Inclusive & climate-resilient urban WASH in Melanesian informal settlements RESEARCH PROJECT

TECHNICAL BRIEF

Localising vulnerability and resilience considerations for water and sanitation service delivery models

Suva, Fiji and Port Vila, Vanuatu

JANUARY 2025

International WaterCentre · Griffith University, Queensland, Australia · USP The University of the South Pacific · The University of Papua New Guinea · UACS urban analytics & complex systems · Water For Women · Australian Aid

Summary of key findings

The document explores inclusive and climate-resilient water, sanitation, and hygiene (WASH) solutions in urban informal settlements across Melanesia, particularly in Suva (Fiji) and Port Vila (Vanuatu). Informal settlements in these regions face unique challenges such as insecure land tenure, inadequate infrastructure, and exposure to climate hazards like cyclones, floods, and sea-level rise. These settlements often lack equitable access to resilient WASH services, exacerbating socio-economic vulnerabilities and environmental risks.

Our key findings include:

A range of different water and sanitation service delivery models exist in settlements. Services in informal settlements typically consist of a hybrid service chain comprising formal, recognised elements and informal, self-managed systems.

Limited and unreliable access continues to be reported across settlements. A significant proportion of residents lack adequate WASH services, and even those with access frequently face disruptions due to routine damage and extreme weather events like floods and cyclones.

People living in settlements are heavily impacted by inadequate WASH that has higher vulnerabilities to climate hazards. Services in informal settlements are more susceptible to climate-related and local hazards compared to those available to other urban populations.

Several factors influence the resilience of water and sanitation systems, including but not limited to:

- Backup water sources are critical during disruptions, but their quality and accessibility vary.
- Proximity to Infrastructure: Distance from roads and services affects maintenance and resilience.
- Facility type: Pit toilets and external water sources are particularly vulnerable to extreme weather damage.

There is an important role for a range of decision-making tools. Structured decision-making tools can help design more resilient service delivery models by integrating data on climate hazards, vulnerabilities, and infrastructure needs, ensuring solutions are better aligned with local realities. WASH service delivery models (SDMs) must be suited to local contexts by considering topographical, environmental, and socio-economic factors.

PACIFIC URBAN WASH RESEARCH PROGRAM

The **Planning for Climate-resilient Water, Sanitation and Hygiene in Urban Informal Settlements** research objective was to investigate how urban planning processes in Melanesia could be supported through participation and integration of additional data and information, to improve the resilience of WASH service delivery in informal settlements within the urban footprint. By doing this, we sought to increase the resilience and inclusiveness of WASH planning in urban Melanesia so residents in informal settlements have access to more resilient WASH services.

This study provides regionally appropriate evidence about what kinds of processes and systems could be explored within different urban contexts in Fiji, Vanuatu, and Papua New Guinea. The mixed methods research included:

- on-site surveys
- key informant interviews
- participatory GIS
- spatially-explicit hazard assessments including water quality monitoring
- participatory planning activities
- public media reviews.

These methods were designed to understand existing WASH services and preferences, urban planning approaches and the existing political economy of the provision of urban WASH

Based on this 2-year research program, several key lessons have emerged for practitioners and policymaker, as well as technical outcomes that can contribute to the planning of resilient WASH services. This brief outlines some of the most important.

More information about the research program can be found here: RESEARCH PROJECT WEBPAGE

Introduction

Informal settlements in Melanesia are characterized by their lack of formal planning, insecure land tenure, and limited access to basic services such as water, sanitation, and waste management (UN Habitat, 2015). These settlements often emerge on marginal lands, including steep slopes, flood-prone areas, or coastal zones, due to rapid urbanization and a shortage of affordable housing options. In Suva, Fiji, approximately 20% of the urban population resides in informal settlements, which are diverse in land ownership, ranging from customary to state and private freehold lands. Informal settlements in Vanuatu's capital, Port Vila, are even more pronounced, with over 50% of the urban population living in these underserved areas (Sanderson & Souter, 2020). In Port Moresby in Papua New Guinea, more than half of the urban population live in settlements (Sanderson, Kotra, Koto, Molitambe, & Souter, 2022). Residents of these settlements often maintain strong familial or kinship ties, contributing to their establishment as "rural villages in the city," (Jones, 2016) but also face challenges such as inadequate infrastructure, exposure to climate hazards, and limited governance support. These settlements represent a critical intersection of urban growth, socio-economic vulnerability, and environmental risk.

Settlements in Melanesia exhibit a diverse range of water and sanitation systems, from unimproved dry pit latrines to water-based septic tanks and sewer connections. Nearly half of households in Port Vila and 10.7% in Suva lacked basic sanitation services, which stood in stark contrast to the official Joint Monitoring Programme (JMP) estimates, suggesting that only 6% of urban residents in Vanuatu and 0% in Fiji lacked access to basic sanitation. These findings highlighted critical gaps in sanitation service provision in informal urban areas.

Further, these systems are often unable to meet residents' needs both under usual conditions as well as when confronted by hazards and shocks. Exploring the vulnerabilities of these systems alongside their adaptive capacities is essential to identifying pathways for resilient service delivery models. Despite some progress, settlements in Suva, Port Vila and Port Moresby continue to face significant barriers in achieving equitable and resilient water and sanitation services. Data collected through surveys and fieldwork in selected locations reveal a high reliance on shared and unimproved sanitation systems, limited access to safe faecal sludge management, and inadequate preparation for climate impacts. While Suva has a higher prevalence of water-based systems, its septic tanks and pit latrines frequently lack routine desludging and maintenance. In contrast, Port Vila demonstrates a reliance on both dry and water-based systems, with residents reporting damage from cyclones and other hazards.

This document builds on previous contributions from this research on the vulnerability and resilience of water and sanitation service delivery models (Sanderson et al., 2022) by embedding the theoretical and literature-based analysis in the primary evidence gathered through mixed method research activities in 2023 and 2024. This document presents a selection of ways to use risk-based methodologies, well-defined in literature, to make place-based decisions on the appropriateness or otherwise of water and sanitation service delivery models in settlements in Suva and Port Vila.

Research methodologies

This research was conducted by the International WaterCentre (IWC) and the University of the South Pacific (USP) in Port Vila, Vanuatu and Suva, Fiji, during 2023-2024. Research activities that informed the contents of this technical brief include:

- Household survey of 395 participants across nine settlements (216 survey participants in Suva and 179 survey participants in Port Vila), comprising approximately 130 questions and enumerator observations. The survey had four sections: water access, sanitation access, water climate impacts and sanitation climate impacts. Questions were either multiple choice, open response, or Likert scale in response.
- Impact interviews conducted with 33 residents across nine settlements.
- Water quality monitoring, conducted over 6 months including cyclone and part of the dry season, across four different water source types in Port Vila, Vanuatu.
- A piped mapping hazard and risk assessment, conducted in two settlements in Suva, Fiji.
- Desktop GIS approaches to analyse and investigate the spatial positioning and connectivity to environmental and geographical features for households.

Key concepts underlying the research

Water and sanitation service chains

When we talk about water and sanitation service delivery models, we mean services delivered end to end (Figure 1). Not all SDMs look the same or comprise all elements of the service chain models, however without consideration of all components of the chains there is greater risk of loss of containment, or interruptions in service, or introduction of social and environmental risks into the system. As part of our research, we sought to put more clarity around the nuances of water and sanitation service delivery models in informal settlements in Suva and Port Vila, such that we could better identify points of vulnerabilities and exposures inherent in those models.

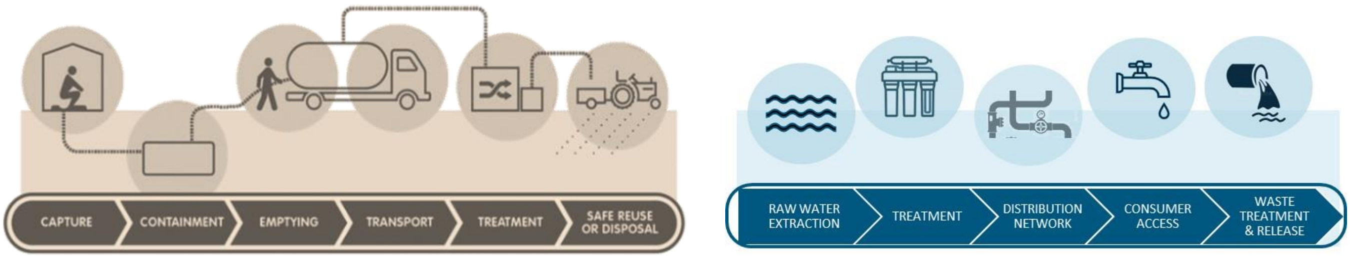

Figure 1: Sanitation (left) and water (right) service chains

Urban planning

Urban planning as a concept can provide processes and tools that can make decisions about land uses, including the types of services available, in particularly urban areas. It does this by bringing together knowledge and values. This is relevant to place-based decision-making about which WASH services are most relevant to which areas of informal settlements, given their unique combinations of topography, physical attributes, hazard exposure and socio-economic characteristics.

Mixed services for city-wide WASH

The local and surrounding environment, and social and economic settings affect the local resilience of different water and sanitation services. By local, we are specifically referring to within settlements. If everyone in a city uses safe water and sanitation at home, the services preferences of residents are accounted for, and the risks of those services being affected by climate change are minimised and managed, across any city there will need to be a mix of water service delivery models, and sanitation delivery models, that are best suited to different locations.

Climate-related risks

To reduce the level of risk posed by climate-related hazards to water and sanitation services in informal settlements, we need to understand and manage where we can the three dimensions of risk – hazards, vulnerability and exposure, as presented in the Intergovernmental Panel on Climate Change (IPCC)'s 6th Assessment Report (AR6) (Reisinger et al., 2020). In Figure 2, adapted from this IPCC diagram, we identify some of the elements of these dimensions in relation to climate resilient water and sanitation. This conceptualisation has been used to inform our research approach.

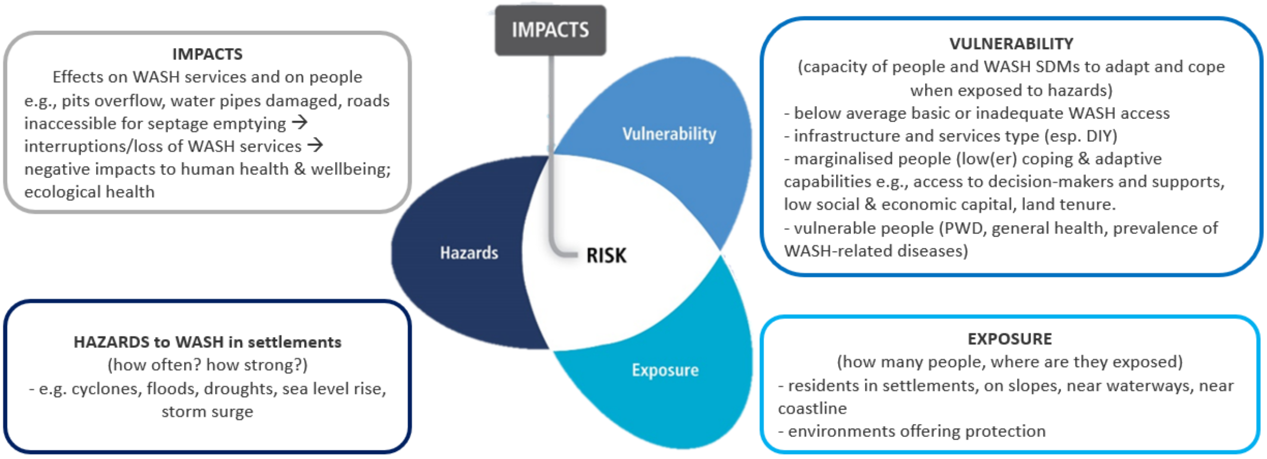

Figure 2: Dimensions of risk and how they apply to climate-related impacts to water and sanitation services

Strengths-based approaches

A strengths-based approach to enhancing water and sanitation services in informal settlements emphasizes leveraging existing tools, processes, and the expertise of professionals within planning departments and water utilities. In addition to building on existing research and grey literature, the research activities have included workshops that comprised key institutional representatives (for example Unelco, Vanuatu Department of Water Resources, the Water Authority of Fiji, the Ministry of Health and Medical Services (Fiji), UNICEF, settlement residents and civil society organisations). We identified existing spatial planning tools, hazard mapping, and local governance structures that were relevant to exploring the vulnerability and resilience of water and sanitation SDMs in informal settlements and sought to include these where possible. Research suggests that participatory approaches leveraging institutional strengths can result in more sustainable urban infrastructure solutions (Geertman & Stillwell, 2013). This methodology encourages innovation and capacity-building among both communities and institutions.

Localised Service Delivery Models in urban informal settlements in Suva and Port Vila

A range of different water and sanitation service delivery models exist in settlements, most of which are a hybrid service chain comprising some formal, recognised elements and many informal, self-managed and self-constructed elements. For example, utility water is accessed by many, but the conveyance and storage in households is self-managed. These more informal practices are where much of the vulnerabilities to external shocks lie.

In the informal settlements of Port Vila and Suva, we found water service delivery models were more externalised than sanitation, which tends to remain primarily a household responsibility. While some households reported engaging a private contractor to empty pits and tanks when they were full, a greater proportion did not empty or simply closed off full pits to start again, even in dense urban contexts. Conversely, for water services, it was far more common for households to pay for utility water than access self-supply such as groundwater or rainwater.

In Table 1 and Table 2, we describe different iterations of water and sanitation service delivery models exposed in our household survey of 395 households across Suva and Port Vila. The water SDMs were generally based around utility or self-supply (groundwater, rainwater, bottled water and surface water), and the sanitation SDMs were generally based around waterless or water-based options. As could be expected, there are limited fully pipe-transported systems in informal settlements in either city, with most expected to be fully road-transported if the sanitation service chain was fully functioning. It is noted that not all service delivery options identified should be considered adequate, safe or appropriate. A key characteristic of water service delivery models observed was the prevalence of households having or identifying a backup source in times of service interruptions or external shocks. Some examples observed during our research are shown in Figure 3 and Figure 4. We recognise there are many other service delivery models globally with different advantages and disadvantages, however we focus here on existing or conceivable in a Melanesia urban informal settlement context.

Figure 3: (a) Water stored in old fridges, Tagabe Bridge, Vanuatu (b) Water pipes after the meter in a settlement in Fiji (c) Group or "gang" meter, Efirica, Fiji (d) Shallow well in Blacksans, Vanuatu

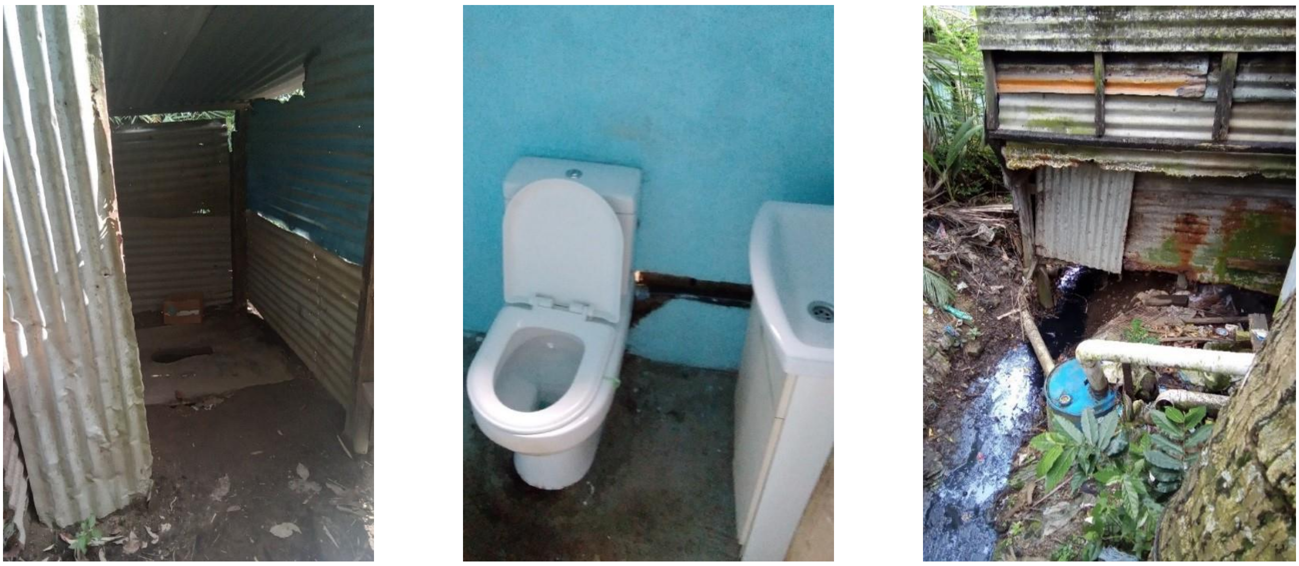

Figure 4: (a) Household pit toilet, Blacksan, Vanuatu (b) household flush toilet with handwashing basin, Korman, Vanuatu (c) Household pour-flush toilet to pit, Navcovu, Fiji (d) Waste pipes to septic tank, Nanuku, Fiji

WATER

Table 1: Water service delivery models identified in HHS

Water Source	Water Delivery Method	Water Storage	Water access point	Drainage / wastewater management	Suva	Port Vila	Potential to satisfy SDG6.1 if properly functioning?
Utility water	Utility distribution infrastructure + individual HH meter	Nil	Tap inside house	Piped out of house	Yes	Yes	Yes
Utility water	Utility distribution infrastructure + shared meter	Nil	Tap inside house	Piped out of house	Limited	Yes	Yes
Utility water	Utility distribution infrastructure + gang meter + Internal settlement pipe network	Nil	Tap inside house	Piped out of house	Yes	No	Yes – but increased chance of contamination
Utility water	Utility distribution infrastructure + gang meter + Internal settlement pipe network <25m	Nil	Tap in yard	*UNRESOLVED FROM DATA*	Yes	No	Yes – but increased chance of contamination
Utility water	Utility distribution infrastructure + gang meter + Internal settlement pipe network >25m	Nil	Tap in yard	*UNRESOLVED FROM DATA*	Yes	No	Yes – but increased chance of contamination
Utility water	Purchased in containers from neighbours and others	(buckets, bottles, makeshift tanks)	From containers	Likely nil	Yes	Yes	Unlikely – possible contamination and may not be available when needed
Rainwater	Direct capture at household	Rainwater tank	Tap on tank	*UNRESOLVED FROM DATA*	Limited	Yes	Yes
Rainwater	Direct capture at household	Containers (buckets, bottles, makeshift tanks)	From containers	*UNRESOLVED FROM DATA*	Yes	Yes	Unlikely (contamination of containers)
Rainwater	Direct capture at community building (e.g. church, hall, meeting house)	Rainwater tank	Tap on tank – residents fill containers	*UNRESOLVED FROM DATA*	Yes	Yes	Unlikely as a primary source – may not be available when needed
Groundwater - unprotected spring or shallow well	Manually retrieved and transported	Containers (buckets, bottles, makeshift tanks)	From containers	Nil observed	Yes	Yes	Yes – if properly protected and maintained
Groundwater – constructed borehole	Pump retrieval – manual capture and transport	Containers (buckets, bottles, makeshift tanks)	From containers	Nil observed	Not observed	Yes	Yes
Bottled water for drinking	Purchased from store and manually transported	Bottle	From bottle	Likely nil			Yes
Surface water	Collected from stream or river	Containers (buckets, bottles)	From containers	Likely nil	Yes	Yes	No

Sanitation

Table 2: Sanitation service delivery models identified in HHS

User interface	Collection	Storage / Treatment	Offsite Conveyance	Offsite Treatment	Use and/or disposal	Suva	Port Vila	Potential to satisfy SDG6.2 if properly functioning?
Waterless - **pedestal or squat**	Direct to unimproved pit	Containment only (likely infiltration)	Nil	Nil	Close off (cover) and construct new	Yes	Yes	Unlikely unless properly closed off
Waterless - **pedestal**	Direct to improved pit (slab / VIP)	Containment only (likely infiltration)	Road based – emptied by private truck-based contractor	Transported via road to Kinoya WWTP (Suva) or Bouffa Landfill septage treatment facility (Port Vila)		Yes	Yes	Basic or safely managed
Waterless - **pedestal**	Direct to improved pit (slab / VIP)	Containment only (likely infiltration)	Emptied by householder to nearby environment	Nil	Disposed to nearby environment or another pit. Sometimes later used for compost	Yes	Yes	Basic or safely managed
Waterless - **pedestal**	Direct to pit	Composting	UNKNOWN FROM HH DATA		*UNRESOLVED FROM DATA*	No	Limited	Basic or safely managed
Water based - **pedestal**	Uncontained	Nil	Nil	Nil	Nil	Yes	Yes	Basic
Water based - **pedestal** - **pour flush**	Pipe to pit	Infiltration	Nil	Nil	Nil	Yes	Yes	Basic
Water based - **pedestal** - **pour flush**	Pipe to septic tank	Septic tank	Road based – emptied by private truck-based contractor	Transported via road to Kinoya WWTP (Suva) or Bouffa Landfill septage treatment facility (Port Vila)	*UNRESOLVED FROM DATA*	Yes	Yes	Basic or safely managed
Water based - **pedestal** - **pour flush**	Pipe to septic tank	Septic tank	Emptied by householder to nearby environment	Nil	Disposed to nearby environment or another pit	Yes	Yes	Potentially unsafe
Water based - **pedestal** - **utility flush**	Nil	Nil	Connected to centralised sewer	Suva – Kinoya Sewage Treatment Plant	*UNRESOLVED FROM DATA*	Yes	No	Basic or safely managed
Water based - **shared toilet block** - **utility flush**	Pipe to septic tank	Septic tank	Road based – emptied by private truck-based contractor	Transported via road to Kinoya WWTP (Suva) or Bouffa Landfill septage treatment facility (Port Vila)	*UNRESOLVED FROM DATA*	No	Yes	Limited - shared
Hanging or floating toilets	Nil	Nil	Nil	Nil	Nil	No	Yes	Unsafe
Open defecation	Nil	Nil	Nil	Nil	Nil	Backup	Backup	Unsafe

Localising resilience of SDMs to climate-related shocks

Our research involved assessing the water and sanitation access of 395 households across nine informal settlements in Suva and Port Vila. This investigation included targeted survey questions to identify households that had experienced hazards impacting their systems and the resulting levels of damage. Additionally, we examined service interruptions, breakdowns, leaks, and overflows to evaluate the vulnerability of various facility types commonly used in these settlements.

The study aimed to identify factors influencing the resilience of different service delivery models in informal settlements. Water and sanitation resilience to climate change is defined as the capacity to adapt and maintain WASH services under climate-related challenges (Water for Women, 2024). Our findings revealed a significant proportion of settlement residents lacked adequate access to WASH services, and even those with access frequently experienced disruptions. These disruptions ranged from routine issues, such as damage to conveyance infrastructure, to severe shocks, including floods and cyclones.

Natural hazards are a persistent challenge in both Fiji and Port Vila, as reflected in our household data. In Fiji, the most common hazards affecting water supply systems were major storms, heavy rains, floods, and cyclones. In Port Vila, cyclones were the primary hazard impacting water systems. In most cases, residents required external assistance to resolve these issues and restore services.

In previous publications, we presented tables rating the resilience of various water and sanitation service delivery models against different natural hazards, tailored to specific geographical and environmental conditions (Sanderson et al., 2022). While these tables were primarily constructed from literature sources, our field-based research confirms their continued relevance. Moreover, we identified additional factors through our research that appeared to influence the resilience of water and sanitation facilities, particularly as reflected in the levels of damage sustained during extreme weather events.

> In the following sections, we use "**level of damage**" reported by residents as a proxy for how resilient or otherwise a water or sanitation facility was during the last extreme weather event. Levels reported included:
>
> **Minor damage** – could still use or access facility
> **Moderate damage** – limited access to facility
> **Major damage** – could not use or access facility
> **No damage reported**

WHICH HAZARDS IMPACT WATER AND SANITATION SERVICES IN SETTLEMENTS?

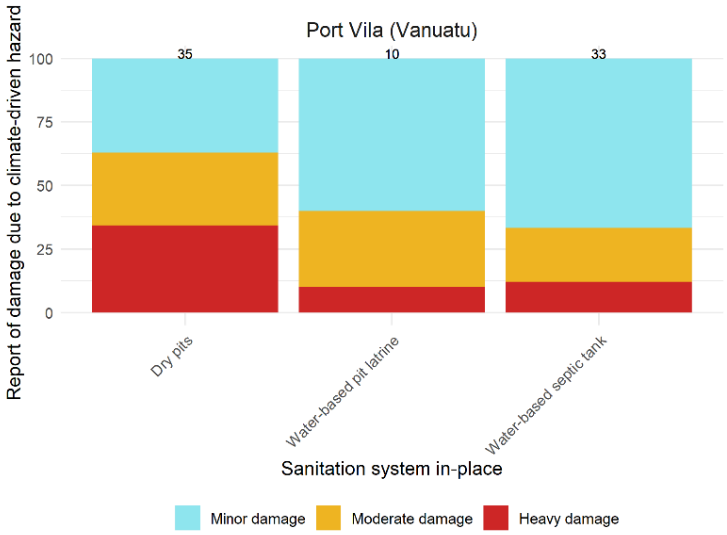

Figure 5: Damage levels of sanitation systems reported against all hazards in Port Vila

Based on household survey results, in Suva there were low reports of sanitation impacts from extreme weather hazards, except one settlement where 25% reported minor damage from floods, heavy rain or cyclones. Across the five settlements we surveyed in Port Vila, between 20-50% of each settlement reported moderate to major damage.

It is noted that most residents were likely reporting damage to their sanitation user interface, introducing a potential research bias of judging when a sanitation system "fails" from a user perspective. For example, subsurface failures or losses of containment may be more difficult for users to observe and report.

The magnitude of reported damage to water services and systems across both countries seemed to vary according to various climate hazards. Impacts from cyclones were the most commonly reported amongst residents (85 / 395 households).

Except for heavy rain, proportions of moderate and major damage were found to be higher for all hazards when the tap was located outside the household.

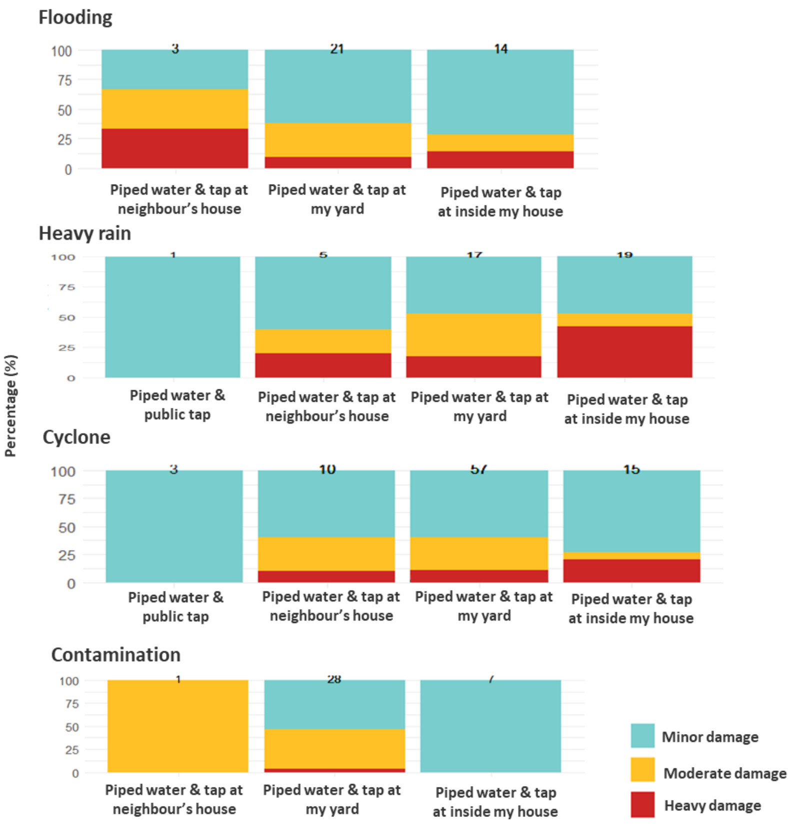

Figure 6: Different hazards and their affects (in terms of magnitude of damage) on different water service models.

Reviewing factors that might influence resilience to damage

Numerous factors influence the resilience of water and sanitation access to extreme weather events and climate change, many of which interact and amplify vulnerability or exposure. Underlying economic and social determinants—such as household socio-economic status, educational attainment, social cohesion, and the strength of social networks—form part of this complex web (Aihara et al., 2018; Balaei, Noy, Wilkinson, & Potangaroa, 2021; Balaei, Wilkinson, Potangaroa, Adamson, & Alavi-Shoshtari, 2019; Elliott et al., 2019). It is important to note that individual or household preferences for different water and sanitation services play an important role in ensuring long-term sustainability.

Vulnerability: *the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed and its sensitivity.*

Exposure: *The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.*

Source: IPCC 2007

Building on previous investigations into informal settlements in Melanesia (Sanderson et al., 2022; Souter & Orams, 2019), our research examined a set of factors that influence WASH resilience, commonly observed in this context and emergent from the current research.

Facility type

In both cities, residents relying on boreholes, shallow dug wells, and surface water sources reported the highest proportions of moderate and major damage (Figure 5). However, it is noteworthy that damage was reported across all water sources, with the exception of one household that purchased water in containers. Households accessing water from outside their home (either in their yard or beyond it) were more likely to report some level of damage compared to those accessing water from within their home (Figure 6). However, among residents with access to water inside their homes, a higher proportion reported major damage.

Regarding sanitation facilities, pit toilets—particularly dry pit toilets—were found to sustain the highest levels of damage among all facility types (Figure 7). This may be further related to superstructure condition (discussed below) and the socio-economic status of residents that rely on pit toilets (and therefore may have lower overall levels or resilience). Further compounding the issues around inadequate sanitation services, around 10% of respondents had a misunderstanding of the system they use. The most common mismatch was perceiving a pit as a septic tank.

Water quality analysis conducted across a select number of water sources in settlements in Port Vila revealed that:

- surface waters (river) exhibited the highest level of total faecal coliforms (a marker of faecal contamination) compared to rainwater tanks, groundwater and utility sources.
- Rainwater and groundwater sources exhibited similar levels
- Utility tap water mostly exhibition no concentration of total faecal coliforms, with the occasionally spike in the wet season, making it the safest in terms of quality of the sources tested.

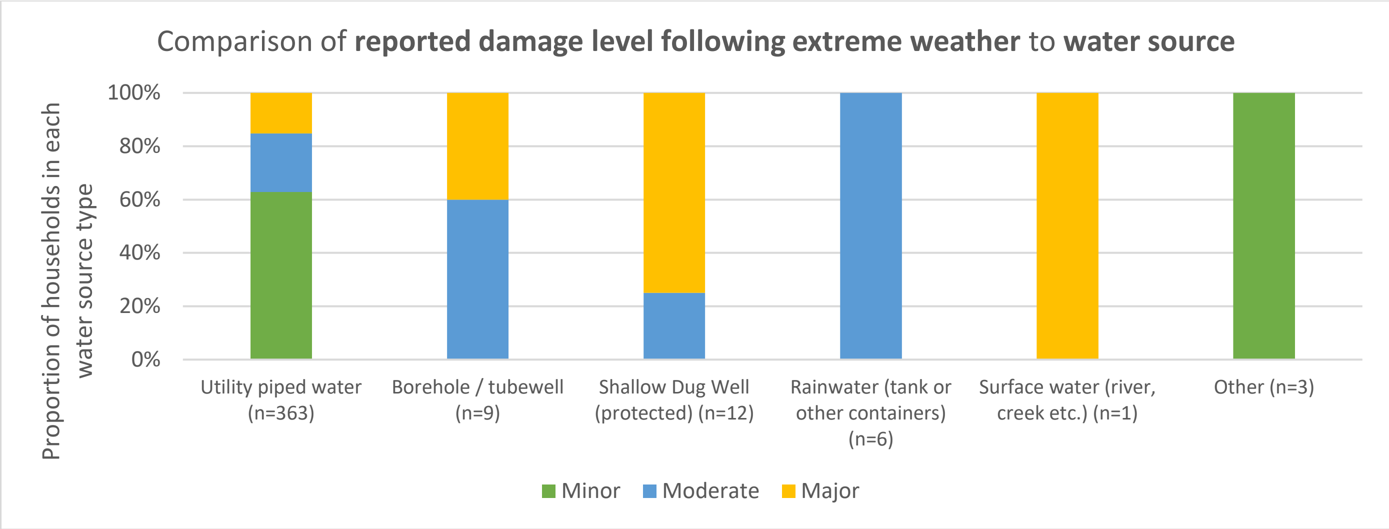

Figure 7: Including only those households that had experienced an extreme weather event that affected their water or sanitation access, utility piped water showed the highest proportion of minor damage compared to other sources.

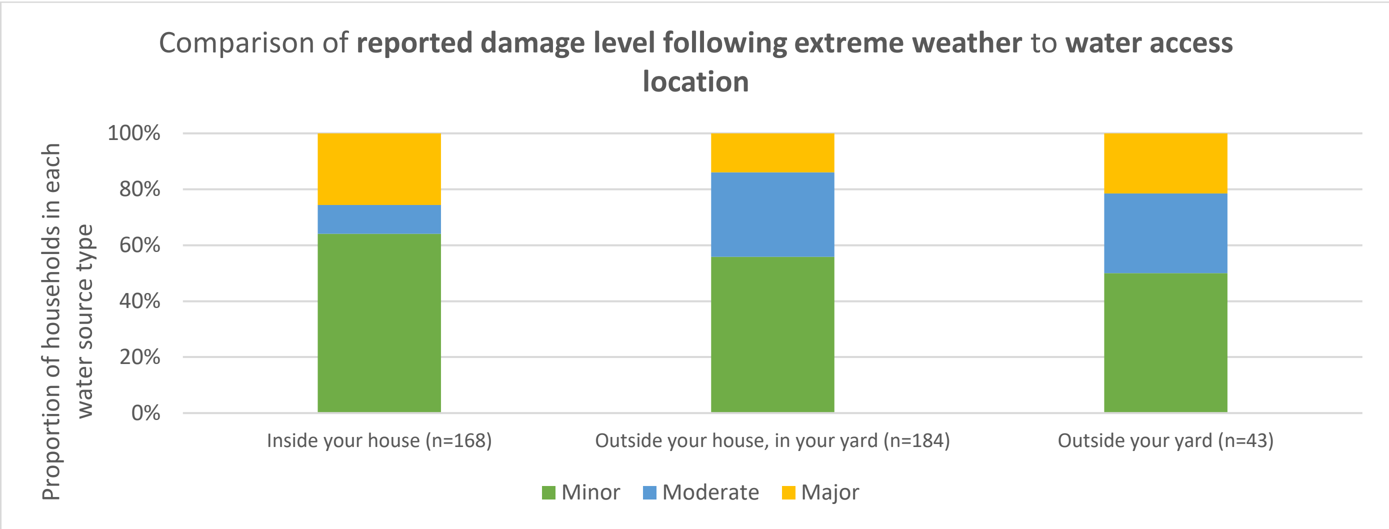

Figure 8: Including only those households that had experienced an extreme weather event that affected their water or sanitation access, higher levels of damage overall were reported for access points outside the house, although a higher proportion of major damage was reported for water piped to the house.

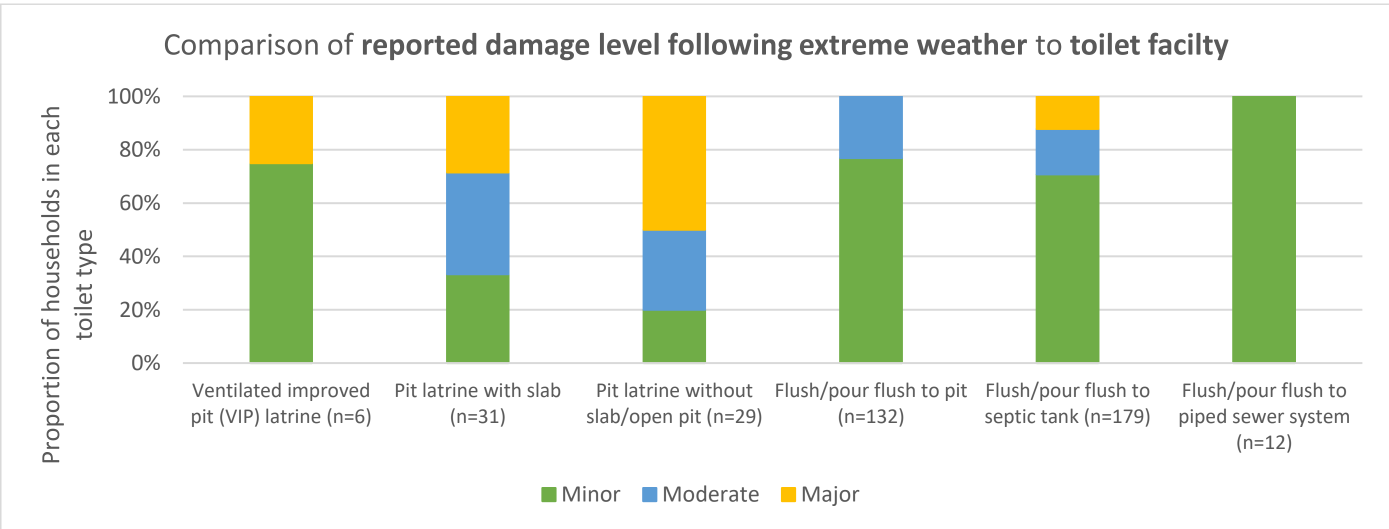

Figure 9: Including only those households that had experienced an extreme weather event that affected their water or sanitation access, pit latrines of all types showed higher levels of damage.

Prevalence of sharing of facilities

The sharing of water and sanitation services is a prevalent practice in informal settlements in Suva and Port Vila, manifesting in various ways, such as shared infrastructure, shared costs and bills, or shared distribution networks. Our survey indicated that nearly 60% of residents shared their piped water connections with other households, while approximately 30% of households with toilets reported sharing these facilities. Sharing rates were notably higher in Port Vila compared to Suva, particularly for sanitation access. For both water and sanitation services, sharing—whether with family members or unrelated individuals—was associated with an increased incidence of moderate and major damage following extreme weather events, compared to minor damage (Figure 8).

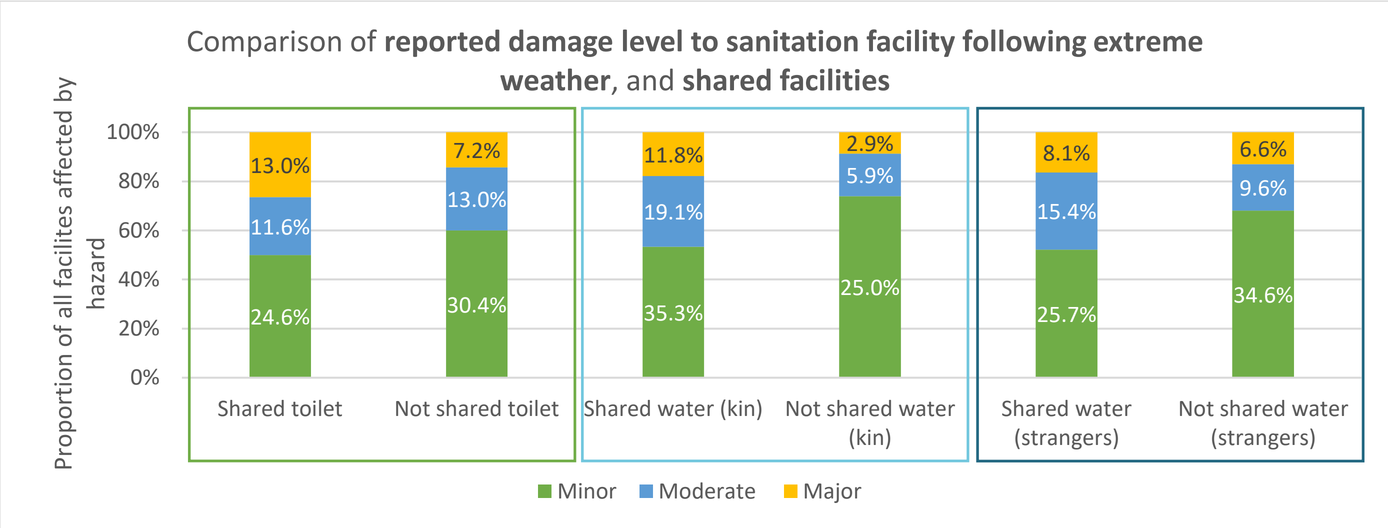

Figure 10: Including only those households that had experienced an extreme weather event that affected their water or sanitation access, prevalence of sharing of those facilities appeared to influence the level of damage sustained.

Superstructure condition – sanitation user interface

As part of our household survey, we obtained consent to photograph the toilet superstructures of the surveyed households. These photographs were utilized to conduct a subjective rapid condition assessment based on predefined criteria, including floor and wall materials, the presence of a door, and any visible damage or holes. Subsequently, we compared the reported levels of damage following extreme weather events with the observed condition of the toilet superstructures (Figure 9). Our analysis revealed a general trend: poorer structural conditions were associated with higher levels of damage sustained.

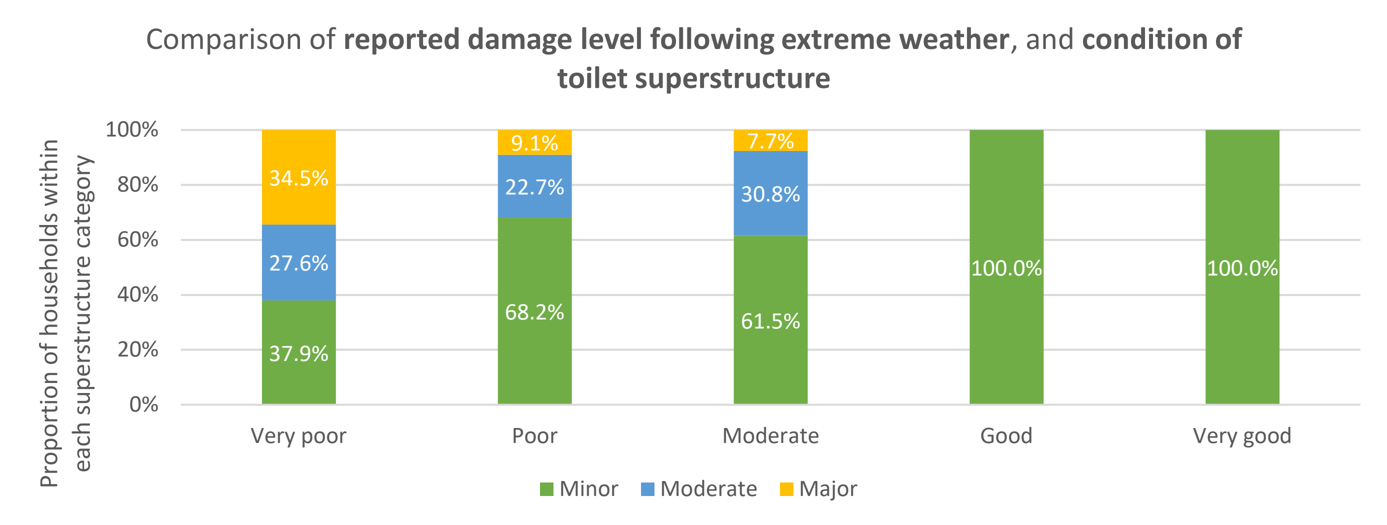

Figure 11: Superstructure condition for households that had experienced extreme weather, and the resultant level of damage sustained by their sanitation facility.

Land tenure status

In interviews, anecdotal evidence suggested that the tenure status of the land occupied by residents of informal settlements influenced the timing and extent of household investments in permanent water, sanitation, and hygiene (WASH) infrastructure. However, our analysis comparing land tenure types with the extent of damage to water and sanitation facilities did not reveal a consistent trend. While sanitation facilities on resident-owned or freehold land generally exhibited lower levels of damage, water facilities across all land tenure types demonstrated similar proportions of damage (Figure 10 and Figure 11).

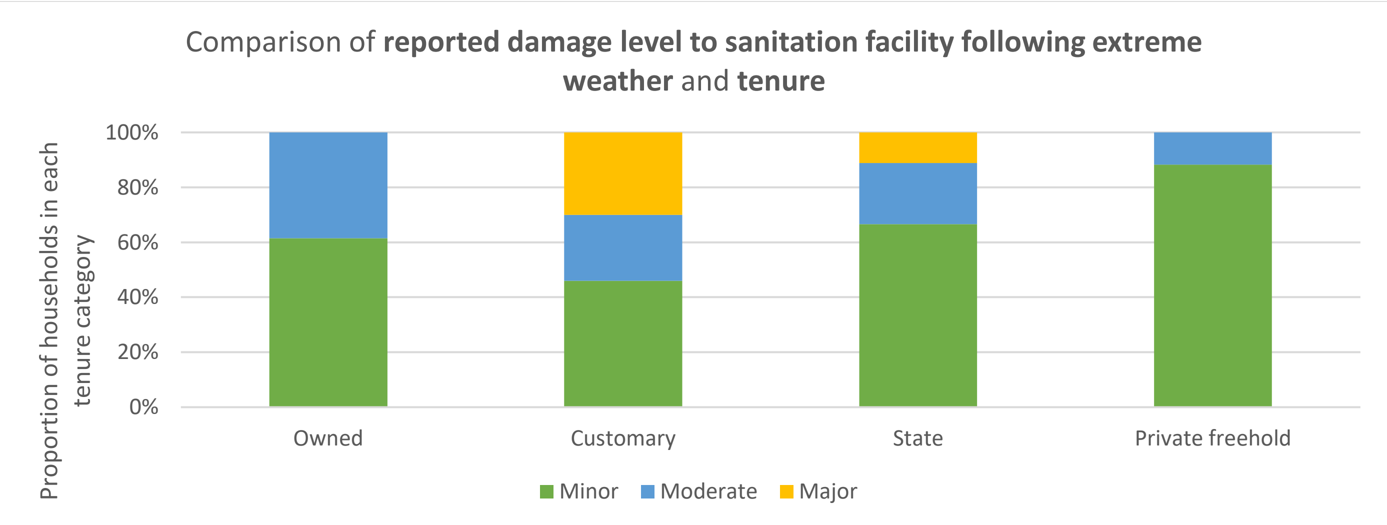

Figure 12: Land tenure status for households reporting exposure to different extreme weather events. Sanitation facilities located on land owned by the residents appeared to sustain lower levels of damage.

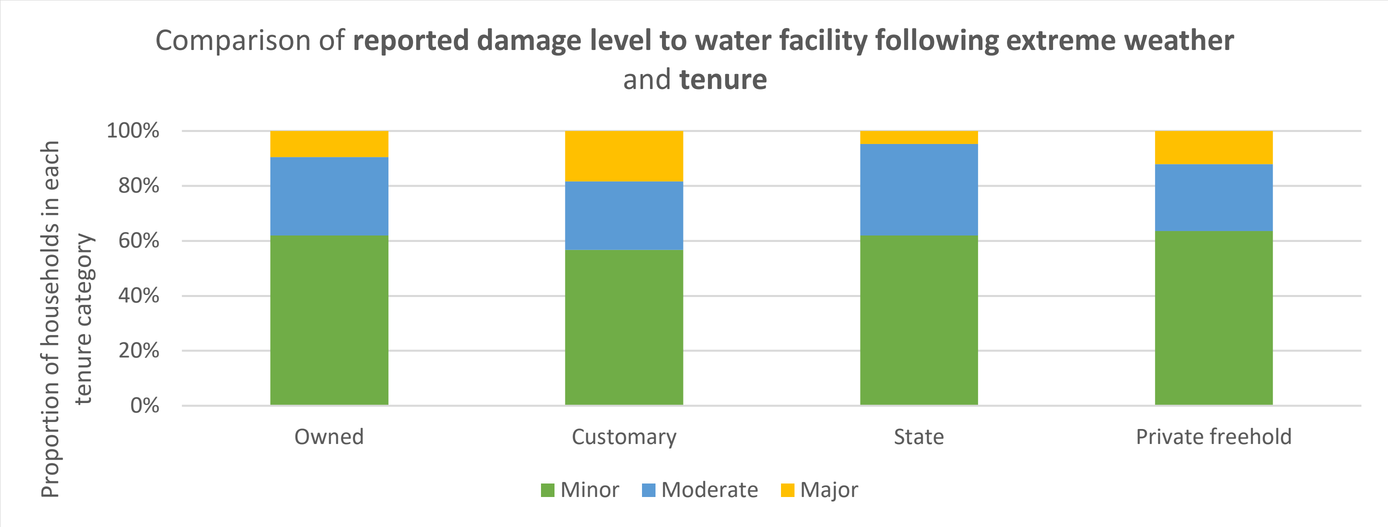

Figure 13: Land tenure status for households reporting exposure to different extreme weather events. Households with all tenure types reported similar proportions of damage to water facilities.

Household distance from the water meter

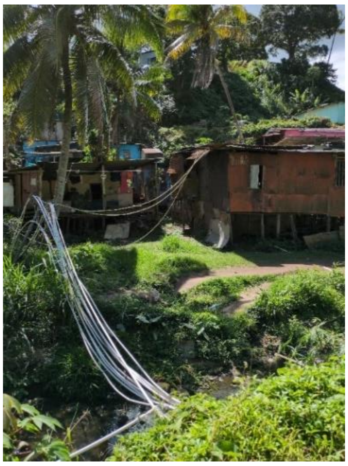

Figure 14: Settlement internal pipe networks overcoming a topographical barrier

Our research methods revealed that, particularly in settlements in Suva, Fiji, a prevalent water service delivery model involved utility water being conveyed to a cluster of water meters at the settlement's boundary. Individual households then conveyed the water via small diameter pipes to their respective access points. This arrangement resulted in pipe lengths of between 3m and 300m from the water meter to the house, with an average of nearly 100m among the 41 households surveyed.

Regardless of the length of pipe, these conveyance networks were predominantly self-installed and exposed to numerous hazards. Many pipes were not buried or properly maintained, and physical barriers such as waterways were often circumvented by precariously elevating sections of the pipes (Figure 12). Reports of damage and deterioration were common. In addition to the overall length, key hazard factors identified during the transect risk assessment included pipe level, obstacles around the pipe, pipe depth, accessibility to the pipe, and pipe condition.

During our risk assessment transect walk, we categorized hazard factors into flooding hazards, operation and maintenance hazards, physical hazards, solid waste hazards, and toilet hazards. Each of these categories was considered likely to impact the overall safety and accessibility of a reliable, uninterrupted water service. When all hazard categories were assessed collectively, higher levels of risk were generally observed with longer pipe lengths. When assessed individually, physical hazards and toilet hazards were the most likely categories to worsen as the pipe length increased along the transect.

Backup water sources

A range of backup water sources were confirmed by residents when they experienced disruptions to their regular (normally piped water) service. We found 20% of households surveyed had experienced an interruption to their water service in the last month, and more than 40% experienced this at least multiple times every year. Almost 10% of households experienced disruptions more frequently than monthly.

Approximately half of all households nominated a backup water source they accessed during primary water interruptions, although only one-third reported they regularly accessed multiple sources. Backup sources commonly included rainwater, piped utility water from a neighbour, trucked water from the utility or from a private seller, bottled water and surface water. As previously discussed, surface water sources are likely to be less resilient and more contaminated than other sources. Notably, the proportion of households accessing unimproved water sources as a backup increased from 1% as a primary source to more than 5% of households surveyed.

Some households are forced to pay exorbitant prices for backup water from private sellers in times of supply disruption. No households nominated a paid service as their primary water source (apart from utility piped water), while almost 10% revealed they paid for water during interruptions, whether in bottles, containers or trucks. One resident in Port Vila reported paying 250 vatu for a 200L drum, which is the equivalent of 10 times as much as the price for utility supplied water[1].

Access to backup sources is essential during water service interruptions. However, challenges with respect to contamination and associated health risks; reliability and reliance on weather conditions or road access; and increased costs should be considered by decision-makers and residents.

Distance to nearest road

For both water and sanitation facilities that sustained damage following extreme weather events, a range of distances of households to the nearest road were represented in each damage level category (Figure 13and Figure 14). A slight trend can be seen indicating households further from roads sustained higher levels of damage for water facilities, and the sanitation facilities furthest from roads generally sustained higher levels of damage.

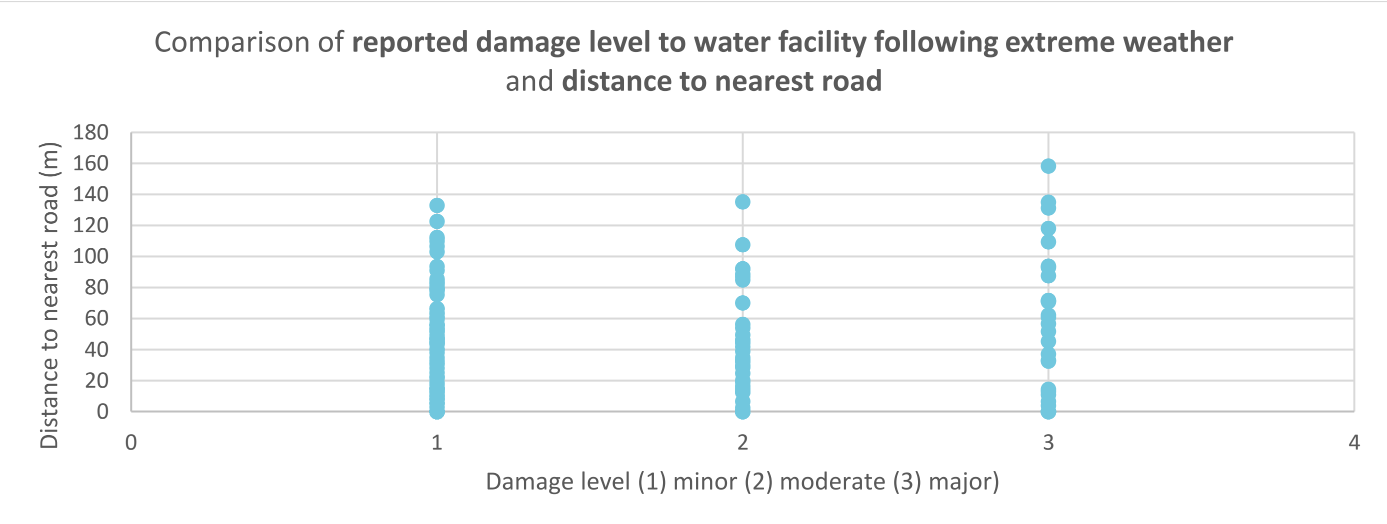

Figure 15: All households surveyed showing their distance to the nearest road and the level of damage sustained to water facilities following extreme weather.

[1] UNELCO rates are 240vatu per month for 2ML of water. For the same amount per month a resident would need to purchase 10 drums, for a total of 2,500 vatu.

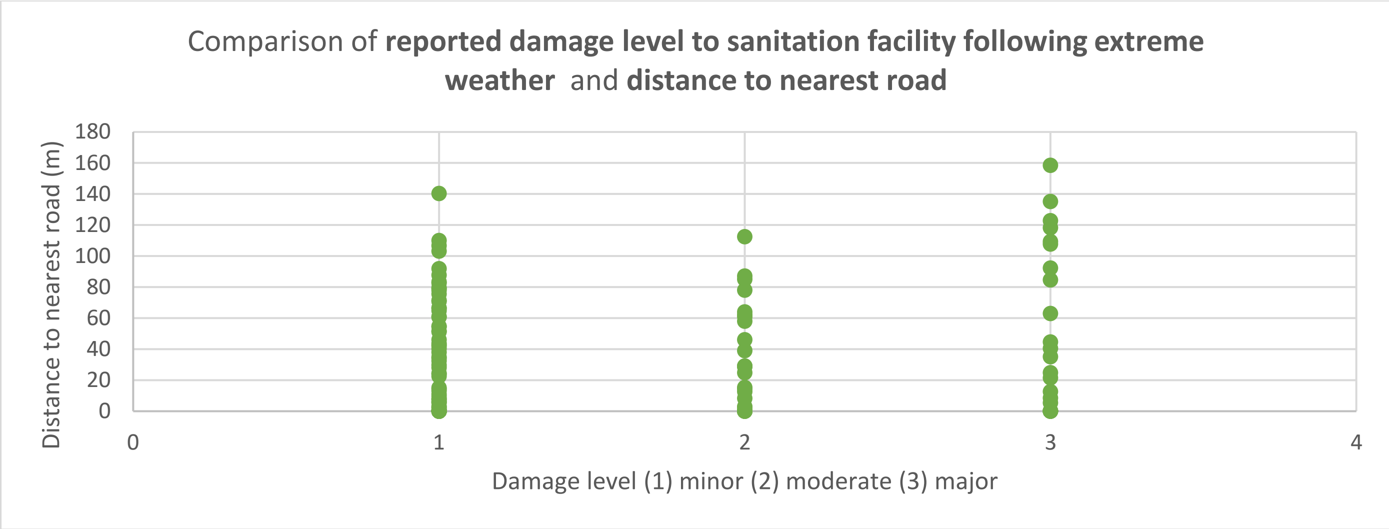

Figure 16: All households surveyed showing their distance to the nearest road and the level of damage sustained to sanitation facilities following extreme weather

Distance to coastline

In Port Vila, of the eight households surveyed within 100 meters of the coastline, only one reported minor damage to water facilities, and no households reported any damage to their sanitation facilities during extreme weather events.

In Suva, no households were surveyed within 100 meters of the officially recognized coastline. However, the settlement of Veidogo is located adjacent to coastal mangroves influenced by tidal activity, and all households in this settlement are within 100 meters of the mangrove area. Among the 29 households surveyed in Veidogo, seven reported minor damage and one reported major damage to their water facilities following extreme weather events. Additionally, seven households reported minor damage to their sanitation facilities.

Figure 15 and Figure 16 show households' distance from the coast compared to the damage level sustained to their water or sanitation facilities after extreme weather. EVALUATE HERE

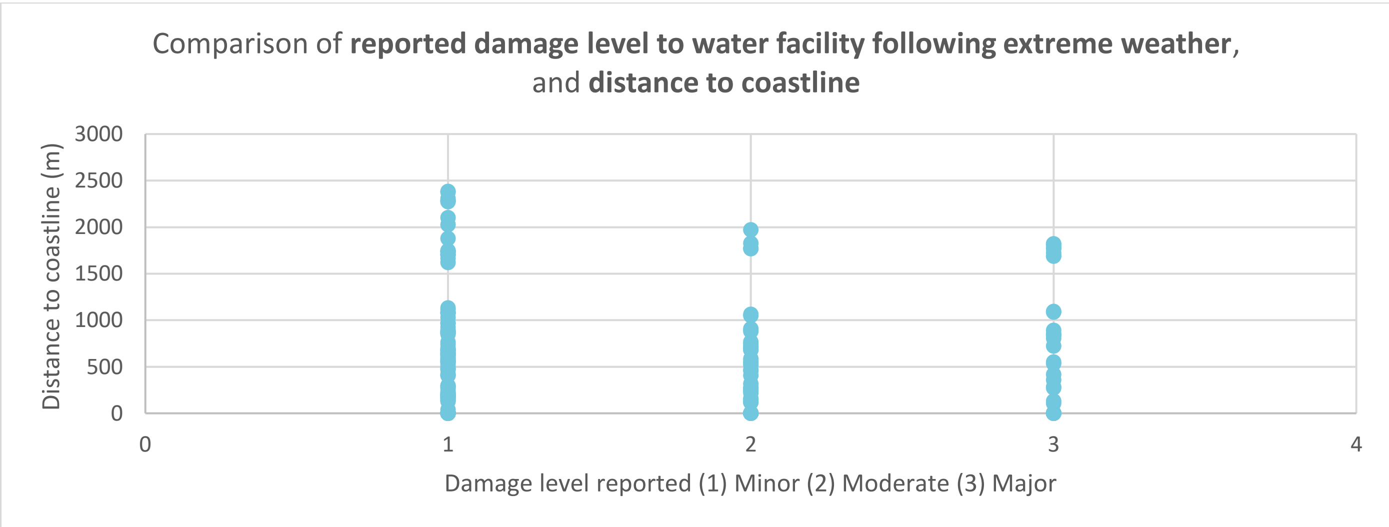

Figure 17: All households surveyed showing their distance to the nearest coastline and the level of damage sustained to water facilities following extreme weather

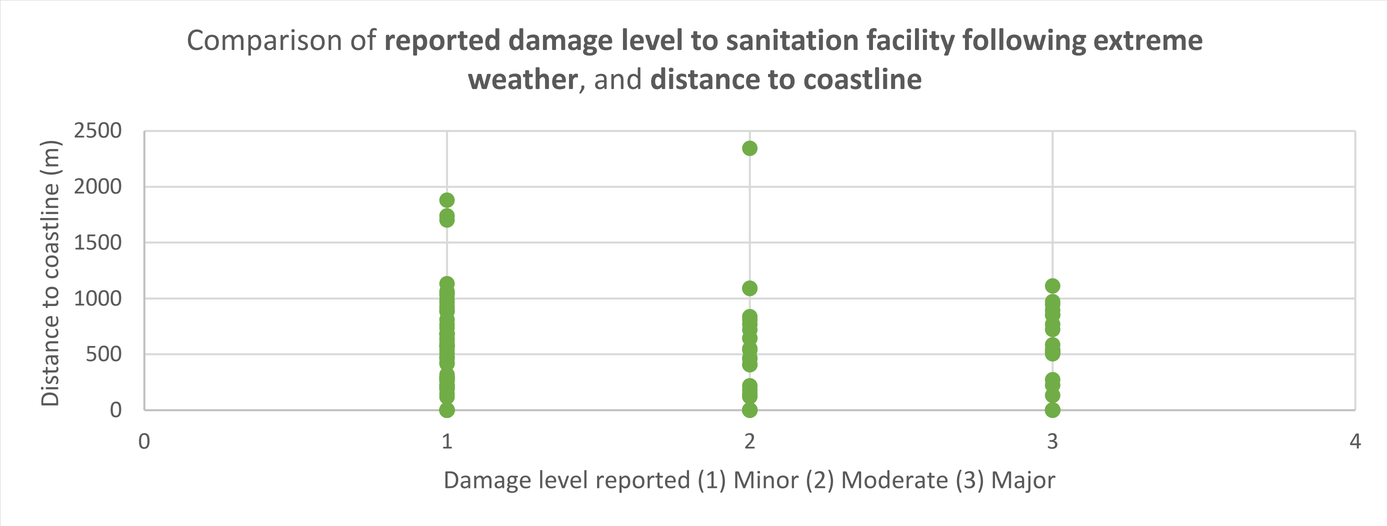

Figure 18: All households surveyed showing their distance to the nearest coastline and the level of damage sustained to sanitation facilities following extreme weather

Proximity to waterways

In Port Vila, among the six households surveyed within 50 meters of a recognized waterway, 50% reported major damage to their water facilities, while one household reported moderate damage and one reported minor damage. Regarding sanitation facilities, two households reported major damage, two reported moderate damage, and two reported no damage resulting from extreme weather events.

In Suva, of the 28 households located within 50 meters of a waterway, only three reported minor damage to their facilities, while the remaining households reported no damage following extreme weather events.

Steep topography

In Port Vila, among the three households surveyed on steeply sloped land (greater than 26 degrees), one household reported minor damage, one moderate damage, and one no damage to their water facilities due to extreme weather events. For sanitation facilities, one household reported major damage, one minor damage, and one no damage attributed to such events.

In Suva, of the five households surveyed on steeply sloped land, all reported no damage to their facilities following extreme weather events, with the exception of one household that experienced minor damage to its water facility.

Applying these factors

The factors discussed affect the vulnerability or exposure of household water and sanitation facilities in informal settlements in Suva and Port Vila. Addressing some or all of these factors will increase the resilience of these services and the households which rely on them. These ten factors are summarised in Table 3. Key to addressing these factors is the availability and application of place-based and localised information and data, combined with data on a larger scale, that can assist with decision-making.

Table 3: Review of factors affecting resilience of water and sanitation services in Port Vila and Suva

Factor	Vulnerability	Exposure
Facility type	Inadequate or flimsy infrastructure increased chance of damage during events. Pit toilets, groundwater, surface water sources most likely to be damaged	
Shared facilities	Sharing of both water and sanitaiton facilities decreased the prevleance of minor damage in favour of those facilities sustaining moderate or major damange.	
Superstructure condition	Inadequate or flimsy infrastructure increased chance of damage during events	
Land tenure	Decreased coping ability as less access to decision-makers (e.g. landlords, renters protections) when land tenure is insecure.	Increased exposure as a greater number of residents may be less likely to invest in secure and resilient WASH.
Distance from water meter		Increased expsoure of infrastructre (particularly pipe distribution network) to damage, leakage and contamination.
Backup water sources	If backup water sources are unsafe, vulnerability is increased during interruptions of primary services. If backup sources are safe, can increase resilience during shocks and events.	A greater number of sources used can increase the exposure of those sources to a variety of hazards.
Distance from nearest road	May reduce likelihood of emptying sanitation containment, increasing vulnerability to pits and tanks overflowing during events.	
Distance to coastline		Increased exposure to tidal surge, sea level rise, and effects of cyclones
Proximity to waterways		Increased exposure to flooding
Steep topography		Increased exposure to landslips and impacts from heavy rain and cyclones

Figure 19: Household toilet and water supply pipes in a settlement in Suva, Fiji (Regina Souter, IWC, 2024)

Tools and approaches to apply localised and place-based vulnerability and hazard information to selecting WASH SDMs

Decision-making tools can play an important role in determining suitable water and sanitation service delivery models for informal settlements. These tools provide a structured way to assess environmental, social, and infrastructural factors, helping stakeholders make informed choices that reflect local realities. With an increasing amount of global and national data now available on climate hazards, vulnerabilities, and exposure, these tools can be used to develop models that are more responsive to the challenges faced by communities, both now and in the future.

Equally important is the integration of local knowledge and community-led initiatives into this process. Residents of informal settlements have deep, practical insights into the issues they encounter, from seasonal flooding and water scarcity to cultural norms around sanitation. Including their perspectives not only ensures that solutions are practical and relevant but also builds trust and ownership within the community, making long-term success more likely.

When used in conjunction with urban planning, decision-making tools can help align water and sanitation improvements with broader city development goals. This allows for coordinated efforts that consider land use, environmental sustainability, and infrastructure needs. By embedding these tools into planning frameworks, cities can better support the development of resilient and inclusive service delivery systems that address the complex realities of informal settlements.

Spatial tools

The research identified types of data useful in assessing and planning, across a city, water and sanitation services (Figure 20). These datasets represent different components of the IPCC's Climate Risk framework, and so are helpful in identifying water and sanitation services that decrease the vulnerability of residents in urban informal settlements to climate. The practical application of diverse and locally specific data is made easier with the use of Geographical Information Systems (GIS). Such systems allow for city-wide analysis, that recognises local variability. In particular GIS will support city-wide planning of service options, ensuring that all parts of the city have access to safe and resilient service options.

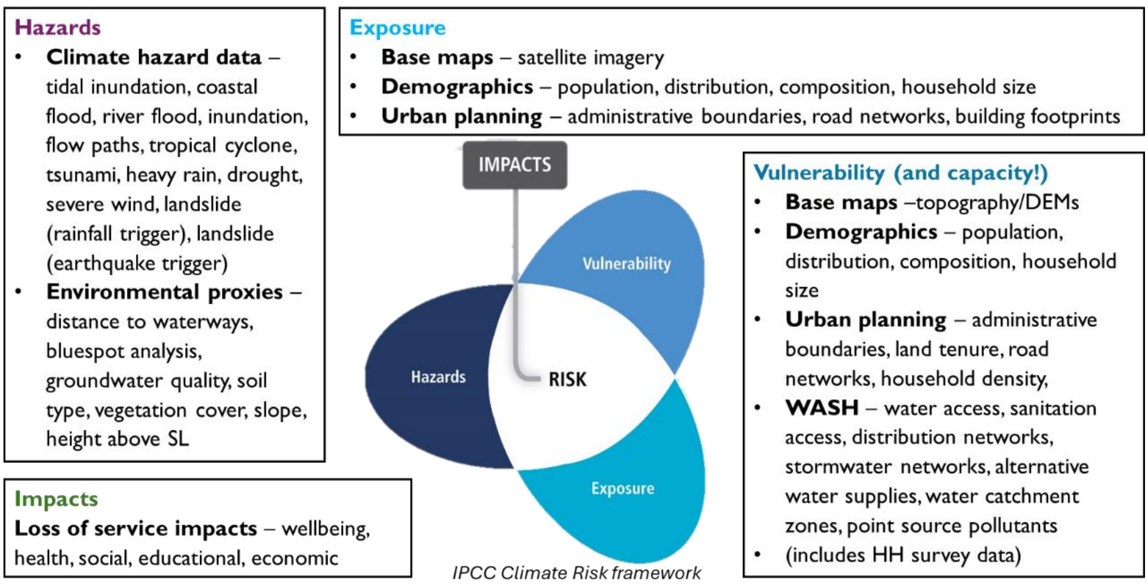

Figure 20: Spatial datasets helpful to understand climate risks associated with water and sanitation services, in local areas

Participatory GIS

Previous research conducted by the International Water Centre (IWC) in informal urban settlements in Suva, Fiji, highlighted the significant vulnerability of water and sanitation systems in these areas to the impacts of wet weather events exacerbated by climate change. This research revealed a low level of resilience in these systems. However, there remains a notable gap in documented spatial information about hazard-prone areas and their connection to impacts on water and sanitation infrastructure.

To bridge this knowledge gap, a participatory mapping activity using Geographic Information Systems (P-GIS) was undertaken. This initiative aimed to collect and consolidate local knowledge on the effects of wet weather events through active community engagement.

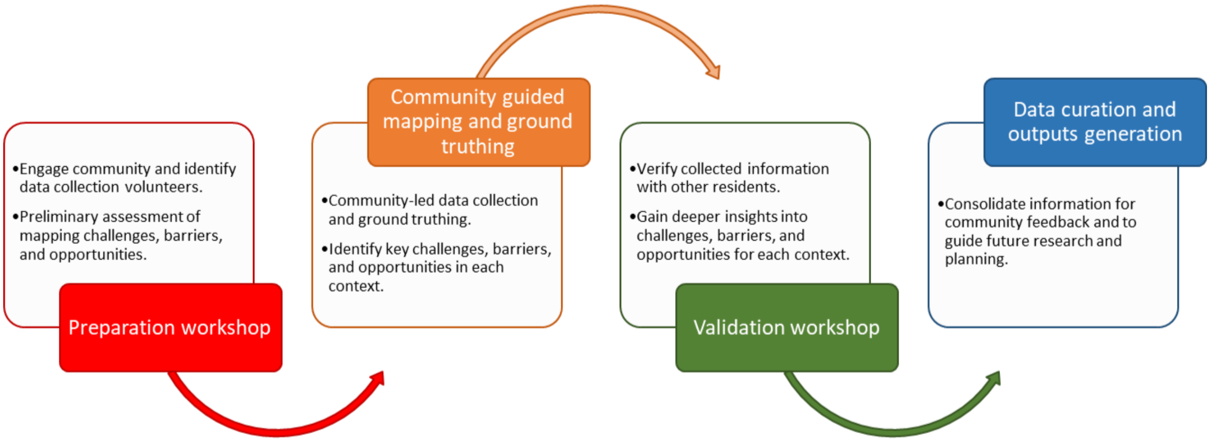

Figure 21: Methodology for Participatory GIS approach

Data collection was conducted using Survey CTO forms on tablets with internet connectivity. Points of interest were categorized into three key areas: ground-truthing hazards, mapping critical infrastructure, and identifying damage affecting water, sanitation, and hygiene (WASH) services. Metadata for each point included information such as flood height, the type of infrastructure (e.g., gang water meters, critical WASH service points, communal gathering spaces), and the extent of damage to WASH services. Photographic documentation of the areas was captured using the tablets, and qualitative data on impacts, challenges, and potential solutions were gathered through conversations with residents.

For instance, when this approach was piloted in two settlements in Suva, Fiji, the identified challenges included issues such as flooding dislodging pipes, landslide-prone areas, river contamination, and concentrated meter placement limiting access. Additional barriers included land tenure disputes that hindered the Water Authority of Fiji's ability to carry out repairs, resource constraints, and inadequate planning of shared spaces. Workshop participants highlighted opportunities to address these challenges, focusing on community organization, behavioural changes, and enhancing the resilience of water supply systems.

Figure 22: Using the participatory GIS mapping tools in an informal settlement in Suva, Fiji. Participants included residents, water utility and government representatives, and researchers

Machine learning models to predict risk of damage

As part of the broader study, we explored a novel approach to assessing the vulnerability of WASH (water, sanitation, and hygiene) infrastructure in informal settlements across Melanesia, focusing on Fiji and Vanuatu using spatial information. Employing a Random Forest machine learning model, the research integrates household survey data, synthetic records, and geospatial hazard information to predict potential infrastructure damage from natural hazards such as cyclones, floods, and sea level rise. By analysing these risks, the model identifies variations in damage probabilities based on infrastructure type, hazard exposure, and local context, contributing critical insights into infrastructure resilience.

This predictive model aims to address challenges unique to informal settlements, where limited formal infrastructure exacerbates vulnerabilities to climate-related hazards. The approach sought to demonstrate the efficacy of combining high-resolution spatial data with community-level insights to enhance predictive accuracy, even in data-scarce environments. The risk of failure model was developed using machine learning techniques based on a Random Forest algorithm, remote sensed hazard datasets and household survey undertaken as part of the broader project. The pilot study area encompassed informal settlements in the Port Vila region, Vanuatu, and the west side of Fiji's largest island Viti Levu, where the capital, Suva, is located. Figure 23 provides a summary of the pilot study method.

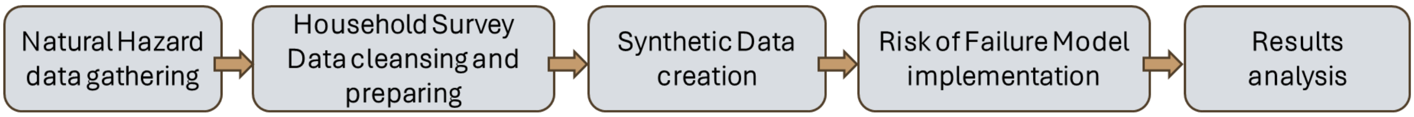

Figure 23: Flowchart of the risk of failure model development

The findings highlighted the disparities in resilience between different WASH systems, such as piped water networks and septic tanks, revealing specific weaknesses that policymakers and planners must address to improve service delivery in high-risk areas.

Aligned with the principles of inclusive and localized urban planning, this work underscored the importance of participatory approaches in building climate-resilient WASH systems. Through this activity, we validated the potential of machine learning in identifying infrastructure vulnerabilities and also highlighted the potential of scalable applications that can guide evidence-based decision-making.

Localised resilience framework

Decision support tools that assist decision-makers in selecting and promotion water and sanitation service delivery models for particular contexts and geographies should include localised information regarding vulnerability and resilience. Ideally, when selecting appropriate SDMs for a region planning agencies would take specific hazards and vulnerabilities into account, however in the absence of detailed data and mapping of such elements, environmental and geographical features, such as distance from waterways, hillside and coastal areas, can be useful proxies.

> **Climate-resilient WASH should:**
>
> **F ==> be designed, maintained, and operated to remain FUNCTIONAL under stress & shocks**
>
> **A ==> be ADAPTIVE – managers, services providers and users learn about relevant risks and responses, and apply lessons**
>
> **C ==> maintain and (where needed) buffer CONNECTIVITY (geographical & social)**
>
> **E ==> be EQUITABLE, in recognition that existing vulnerabilities can exacerbate impacts.**
>
> **D ==>have DIVERSITY and REDUNDANCY built into WASH services**
>
> *Adapted from Biggs, Schlüter, and Schoon (2015)*

As an example, in a series of matrices, published in 2022 as part of this research, we followed Howard, Bartram, and Organization (2010) and Fleming et al. (2019) to provide a qualitative assessment of the relative resilience of different SDMs based on vulnerability and adaptability (Sanderson et al., 2022). A rating of "high" denotes a service delivery model with greater resilience and suitability under the conditions and likely hazards. These tables are included from reference in Annex 1.

"All hazards approach" and place-based specifics checklist

The "all-hazards approach" to disaster risk reduction addresses a wide range of risks, including natural, technological, and human-induced hazards, to ensure comprehensive preparedness and resilience. Most water and sanitation systems in informal settlements are vulnerable to multiple hazards, such as floods, cyclones, and infrastructure failures, which can compound vulnerabilities. Strategies that enhance resilience to one hazard—such as strengthening infrastructure or improving water storage—often simultaneously improve resilience to others. In informal settlements in Suva and Port Vila, this approach can guide the creation of a place-based checklist tailored to local conditions. Such a checklist would account for environmental and socio-economic factors while promoting measures that reduce exposure and vulnerability across various hazards, ensuring essential WASH services remain functional in the face of diverse challenges. An example of such a checklist that draws on the findings of our research activities is included in Table 4. It is expected that water utilities or responsible departments would include additional relevant checks.

Table 4: Place-based resilience checklist

SERVICE DELIVERY MODEL	CHECKS	RISK MITIGATIONS
Utility water piped to settlement	☐ Are there significant topographical impediments to pipe networks inside the settlement (such as valleys, steep embankments, streams etc) ☐ Are households connecting long distances (25m or more) from water meter? ☐ Who is responsible for the planning, installation, and operation & maintenance of internal settlement pipe networks? ☐ Are households sharing meters, water bills, or access points? ☐ Are water access points inside or outside the house?	Utility technicians may be needed to: - Assist with planning, design and layout of internal settlement pipe networks if group meter stations are installed - Conduct more routine checks on internal settlement pipe networks for damage and leakage. - Provide guidance and standards for pipe installation
Rainwater harvesting	☐ Are appropriate storage vessels (rotomould, concrete, steel tanks) being used instead of repurposed containers? ☐ Are storage vessels being cleaned and maintained (taps, mesh covers, soaks) ☒ Are collection and conveyance infrastructure sufficient, cleaned and maintained (e.g. roofs, gutters, downpipes)	Water utilities and water departments could consider targeted water tank subsidy programs across vulnerable populations in settlements. Conduct targeted awareness campaigns for appropriate use and maintenance of urban rainwater systems (CSOs, NGOs, WU & WDs)
Local use of groundwater	☐ Is it within a flood-prone area? ☐Does the well or spring have protection, including, if applicable, raising the access point with a sealed concrete cover? ☐ Is the water retrieval mechanism safe, cleaned and secure? ☐ Are groundwater contamination risk factors considered (i.e. proximity of below-ground sanitation, animal husbandry, surface water ingress potential)?	Water utilities and water departments may need to extend registration of bores and wells to urban environments, and conduct semi-regular monitoring of the water resources to ensure ongoing acceptability and reduce risks from contamination.

SERVICE DELIVERY MODEL	CHECKS	RISK MITIGATIONS
Backup water sources	☐ What are the backup water sources are available to residents, and what are their preferences? ☐ Are water service interruptions regular enough to encourage backup water sourcing such as household water tanks? ☐ Is the settlement located close to a river or waterway? ☐ Are residents likely to be or currently being exposed to predatory or exploitative pricing for backup water access? ☐ Are there options for managed community backup water sources?	Water utilities and local governments potentially have a role to play in advocating for residents to have backup water sources. This may extend to provision of tank subsidies or promotion activities as previously discussed. Bylaws may be required to regulate the price of non-utility water being sold for profit.
Sanitation user interface	☐ Is the superstructure built with strong and durable materials? ☐ In flood-prone areas, are the toilet and superstructure raised above flood-level? ☐ Are households sharing toilets or latrines?	
Emptying of sanitation containment units	☐ Is there a need to empty the containment unit? If not, what is the mechanism for managing the unit when full? ☐ Does the containment unit have appropriate access from the road or via pipes to be emptied via a sucker truck or other appropriate means? ☐ Are sanitation emptying service operators including in disaster risk reduction and emergency planning activities? ☐ Are residents aware of the benefit of emptying containment units, in particular in preparation for extreme rainfall events?	Sanitation emptying service providers are a key stakeholder at all stages of the extreme weather and disaster management cycle, and should be included in planning and made aware of their role. For example, service providers may be invited to WASH Sector Working groups, if they exist.

References and further reading

Aihara, Y., Shrestha, S., Rajbhandari, S., Bhattarai, A. P., Bista, N., Kazama, F., & Shindo, J. (2018). Resilience in household water systems and quality of life after the earthquake: a mixed-methods study in urban Nepal. *Water Policy, 20*(5), 1013-1026. doi:10.2166/wp.2018.117

Balaei, B., Noy, I., Wilkinson, S., & Potangaroa, R. (2021). Economic factors affecting water supply resilience to disasters. *Socio-Economic Planning Sciences, 76*, 100961.

Balaei, B., Wilkinson, S., Potangaroa, R., Adamson, C., & Alavi-Shoshtari, M. (2019). Social factors affecting water supply resilience to disasters. *International Journal of Disaster Risk Reduction, 37*, 101187.

Biggs, R., Schlüter, M., & Schoon, M. L. (2015). Principles for building resilience: sustaining ecosystem services in social-ecological systems.

Elliott, M., Foster, T., MacDonald, M. C., Harris, A. R., Schwab, K. J., & Hadwen, W. L. (2019). Addressing how multiple household water sources and uses build water resilience and support sustainable development. *npj Clean Water, 2*(1), 6. doi:10.1038/s41545-019-0031-4

Fleming, L., Anthonj, C., Thakkar, M. B., Tikoisuva, W. M., Manga, M., Howard, G., . . . Bartram, J. (2019). Urban and rural sanitation in the Solomon Islands: How resilient are these to extreme weather events? *Science of the Total Environment, 683*, 331-340.

Geertman, S., & Stillwell, J. (2013). Introduction to 'Planning Support Systems for Sustainable Urban Development'. In (Vol. 195, pp. 1-18).

Howard, G., Bartram, J., & Organization, W. H. (2010). *Vision 2030: the resilience of water supply and sanitation in the face of climate change: technical report*. Retrieved from

Jones, P. (2016). The emergence of Pacific urban villages: urbanization trends in the Pacific islands.

Leney, A. (2017). *Compost toilets and the potential for use in the Pacific Islands*. Retrieved from Integre: https://integre.spc.int/images/telechargements/compost_toilets_and_the_potential_for_use_in_the_Pac_islands_-_ANG.pdf

Reisinger, A., Howden, M., Vera, C., Garschagen, M., Hurlbert, M., Kreibiehl, S., . . . Pathak, M. (2020). The concept of risk in the IPCC Sixth Assessment Report: A summary of cross-working group discussions. *Intergovernmental Panel on Climate Change, 15*, 130.

Sanderson, R., Kotra, K. K., Koto, C., Molitambe, H., & Souter, R. (2022). *Climate resilient and climate vulnerable WASH service delivery models in Melanesian urban informal settlements*. Retrieved from Brisbane, Australia: https://watercentre.org/wp-content/uploads/2024/04/TechBrief_CR-WASH-SDM_8Dec_FinalV1-1.pdf

Sanderson, R., & Souter, R. (2020). *Research Brief: Investigating the transmission of faecal pathogens in urban informal settlements in and around Port Vila, Vanuatu, recognising biophysical and demographic diversity - water, sanitation and hygiene informal settlement characterisation*. Retrieved from Brisbane, Australia: https://www.watercentre.org/wp-content/uploads/2021/08/Sanderson_MIWM_Vanuatu_WASHResearchBrief_V2_.pdf

Souter, R., & Orams, P. (2019). *Water and Sanitation Services for Informal Settlements in Honiara, Solomon Islands*. Retrieved from

UN Habitat. (2015). *Habitat III Issue Paper 22—Informal Settlements*. Retrieved from New York: United Nations:

Water for Women. (2024). *What Does Climate-Resilient Inclusive WASH Look Like? Insights from Water for Women*. Retrieved from https://www.waterforwomenfund.org/en/news/what-does-climate-resilient-inclusive-wash-look-like.aspx

Acknowledgements

First and foremost, the authors would like to thank residents of informal settlements who generously provided their time, knowledge and experiences for our researchers to work with. Without this generosity the synthesis presented herein would be impossible. The authors would like to thank those individuals and organisations who provided information and insight into this work, including The Fijian Government, The Vanuatu Government, and numerous other organisations who made this research possible. We thank the staff from the following organisations and departments who constructively participated in project meetings and stakeholder workshops and interviews: Fiji Roads Authority, Ministry of Health and Medical Services - Environmental Health Department, Department of Water and Sewerage, Suva City Council, Water Authority of Fiji, Ministry of Lands and Mineral Resources, Port Vila Municipal Council, Ministry of Health, Department of Urban Affairs and Planning, Ministry of Lands and Natural Resources, Public Works Department, Water PNG, the Project Management Unit PNG, and UNICEF. We also acknowledge the contributions of our excellent research assistance team at USP in Fiji and Vanuatu.

This project was supported by the Australian Government Water for Women Fund and implemented by the International WaterCentre at Griffith University, Australia from 2023 to 2025. Water for Women is the Australian Government's flagship WASH program and is being delivered as part of Australia's aid program.

Disclaimer: This publication was funded by the Australian Government through the Department of Foreign Affairs and Trade. The views expressed here are the contributing authors' alone and are not necessarily the views of the Australian Government.

Suggested citation

Sanderson, R., Russo, B. Z., Koto., C., Unguna, D., Patorniti, N., da Silveira, M. C., Benedecti, R., Souter, R. 2024 *Localising vulnerability and resilience considerations for water and sanitation service delivery models in urban informal settlements in Suva, Fiji and Port Vila, Vanuatu.* International WaterCentre, Brisbane Australia

COVER IMAGE Navigating between homes in a settlement in Suva, Fiji (R. Souter, IWC, 2024)

ADDITIONAL RESOURCES

The project has produced other publicly available resources available at

www.watercentre.org/projects/PacificUrbanWASHplanning

RESEARCH PARTNERS

SUPPORTED BY

Annex 1

Table 5: Resilience of water service delivery models to storms (cyclones, rainstorms) and flooding

Resilience to storms and floods		Land type			
Type	**Water Service Delivery Model**	**Low-lying & close to surface waters**	**Coastal areas**	**Hillside areas**	**Other areas**
Type 1a	Individual private household water connections managed by utility (metered) (inside)	High	High	High	High
Type 1b	Individual private household water connections managed by utility (metered) (outside house)	Low	Medium	Medium	Medium
Type 2	Individual private rainwater tanks, with back-up tankered water provider	Medium	High	Low	High
Type 3	Shared private water connections (metered) using pay-as-you-go fee structures	Low	Medium	Low	Medium
Type 4	Water kiosk/vendor (private or public operator)	High	High	Medium	High
Type 5	Backup community sources at established community centres (e.g., rainwater tank at churches)	High	High	High	High
Type 6	Shared groundwater / tubewell source with container-based collection.	Medium	Low	High	High
Type 7	Private unprotected dug wells or springs (shallow groundwater)	Low	Low	Low	Low
Type 8	Household collection of surface water in containers	Low	Low	Low	Low

Table 6: Resilience of water service delivery models to sea level rise and coastal erosion

Resilience to sea level rise and coastal erosion		Land type	
Type	**Water Service Delivery Model**	**Coastal areas**	**Other areas**
Type 1a	Private household piped connection, inside	High	High
Type 1b	Private household piped connection, outside	Medium	Medium
Type 2	Rainwater and tankered backup	Medium	High
Type 3	Shared pay-as-you-go piped connection	High	Medium
Type 4	Water kiosk/vendor	High	High
Type 5	Backup community resources	Medium	High
Type 6	Shared deep groundwater	Low-medium	High
Type 7	Private unprotected dug wells or springs	Low	Medium
Type 8	Household collection of surface water in containers	Low	Medium

Table 7: Resilience of water service delivery models to droughts and extreme heat

Resilience to water scarcity (droughts and extreme heat)	Land type

Type	Water Service Delivery Model	Low-lying & close to surface waters	Hillside areas	Other areas
Type 1a	Private household piped connection, inside	High	High	High
Type 1b	Private household piped connection, outside	Medium	Medium	Medium
Type 2	Rainwater and tankered backup	Medium	Low	Low
Type 3	Shared pay-as-you-go piped connection	Low	Low	Medium
Type 4	Water kiosk/vendor	Medium	Medium	High
Type 5	Backup community resources	High	High	High
Type 6	Shared groundwater	High	Medium	High
Type 7	Private unprotected dug wells or springs (shallow groundwater)	Medium	Low	Low
Type 8	Household collection of surface water in containers	Medium	Low	Low

Table 8: Resilience of sanitation service delivery models to storms (cyclones, rainstorms) and flooding

Resilience to storms and floods		Land type			
Type	Sanitation Service Delivery Model	Low-lying & close to surface waters	Coastal areas	Hillside areas	Other areas
Type 1a	Individual private household toilets (flushed, piped, central sewerage managed by utility)	Medium*	Low	High	Medium
Type 1b	Shared toilet blocks (flushed, piped, central sewerage, utility managed)	Low	Medium	Medium	Medium
Type 2a	Individual private household toilets (flushed, piped, fully serviced septic tanks)	Low	Medium	Medium	High
Type 2b	Low flow household to flush to septic	Low	Medium	High	High
Type 3	Simplified / decentralised sewer systems	Medium-High	Medium	High	High
Type 4a	Pour flush pit toilets, fully serviced, twin offset	Low	Low	Medium	Medium
Type 4b	Raised Pour flush pit toilets, fully serviced, twin offset	Medium	High	High	High
Type 4c	Pour flush toilets, not serviced	Low	Low	Medium	Medium
Type 5a	Ventilated Improved Pit (VIP), fully serviced, single or twin offset	Low	Low	Medium	Medium
Type 5b	Raised Ventilated Improved Pit (VIP), fully serviced, single or twin offset	Medium	High	High	High
Type 6	Above-ground sanitation (container-based, fully serviced, or composting, maintained [2])	Medium	Medium	High	High
Type 7	"Bush toilets" – unimproved pit toilets	Low	Low	Low	Low
Type 8	Hanging or floating toilets	Low	Low	N/A	N/A

* Resilience could be increased to "high" with appropriately planned and operated pressure sewer lines

[2] (Leney, 2017)

Table 9: Resilience of sanitation service delivery models to sea level rise and coastal erosion

Resilience to sea level rise and coastal erosion		Land type	
Type	**Sanitation Service Delivery Model**	**Coastal areas**	**Other areas**
Type 1b	Household flush to sewer	High	High
Type 2a	Shared toilet block, flush to sewer	High	Medium
Type 2b	Household flush to septic	Medium	Medium
Type 3	Simplified sewer system	High	High
Type 4a	Pour flush pit, twin offset	Low	High
Type 4b	Raised pour flush pit, twin offset	Medium	Medium
Type 4c	Pour flush pit, not serviced	Low	Low
Type 5a	Ventilated Improved Pit (VIP), single or twin offset	Low	Medium
Type 5b	Raised Ventilated Improved Pit (VIP), single or twin offset	Medium	Medium
Type 6	Above-ground sanitation	High	High
Type 7	"Bush toilets" – unimproved pit toilets	Low	Low
Type 8	Hanging or floating toilets	Low	N/A

Table 10: Resilience of sanitation service delivery models to droughts and extreme heat

Resilience to water scarcity (droughts and extreme heat)		Land type		
Type	**Sanitation Service Delivery Model**	**Low-lying & close to surface waters**	**Hillside areas**	**Other areas**
Type 1a	Household flush to sewer	Low	Medium	Low
Type 1b	Shared toilet block, flush to sewer	Low	Medium	Low
Type 1c	Household flush to septic	Medium	Medium	Low
Type 2b	Low flow household to flush to septic	High	High	High
Type 3	Simplified sewer system	Medium	High	High
Type 4a	Pour flush pit, twin offset, serviced	Medium	Medium	Medium
Type 4c	Pour flush pit, twin offset, not serviced	Low	Low	Low
Type 5a	Ventilated Improved Pit (VIP), single or twin offset	High	High	High
Type 6	Above-ground sanitation	High	High	High
Type 7	"Bush toilets" – unimproved pit toilets	Low	Low	Low
Type 8	Hanging or floating toilets	Low	N/A	N/A