scoring framework:

- Critical Risk: Supply will last < 2 weeks
- High Risk: 2–4 weeks
- Medium Risk: 1–2 months
- Low Risk: > 2 months

To ensure this classification reflects real exposure risk, the thresholds are calibrated to local conditions. If winter is expected to continue for another three months, then only communities with wood supplies exceeding that duration are considered "low risk." In contrast, those with less than one month of remaining fuel are marked as "high" or "critical" based on the shortfall.

This flexible scoring system ties fuel scarcity directly to health vulnerability. It enables planners to prioritize emergency interventions – such as fuel briquette distributions, insulation kits, or safe heating alternatives – before households run out of safe options in freezing conditions.

Step 6: A) Conduct field assessments and B) Observe the infrastructure systems that enable essential services

Focused User: Humanitarian Field Actors

This step represents the field assessment phase of the framework. It introduces the methods for collecting and recording field data to evaluate essential service performance and characterize the infrastructure dependencies observed during field assessment. Step 6 is divided into two complementary sub-steps:

- *Step 6A outlines the data collection methods used to observe, measure, and document the indicators defined in Step 4. It provides practical guidance on applying these indicators consistently across different field conditions.*
- *Step 6B focuses on observing and documenting the broader infrastructure systems that enable the essential services of concern, by identifying how components depend on one another across the built, human, natural, and virtual domains.*

Together, these sub-steps guide assessors through the systematic collection of field evidence on both service performance and system context. When organized spatially, these observations support later analysis of infrastructure independencies, service reliability, and intervention priorities.

Conduct the assessment using the performance indicators defined in Step 4. Prioritize clinic catchment areas (CAs) based on factors such as population density, recent disease incidence, or accessibility and security conditions. Within each CA, assessors apply a combination of suitable methods – including field walks, structured observations forms, brief household interviews, and coordination with local health or service actors – to obtain consistent, verifiable information on each indicator.

For indicators collected at the household level, the number of households visited (assessed) should reflect the size and variability of conditions within the CA delineated in Step 2. Variability in conditions refers to differences in settlement type, population density, infrastructure access, or exposure to environmental hazards that may influence the results of the assessment. As a general guide, if conditions within the CA are largely homogenous, assessors should aim to visit at least five to ten households. In smaller, densely populated CAs, this sample may be sufficient because most households are close together and likely experience similar essential service performance. In contrast, larger catchments with dispersed households may require a larger sample to capture differences in how essential services are performing across different parts of the CA. In all cases, assessors should note any visible spatial variation, especially regarding population density and where it affects people's access to essential services.

Step 6A: Field assessment

The purpose of Step 6A is to establish a standardized approach for observing and measuring indicator data in the field. The following subsections describe the methodological approach for each indicator, outlining how assessors can reliably gather evidence on essential service performance under post-conflict conditions.

A.1 Facilities Not Contained

SUGGESTED METHODS:

First, a qualitative assessment is conducted to assign a ‘Contained’ or ‘Not Contained’ status to each sanitation facility observed, using **Table 2** – a diagnostic table published by SFD Promotion Initiative (SFD-PI, 2018). Assessors can use this table to quickly assign a containment status to observed sanitation facilities. A ‘not contained’ status is assigned to sanitation facilities where A) facilities have not been adequately designed and constructed (e.g., unlined dug pit); B) containment systems (e.g., concrete liner) are damaged; or C) containment systems reach capacity (i.e., overflow). The sanitation facility types observed should be tallied in the diagnostic table.

In some sanitation facilities, a portion of excreta may enter the environment (e.g., through damaged linings or unlined pits with open bottoms). These facilities are only consid-

Table 2. *Containment systems from SFD-PI (SFD-PI, 2018).*

Containment: where does the toilet discharge to?	**What is the containment connected to?**				
	To sewer	**To soakpit**	**To open drain or storm sewer**	**To water body, to open ground, or to don’t know where**	**No outlet or overflow**
No onsite containment. Toilet discharges directly to sewer, or open drain etc.	C	C/NC	NC	NC	**Not applicable**
Septic tank	C	C/NC	NC	NC	
Fully lined tank (sealed)	C	C/NC	NC	NC	C
Lined tank with impermeable walls and open bottom	C/NC	C/NC	NC	NC	C/NC
Lined pit with semi-permeable walls and open bottom	**Not applicable**				C/NC
Unlined pit					C/NC
Pit (all types), never emptied but abandoned when full and covered with soil					C/NC
Pit (all types), never emptied, abandoned when full but NOT adequately covered with soil					NC
Toilet failed, damaged, collapsed or flooded	NC	NC	NC	NC	NC
Containment (septic tank or tank or pit latrine) failed, damaged, collapsed or flooded	NC	NC	NC	NC	NC
No toilet. Open defecation	**Not applicable**			NC	**Not applicable**

C = Excreta are contained; NC = Excreta are NOT contained; C/NC = Extent to which excreta are contained is dependent on level of risk of groundwater pollution; **Not applicable** = Combination of technologies is not possible ered ‘not contained’ *if they pose a groundwater pollution risk*. Containment status depends on whether the system presents a public health risk, which occurs when there is exposure to a hazard (i.e., fecal pathogens) *and* vulnerability (i.e., a nearby groundwater source used for drinking). A groundwater pollution risk estimation is used to determine whether the conditions observed constitute a risk to the household or community. The recommended assessment method is discussed in Transmission Pathway C: Drinking Water Contamination.

A.2 Average Users per Facility

SUGGESTED METHODS:

Estimate the average number of users per shared household sanitation facility, such as latrines shared among multiple families in a compound, yard, or informal housing cluster. Use semi-structured interviews with residents to gather this information. The goal is to understand how many individuals typically use a single facility in the area – not just how many households have access.

Interview respondents in different parts of the CA to reflect local variation in population/household density. Then calculate an average by the dividing the total reported number of users by the number of facilities described. Facilities serving more than 20-30 users that are publicly accessible should be considered outliers and noted separately as potential overuse hotspots.

Assessors may use the following prompt questions to guide interviews:

- How many households currently share this toilet facility?
- Roughly how many people use the toilet on a typical day?
- Has the number of users changed recently (e.g., due to displacement)?
- Do you ever experience delays or queues to use the toilet?

These prompts are not exhaustive but can help assessors estimate typical usage and identify unusually high-use facilities.

A.3 Sanitation Hotspots; Visual and Olfactory Cues

SUGGESTED METHODS:

Identify sanitation “hotspots” through field walks and conversations with residents. These are locations where pooled sewage, clogged or overflowing drains, or persistent sewage odors indicate breakdowns in physical sanitation infrastructure. Record GPS coordinates and brief notes for each site, describing the observation.

After completing fieldwork in the CA, calculate the total number of observed hotspots. Where spatial or population data are available to assessors, express this total as an area-based density (e.g., hotspots per km2) or a population-normalized ratio (e.g., hotspots per 1000 residents or per 100 households). These metrics allow comparison between catchments and help identify areas where sanitation system failures are especially concentrated.

A.4 Surface Water Dumping

SUGGESTED METHODS:

Identify locations where untreated fecal waste or raw sewage is visibly discharged into surface water bodies by individual users (residents) or service providers (e.g., vacuum trucks). For each discharge site, determine whether the contaminated water is used for other purposes that involve direct human exposure – such as bathing, washing clothes, recreation, or informal water collection for drinking. Record GPS coordinates of sites and the estimated volume of fecal waste discharged (e.g., single user volumes or containment system volume).

Count the number of dumping sites observed within the CA where surface water is both contaminated and actively used for these exposure-related activities. Confirm suspected sites through brief interviews with residents or service actors if direct observation is limited. This indicator reflects the number of high-risk locations where surface water contamination presents a realistic transmission pathway for FOD.

B.1 Facilities Fertilizing On-Site

SUGGESTED METHODS:

This indicator measures the proportion of households using untreated excreta from on-site facilities as fertilizer. Confirm use through interviews with residents and note whether disposal occurs on-site or off-site. Consider this indicator in combination with hygiene and water access data to interpret overall risk.

C.1 Groundwater Pollution Risk Assessment (Microbiological)

SUGGESTED METHODS:

Allocate resources (time, personnel) towards this indicator assessment, based on the estimated or known community reliance on groundwater systems. If it is known that there is very little or no reliance on groundwater, then it is reasonable to exclude these methods from the immediate post-conflict assessment. Alternatively, if groundwater is a significant source of drinking water, sufficient resources should be deployed to assess risks to groundwater systems. The SFD-PI groundwater pollution risk estimation tool offers an accurate, yet practical method for assessing this risk indicator of FOD transmission (SFD-PI, 2025). Use the groundwater pollution risk tool at https://sfdapp.susana.org/gw-helper.php. If internet is not available to access this resource, use the adapted questionnaire in **Table 3** to record local conditions influencing the risk of groundwater sources becoming contaminated by nearby sanitation facilities.

Table 3. *Groundwater risk assessment, adapted from SFD-PI (2025).*

Pollution Dynamic	Assessment Question
Aquifer Vulnerability	*What is the rock type in the unsaturated zone?*
	What is the depth to the groundwater table?
Lateral Separation	*What is the percentage of sanitation facilities that are located <10 meters from groundwater sources?*
	What is the percentage of sanitation facilities that are located uphill of groundwater source?
Water Supply	*What is the percentage of drinking water produced from groundwater sources?*
Water Production	*What is the water production technology used?*

C.2 Unimproved Source

SUGGESTED METHODS:

Identify and classify drinking water sources according to the Joint Monitoring Program (JMP) definition of unimproved sources.[13] Conduct observations at community or household level to determine source types currently in use. Record the percentage of observed households that rely on unimproved sources. Where possible, confirm findings with residents through interviews.

C.3 Point-of-Consumption Treatment

SUGGESTED METHODS:

Assess the use of POC water treatment methods through household observations and interviews. Identify whether treatments such as boiling, multimedia filtration, chlorination, or UV disinfection are being used consistently. In addition to treatment practices, observe household water handling and storage behaviors that can influence water quality. This includes examining whether storage containers are clean, covered, and designed to prevent contamination. Where possible, corroborate self-reported practices with visual evidence, such as the presence of treatment devices or clean storage containers. This approach aligns with the WHO's emphasis on both water treatment and safe storage practices to reduce diarrheal diseases in areas relying on unimproved water sources (UNICEF & WHO, 2020).

For each household surveyed, record the treatment method(s) used, the reported or observed frequency of use, and whether the method appears effect (e.g., water is visibly clean, containers are covered and hygienic). Use a standard recording table, such as **Table 4** to track which methods are observed and how often. At the catchment level, calculate the total number of households using any POC treatment method and the frequency of each treatment type. This helps determine the overall prevalence of household POC treatment across the CA and identify dominant or neglected methods.

Table 4. *Example recording table for POC treatment observation at the household level.*

Household ID	Boiling	Multimedia Filtration	Chlorination	UV Treatment	Frequency of Treatment	Water Visibly Clean?
001	Yes	No	No	No	Daily	Yes
002	No	Yes	Yes	No	Occasionally	Yes
003	Yes	No	No	No	Daily	No
TOTAL	2	1	1	0	n/a	2

D.1 Handwashing Practice

SUGGESTED METHODS:

Studies show that even when handwashing facilities exist, actual behavioral compliance may be low due to factors like cultural norms, awareness of its importance, and convenience (WHO, 2018). In this case, it is appropriate to combine indicators of physical access

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[13] Unimproved drinking-water sources include unprotected dug wells, unprotected springs, surface water, and other sources, which by their nature, cannot assure the absence of priority contaminants (Howard et al., 2020; UNICEF & WHO, 2020) (Howard et al., 2020; UNICEF & WHO, 2020).

with users' self-reported handwashing behavior to assess whether handwashing is practiced, and if not, whether it is due to a behavioral or infrastructure limitation.

Observe whether households have a designated handwashing facility near the toilet and/or kitchen area. Record the presence of key components: water, and soap (or soap substitute). Further, evaluate access to handwashing infrastructure at shared sanitation facilities, by noting whether a functional sink or equivalent is present.

Conduct short interviews to confirm whether household members regularly wash their hands with soap at critical times – particularly after toilet use and before food handling. Use observations and interview responses to classify handwashing behavior as consistent, occasional, or absent.

Calculate the following two metrics:

1. The proportion (%) of observed or surveyed facilities with a functional handwashing setup (with water and soap).
2. The proportion (%) of respondents who report regularly washing hands with soap at critical times.

D.2 Food Hygiene

SUGGESTED METHODS:

Observe household eating practices to assess hygiene-related risk. Note whether meals are eaten with clean utensils or with washed hands. Evaluate the visible cleanliness of utensils and ask brief follow-up questions when needed to confirm hygiene routines. Record the proportion of observed eating practices that meet basic hygiene standards.

E Water Access

SUGGESTED METHODS:

Observe household water collection practices at off-premises sources (e.g., protected wells, public taps, water trucks). For each water collector (individual), record the following, where possible:

1. Storage volume (V): Volume collected per trip.
   Larger storage containrs mean more water can be collected per trip but are not practical when the user must travel long distances by foot to collection points.
2. Trips per day (T): Estimated number of household water collection trips per day.
   Estimate through short interviews with household members or collectors at water sources. Ask how many times water is collected daily. Where interviews are not feasible, approximate trips per day, based on the visible number of containers used during collection and total collection time/distance. Assume that larger containers and long collection time/distance reduces trip frequency.
3. People per Household (P): Number of individuals sharing the collected water.

Estimate per capita water access, LPCD, using:

$$LPCD=VT/P$$

This calculation provides a practical approximation of household water access, assuming collected volumes reflect usable water. The result represents an estimate of daily water availability per person, which can be measured and compared across households or communities to characterize current service performance.

In parallel with measuring these indicators, assessors should also observe the broader systems that enable these services. Step 6B describes how to recognize and record these infrastructure dependencies during field assessment.

6B – Infrastructure Dependency Modelling

While conducting field measurements, assessors should also observe how essential services depend on one another and on shared enabling components (i.e., consumables, hardware, personnel). Infrastructure dependencies refer to the relationships that allow one service or component to function only if another is available or functioning. For instance, a water distribution system that depends on a constant fuel supply to power water pumps, or a health facility that relies on refrigeration to keep sensitive medications. Recognizing these relationships will help assessors understand not just where services are failing, but why.

Record the key components involved – such as tanks, pipes, pumps, generators, fuel supplies, control systems, or operating staff – and note any adaptations, alternate service arrangements, or visible points of fragility. It is important to consider the full service chain (from inputs to outputs) and to recognize how components interact across the built, human, natural, and virtual domains. These observations are crucial for identifying the underlying causes of poor performance that indicator data alone cannot capture (Hay et al., 2019).

Document both the condition of individual assets and their operational context. Note environmental risks (e.g., flooding), informal systems (e.g., self-installed water or electricity connections), and signs of cascading failure (e.g., water supply limited by energy outages). Where feasible, engage with service providers and users to understand routine disruptions, coping strategies, and resource constraints.

Use GPS-enabled devices to record the locations of infrastructure components, informal service points, and known failures (e.g., sanitation overflows).[14] Supplement these with spatial observations such as variations in population density, exposure to hazards, and barriers to physical access. Organize all information in a GIS-based geodatabase to support later spatial analysis and the construction of a system-wide picture of infrastructure functionality across the area.

By approaching the field assessment with this systems perspective, assessors can recognize patterns of interdependence and cascading failure that might otherwise go unnoticed. These field observations establish the foundation for Step 8, where assessors will develop an infrastructure dependency model to explain current conditions and causal relationships. Observing service performance alongside its enabling components allows later analysis of how services depend on specific infrastructure elements and where failures are likely to propagate across systems.

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[14] The accuracy of GPS measurements depends on the number of satellites that are accessible from the receiver's location (ESRI, 2024). Where receiver access is limited, defer to best available geospatial identifiers, like addresses or street intersections.

Scenario 6

Documenting Infrastructure Interdependencies

Scenario: Infrastructure Dependencies in a Solar-Powered Health Clinic

In a peri-urban community recovering from prolonged conflict, a health clinic and several surrounding homes rely on a small-scale solar energy system for basic electricity. The system includes rooftop photovoltaic panels, a battery bank for energy storage, and a manual switch that allows fallback to the municipal grid. During daylight hours, solar generation supports lighting, refrigeration, and phone charging. At night, services rely on battery power. If batteries are drained and the grid is unavailable or disconnected, the system fails – jeopardizing both health services and basic household energy needs. While the system appears functional during the day, field responders suspect that service interruptions are linked to hidden infrastructure dependencies.

Procedure: Applying Step 6, the assessment team evaluates how essential services within the solar-powered health clinic's catchment depend on interconnected infrastructure components. Field observations are used to understand the full delivery chain – from energy generation, to storage, to distribution and use.

The team documents solar array output by noting panel orientation, shading from nearby structures, and any visible buildup of dust or debris. Battery charge levels are recorded at various points in the day, especially during peak usage and overnight, to assess whether storage meets local demand. To understand dependencies beyond the solar system itself, the team examines the manual transfer switch and confirms whether it is operable, in good condition, and used correctly. Inverter logs or simple voltmeters provide insight into the availability and reliability of the municipal grid connection.

Patterns begin to emerge: refrigeration and lighting are consistently disrupted during the early morning hours – not because of panel failure, but due to undersized battery storage, a broken or unused manual switch, and inconsistent grid backup. The system's performance is therefore not just a function of solar input, but of multiple components working in coordination.

By georeferencing infrastructure observations and linking components by function, the team builds a localized interdependency profile. This spatial and systemic view of performance shows clearly how energy reliability – and, by extension, health service delivery – is shaped by multiple layers of infrastructure. The profile informs practical recommendations: increase battery capacity, automate the transfer switch, or prioritize grid repair at the distribution point. Each action targets a specific point of failure within the local infrastructure network.

Step 7: Evaluate and map public health risk levels by area to prioritize relief and recovery efforts

Focused User: Development Actors using Humanitarian-Collected Data

In this step, development actors analyze the data collected by humanitarian field actors in Step 6A to calculate and visualize relative public-health risk across the assessment area. Indicator scores are normalized and summed across all transmission pathways to generate a total risk score for each clinic catchment, while each pathway's contribution is calculated as its share of that total. The resulting scores are visualized through one choropleth map per transmission pathway and a composite map of overall risk, providing decision-makers a clear basis for identifying priority locations for coordinated relief and recovery.

Once indicators have been scored, apply the established scoring criteria established in Step 5 to evaluate the public health risk level of each clinic catchment area (CA) or comparable geographic unit of analysis. This analysis identifies which transmission pathways contribute the most to overall risk risk, helping humanitarian field workers and development actors to prioritize interventions where they will have the greatest impact on stabilizing the population health.

$$\text{Relative Contribution} = \frac{\text{Individual Risk Score}}{\text{Overall Risk Score}} \times 100\%$$

If multiple transmission pathways have been evaluated, calculate the overall risk score for each CA by summing the individual pathway scores. This total represents the combined public-health risk associated with all measured transmission pathways in that area. To understand the relative importance of each pathway, calculate its proportional contribution by dividing the pathway's score by the total risk score for that CA:

Once total and pathway-specific risk scores are calculated, visualize the results using choropleth maps. Produce one map for each transmission pathway to illustrate spatial variation in that specific category of risk, and a composite map showing the summed total risk across all pathways. This approach allows direct comparison of risk patterns between categories while also revealing where multiple infrastructure-related factors combine to elevate overall public-health risk.

Together, these mapped outputs provide a clear spatial representation of both the magnitude and drivers of public-health risk across the assessment area, enabling coordinated action between humanitarian and development actors.

Scenario 7

Mapping Public Health Risk by Catchment Area

Scenario: Mapping Composite Risk in a Conflict-Affected River Valley

In a flood-prone river valley on the outskirts of a city recently affected by conflict, months of shelling have damaged the electricity grid, ruptured sewer lines, and displaced hundreds of households into informal settlements along the riverbank. Local clinics report recurring outbreaks of acute watery diarrhea (AWD) following seasonal rains. Humanitarian field teams have already completed essential service assessments for sanitation containment, water access, drinking-water safety, and hygiene behavior across seven clinic catchments. Development actors now lead the analysis to determine how these disruptions translate into spatial patterns of public-health risk.

Procedure: Using the risk scoring criteria established in Step 5, the team groups the indicator results by transmission pathway and sums the pathway scores to calculate a total risk value for each catchment. The analysis shows that sanitation and water-access pathways contribute most to overall risk in the low-lying neighborhoods, where latrine pits have flooded, fuel shortages have stalled pumping stations, and the municipal water network remains offline due to power instability. These findings are visualized in a series of choropleth maps – one for each pathway and a composite map highlighting the two catchments with the highest combined risk.

By converting field-measured indicator scores of essential service performance into a spatial representation of risk, Step 7 enables actors to connect essential service failures directly to conflict-related damage and prioritize recovery efforts that reduce immediate disease transmission and future vulnerability.

Step 8: Model all observed infrastructure dependencies

Focused User: Development Actors using Humanitarian-Collected Data

Compile the component-level observations gathered during the field assessment (Step 6B) and document how these components depend on one another. Focus on identifying the infrastructure elements (i.e., people, hardware, consumables) that enable essential services linked to public health. Use these relationships to build a model that examples system structure, highlights performance constraints, and identifies potential points of failure.

A dependency model is a simple but powerful tool that shows how infrastructure components – such as people, hardware, and consumables – rely on one another to deliver essential services. The model visually represents these dependencies to explain how the system is structured and to identify weak points where failures in one component (e.g., fuel) can cascade and disrupt others (e.g., water pumps).

These models serve multiple purposes. They provide a clear explanation for observed service failures, allow field teams to communicate system fragilities to decision-makers and support the prioritization of repairs or investments. For *development actors*, the dependency model offers a quick-reference snapshot of critical interdependencies and reveals how small, targeted interventions can stabilize broader infrastructure systems and improve public health outcomes.

Step 8 builds directly on the field observations recorded in Step 6B. While Step 6B focused on identifying enabling components and service interconnections, this step translates those observations into structured dependency chains that visualize how systems function – and where they are likely to fail. These models are not intended to be technical blueprints but field-informed practicable tools to support systems thinking and coordination.

Begin by reviewing field notes, photographs, and interview records to identify recurring infrastructure dependencies within and across CAs. Then, apply a structured approach to build the model:

1. **Identify critical components:** Record infrastructure components that are critical to essential services. For each, note its role and any other components that it directly depends on, or which depend directly on it (e.g., “Wastewater pump – powered by diesel fuel, maintained by municipal technician”).
2. **Map dependency direction:** Use arrows to indicate the direction of dependency between components. Arrows should point from the enabling component to the dependent component, indicating that one supports the function of another (e.g., diesel fuel ◊ wastewater pump).

3. **Describe degree of influence:** For each connection, estimate how strongly the enabling component influences the performance of the dependent one. Use simple qualitative ratings (e.g., *high, medium, low*) or explanatory notes (e.g., “The wastewater pump can only operate if diesel is available, so diesel availability has a high influence on the functionality of the wastewater treatment plant”).

Dependency models can begin as rough sketches and grow more refined as additional CAs are assessed. Focus first on modeling critical subsystems – those with the greatest influence on service delivery or those already showing signs of failure. The final model may vary in complexity, but even a basic diagram paired with field notes can provide invaluable insight.

See Figure 8 for an example of a rudimentary dependency model. When interpreted alongside the performance scores and risk maps developed in earlier steps, the dependency model helps explain why certain areas are experiencing elevated public health risks. This pairing allows development actors to trace system failures to their root causes and design targeted interventions that reduce system fragility.

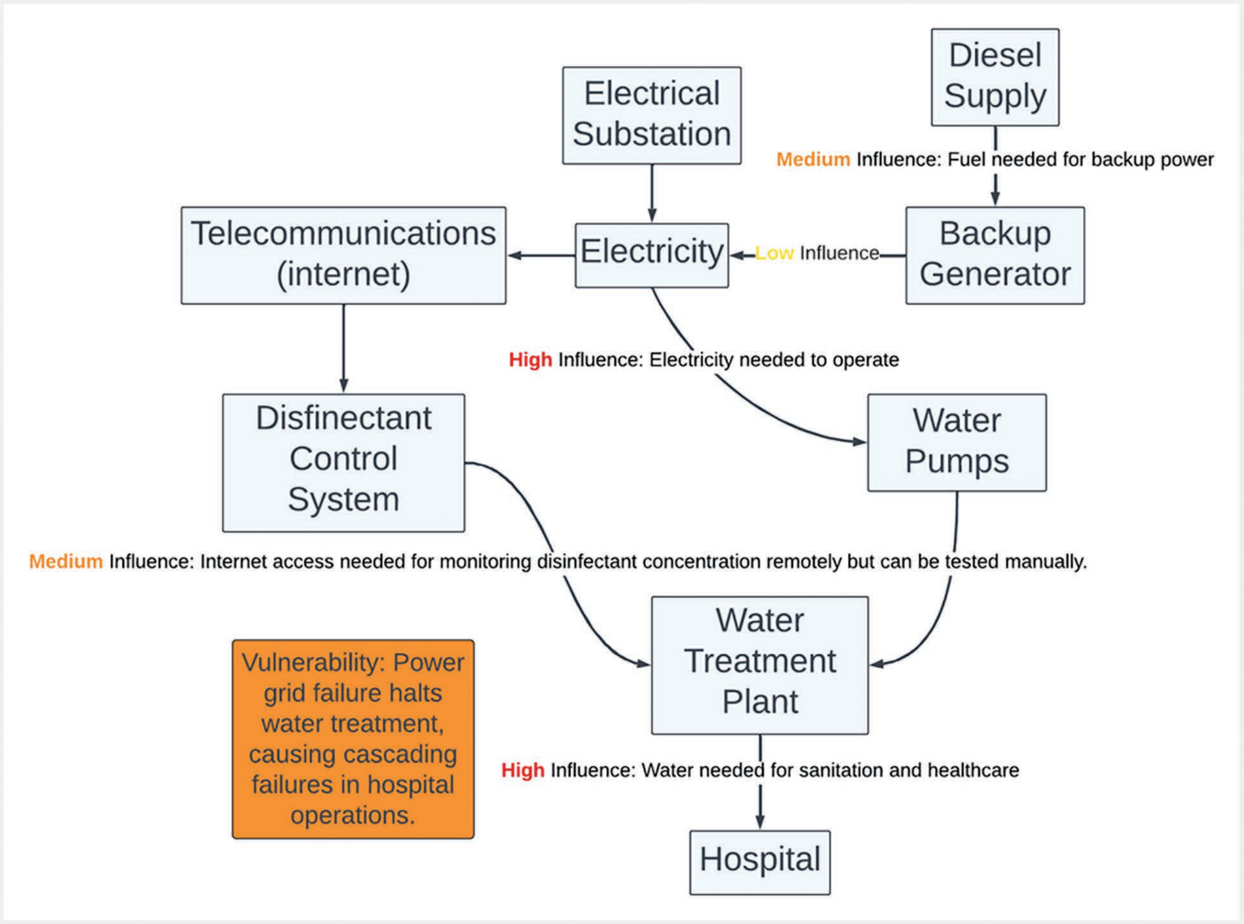

Figure 8. Example dependency model for a water treatment plant, focused on the enabling components and resources for providing water that is free from priority contaminants. The influence levels are color coded for easier viewing.

Scenario 8

Modeling System Dependencies

Scenario: Modeling Water Supply Dependencies During a Cholera Outbreak

In a peri-urban settlement recovering from conflict, Step 7 analysis reveals a spike in cholera cases across two health clinic catchments. Step 6A assessments identify widespread hygiene challenges, while Step 6B observations show that many households rely on a borehole-fed piped water system that delivers water unpredictably – sometimes only at night or for brief intervals during the day.

Interviews with healthcare providers and residents reveal that in the absence of adequate, safe water supply, households have begun collecting water from unsafe water sources. Field interviews also reveal that many families are rationing water for cooking and drinking only, while handwashing and latrine cleaning are neglected. These conditions are believed to be contributing to ongoing transmission.

Procedure: Drawing on field notes and interviews with municipal staff, the team identifies key infrastructure components: a borehole pump, electric booster station, diesel-powered backup generator, and a remote valve system controlled by the municipal water authority.

They characterize the generic service process and map directional dependencies between components: electricity or diesel → pump → pressurized distribution → household taps. Each connection is labelled with a qualitative dependency score: for example, the pump is entirely dependent on electricity (high), while the valve control relies on both electricity and mobile signal but could be manually operated (medium). Municipal water staff report that during power outages, technicians must travel by motorbike to manually open valves – a process often delayed by fuel shortages and poor road access.

The completed model visualizes how the system's performance hinges on both the energy supply and mobility of technicians. It shows that even when water is available at source, cascading failures in energy and transport frequently disrupt delivery.

By identifying dependencies and operational challenges, the model makes system fragilities visible. This helps to identify where interventions can be targeted to have the greatest impact on restoring consistent water access and preventing disease transmission.

Step 9: Synthesize risk and infrastructure data to inform recovery planning

Focused User: Development Actors

This final step brings together the two core threads of the assessment: public health risk patterns derived from field-level indicators, and the system-level dependencies that explain why those risks persist. The purpose is to synthesize these findings to support recovery planning. By reviewing risk scores and dependency models together, assessment teams can identify priority vulnerabilities, clarify root causes, and determine where coordinated infrastructure interventions are most urgently needed.

This step transforms assessment findings into actionable insights to guide coordinated recovery, investment, and resilience planning. The goal is to align humanitarian field workers and development actors around a common understanding of where public health risks are highest, which infrastructure systems are driving those risks, and where targeted interventions can stabilize multiple services simultaneously.

The objective is not to describe individual service conditions in isolation but to understand how those services function as a system under the current conditions – and where that system is fragile, adaptable, or failing. This requires integrating data across infrastructure domains (built, natural, human, and virtual) to produce a coherent picture of how essential services are delivered, where breakdowns are occurring, and why.

Begin by layering clinic catchment risk scores (Step 7) with spatial field and dependency models (Step 6B and 8). This integrative mapping process allows teams to identify:

- Where elevated health risks overlap with known infrastructure failures;
- Which infrastructure breakdowns are most strongly associated with high-risk CAs;
- Where cascading failures – such as energy outages disrupting water treatment – are compounding risk across systems.

To make these linkages clear, interpretation must be anchored in real, co-located evidence. For example, if a catchment scores high for water-related disease risk, refer to its corresponding dependency model: Is the water system reliant on a failing pump, an unstable energy supply, or absent staff? Use this comparison to trace risk signals back to system-level root causes.

The dependency model becomes especially important here. It reveals which components serve as system enablers, and where single points of failure could affect services. These insights help distinguish between problems caused by local service degradation versus upstream or cross-sector fragility.

This analysis should be documented in formats that allow for joint interpretation by multiple recovery planning stakeholders. Risk maps, dependency diagrams, and spatial overlays should be presented in simplified, annotated formats. These products should serve as a shared evidence base – reducing the risk of fragmented, duplicative, or conflicting efforts.

As priorities are identified, compare current service performance against population needs and survival thresholds. Highlights where coping strategies are failing and where gaps in water, sanitation, or energy access require urgent action. It may be useful to classify findings into clear, tiered response levels

- Immediate stabilization needs (e.g., generator repairs, temporary fuel supply);
- Medium-term system reinforcement (e.g., restoring grid access, shoring up human resources);
- Long-term restructuring to reduce future risk (e.g., decentralizing energy supply, creating redundant control systems).

Finally, assess whether any parts of the infrastructure system of systems (SoS) demonstrate resilience – such as the ability to operate under degraded conditions or to switch between service modes. These attributes can inform recovery plans that not only restore function but improve systemic adaptability.

Scenario 9

Analyzing and Interpreting Capacity

Scenario: Assessing Infrastructure Performance in a Conflict-Impacted Coastal City

In a coastal city impacted by conflict and recent flooding, basic infrastructure systems are heavily degraded. The power grid is unstable, water supply is intermittent, and solid waste services have collapsed in several districts. Initial risk scoring in Step 7 reveals that two clinic catchments in the southern district face the highest burden of waterborne disease. These same areas were flagged during Step 6B for repeated power outages and failed sanitation access.

Procedure: Development actors lead the Step 9 analysis by reviewing clinic catchment risk scores alongside spatial infrastructure observations and service dependency models developed in prior steps. In the southern district, they identify a convergence of elevated diarrhea incidence, frequent grid outages, and sewer overflows. The dependency model shows that both the water pumping substation and sewage treatment plant rely on the same flood-damaged electricity substation – a single point of failure affecting multiple systems.

By mapping these relationships, the team traces the health risk directly to cross-sector infrastructure breakdowns and are now equipped with sufficient knowledge and understanding of the situation to plan recovery actions. They identify the southern district as the highest priority for immediate stabilization and recommend coordinated investment to restore power to water and sanitation infrastructure. Medium-term actions include deploying backup generators, while long-term planning focuses on flood-proofing critical substations and decentralizing water treatment capacity.

These findings are compiled into a shared recovery brief, including annotated maps and dependency diagrams, to support join decision-making between development agencies and local infrastructure authorities. This synthesis helps ensure that near-term interventions align with long-term system resilience planning, and that all actors are operating from the same evidence base.

CONCLUSION

In post-conflict environments, infrastructure systems often operate in a state of extreme degradation. Drinking water stops being delivered, sewage systems fail, electricity supply is intermittent – and in this state, public health collapses and human suffering prevails. Humanitarian and development actors responding in these settings are routinely asked to stabilize or repair critical services, yet they often face a profound gap in relevant, usable infrastructure data. Pre-war maps and records no longer reflect the current reality, nor do previous patterns of human behavior. Furthermore, quality data like current, high-resolution satellite imagery that would otherwise enable remote spatial data analysis, may be unavailable due to security restrictions. Even when data exists, it rarely captures how essential services are interconnected or why failures cascade across systems.

This field guide offers a systematic, field-adapted alternative to informing infrastructure recovery of post-conflict urban environments. It presents a nine-step assessment framework designed to help humanitarian and development teams evaluate infrastructure performance and identify system fragilities, using a common public health risk – fecal oral disease (FOD) – as a practical case example. Rather than rely on remote sensing or legacy data, the methods emphasize direct observation, georeferenced field data, and structured analysis of infrastructure dependencies. Central to this framework is the recognition that infrastructure systems do not exist in isolation. They are interdependent, and the failure of one component can cascade through the entire system. The consequences of armed conflict fundamentally change the conditions of infrastructure, often requiring solutions that diverge entirely from pre-crisis conditions. Rebuilding infrastructure to its original state without considering the new realities of the community and environment risks wasting resources and missing the evolving needs of the affected population.

By using FOD risk as a unifying metric of infrastructure functionality, this framework links essential service performance directly to health outcomes. This makes it possible to locate not just where public health risks are concentrated, but why they persist – and which specific system failures or dependencies are driving them. The result is an evidence base that supports both immediate humanitarian triage and longer-term development planning.

The framework is designed to be operational in constrained environments. It can be implemented without advanced sensors or digital infrastructure, using simple tools like GPS-enabled phones, annotated base maps, tabular assessments, and structured interviews. It also products outputs – such as health clinic catchment risk maps, service chain models, and dependency diagrams – that can be used by both humanitarian and development agencies and local infrastructure authorities to align priorities and avoid fragmented recovery efforts.

In conclusion, the methods presented in this paper fill a critical operational gap: it offers a structured way to assess post-conflict infrastructure systems when conventional data is missing, unreliable, or inaccessible. By combining risk-based essential service performance indicators with field-observed infrastructure dependencies, it transforms fragmented observations into coordinated, actionable insight. It is not a blueprint for rebuilding what existed before the war – it is a tool for understanding what matters now, how systems interact under strain, and where limited resources can be deployed to stabilize the greatest number of lives. In settings where the stakes are high and the data is thin, this framework equips teams to see the system, not just its symptoms – and to plan recovery with clarity, purpose, and shared direction.

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