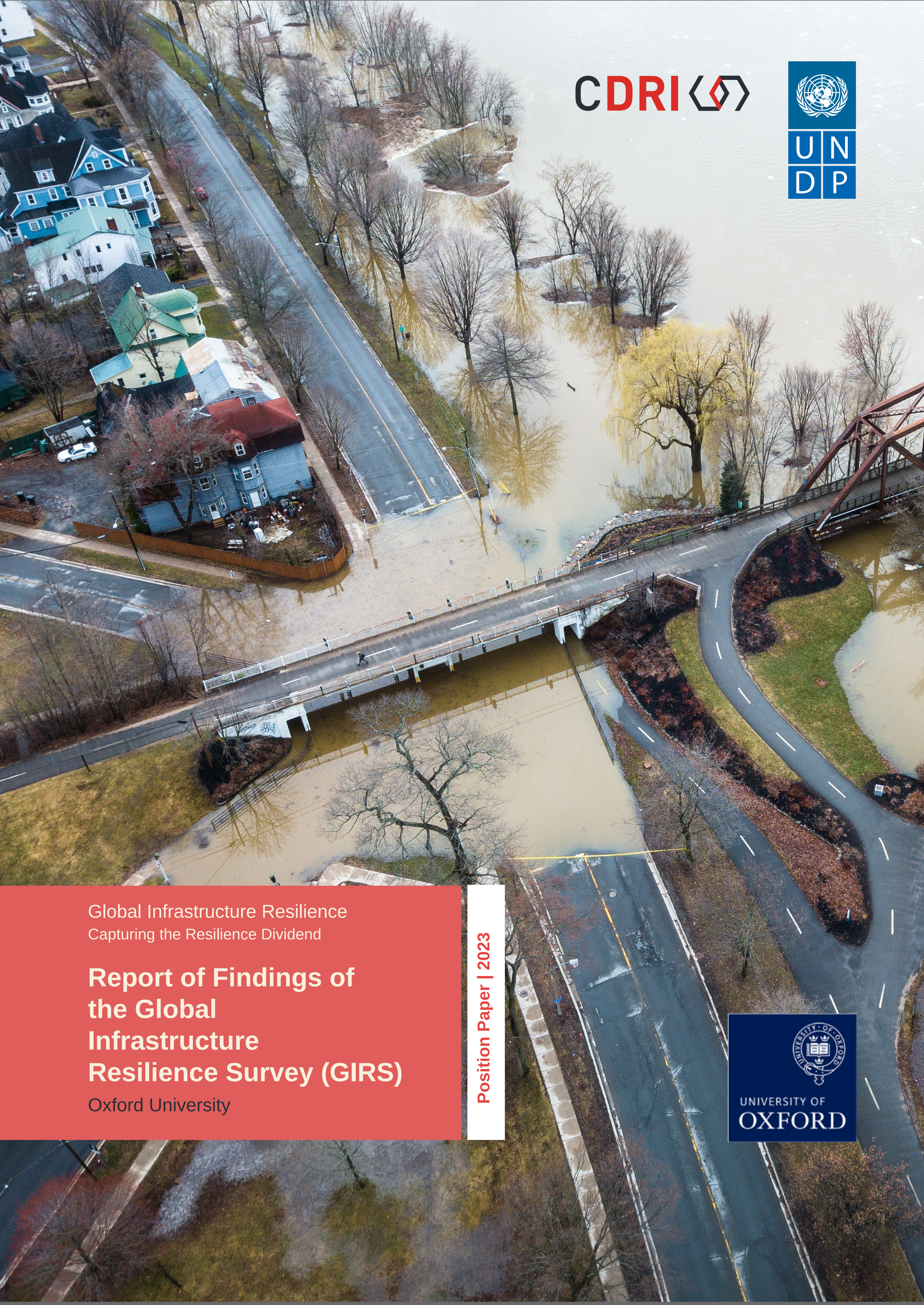

Global Infrastructure Resilience

Capturing the Resilience Dividend

Report of Findings of the Global Infrastructure Resilience Survey (GIRS)

Oxford University

Position Paper | 2023

A Global Infrastructure Resilience Survey

Global Infrastructure Resilience Survey (GIRS)
Report of Final Results
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Summary

There is consensus among infrastructure actors that how we manage our infrastructure systems and assets is important for ensuring effective service, but this assumption isn't yet supported by quantitative data. While several international actors and databases attempt to address this gap using global infrastructure indices as proxies, this project is the first to attempt to capture qualitative evidence directly from infrastructure experts at a global scale. It focuses on the institutional factors that influence infrastructure resilience and does so to better understand infrastructure management. The intention behind this work is to utilise those learnings to inform national and international policy and investment decision-making especially in the face of shifting climate across the coming century.

At the global level, the results of the survey call for changes on two key fronts: improving institutional autonomy of infrastructure utilities and inter-sectoral data sharing to ensure consistent policies and planning. Firstly, the results show that Institutional Stability and Technical Capacity is the single area of infrastructure management in which all sectors score lowest—particularly in reference to changes resulting from political turnover. This conclusion, alongside the parallel finding that infrastructure experts recognise building resilience policies as the most important component of infrastructure management, calls for more robust policy development that looks beyond and outlasts political shifts. In service of developing such policy, and in response to key findings that there is a critical need for consistent data across sectors, this work calls for more systematised data aggregation and sharing approach through a mechanism like a data repository.

A disaggregation of the survey's findings identifies trends of lower-income nations facing greater resilience challenges like more significant impacts to infrastructure system capacity following hazard events and longer recovery times. These findings are broadly consistent with expectations and conclusion from other development work. Sectorally, the survey's results call for the greatest support in the wastewater and road sectors which score lowest in the survey's infrastructure management index. Wastewater experts across the globe, report there is a systemic need for improvement in the sector's financial management—especially around ineffective spending (with only 37% on average being spent effectively) and routinely insufficient budgets, both for maintenance and standards as well as for climate resiliency initiatives (only 30% of what is deemed sufficient). Specific findings in the road sector call for stronger policies and consistent application of those across the hierarchies and geographies of the road sector's actors.

The work completed here was an important first step in understanding infrastructure management from a novel, bottom-up perspective. The preliminary results provide meaningful insights and observations shared across the globe's experts. Due to limitations in the project's sample sizes and global geographic extents however, the reach of the project's conclusions are limited. Instead, this work serves as a useful pilot showing trends for further evaluation and providing key insights for future survey development at this scale. Given this ambitious start, it is imperative that we continue exploring these findings in future iterations of the survey as these results only describe a single snapshot in time. Developing a temporal database enables tracking infrastructure management over time and understanding the national actions and factors that change how infrastructure is managed. Understanding these factors is the ultimate goal of this analysis as it enables the survey to describe not just observations but also make firm recommendations on mechanism to be implemented and their expected influence on a nation's infrastructure management and resilience.

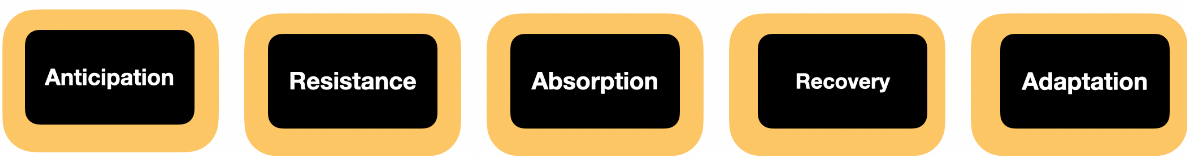
1 Towards Resilient Infrastructure Management

In the face of increasing climate variability, infrastructure systems are particularly vulnerable to climate hazards, which are predicted to become more intense and frequent across the next century. Recent assessments highlight the exposure of society's infrastructure systems to these imminent climate hazards at both the national and the global scales. The impact of hazard events on a population is a function not only of hazard exposure, but also of the infrastructure's ability to resist and recover from the impacts of that hazard and continue to provide service to populations—its *resilience*. While the location, material, or size of our infrastructure systems can be remotely captured and used for decision-making, their resilience is largely unassociated with these features. The framework of infrastructure system resilience is underpinned by five key aspects: anticipation, resistance, absorption, recovery, and adaptation (NIC, 2021; UNDRR,2016) –all of which contribute to systemic resilience and shield customers from the full-service reduction and financial impacts of hazard events.

There is no shortage of global datasets that attempt to describe how countries prosper, their attractiveness to infrastructure investment, and the risks they face from climate hazards. Despite the availability of this information, few datasets approach the question of realised resilience of infrastructure systems and the factors which enable it. Importantly, resilience is influenced by an interplay of both physical design factors and intangible management factors like regulation, policy, and financial capacity. These intangible aspects of resilience and service provision remain widely unassessed as they require the knowledge of experts that can be nation-, sector-, utility-, and context-specific. There is growing recognition that, in addition to 'grey' and 'green' infrastructure investments, this context specific knowledge is a key component of enabling effective asset management. There is a growing body of literature on this topic—often referred to as the *enabling environment*—but little consensus on a formalized definition.

In our exploration we see and describe these intangible management features as the overlap between deliberate governance actions and unintentional societal factors. Examples of deliberate governance actions in the infrastructure space could include management policies (Runhaar, 2014), standards and practices, financing structures, and institutional goals (Pagdadis, 2008). Examples of unintentional societal factors which can influence infrastructure include historical arrangements, workers unions, community advocacy, and workplace cultures. While recognizing the importance of both, this research effort focuses on the former—the deliberate governance actions which influence infrastructure management. Governance directly influences all the key components of resilience and yet still there is a gap in our definitions and understanding of how it applies to infrastructure.

Figure 1-The Five Aspects of Infrastructure Resilience



2 Global Efforts on Infrastructure Management

Conceptually, this project is grounded on a Coupled Infrastructure Systems (CIS) Framework (Anderies et al., 2016) which describes how "hard", "soft", natural, human, and social infrastructures (Frisschmann, 2005) are interlinked in each other's management. Even in the early complex infrastructure resilience literature of Burneau et al. (2003) and Francis and Bekera (2014), the authors recognised the importance of management factors which could not be measured by singular or quantitative performance metrics. Poulin & Kane's (2021) most modern work, reiterates these findings in their conclusion stating that, "existing literature focus[es] on the technical aspects [of infrastructure resilience], leaving a need for future research into the social aspects and their interactions with the technical." A similar sentiment, expressing a greater need for understanding the non-physical aspects of infrastructure decision-making, was presented in other works focusing both on infrastructure management contextualisation (Araya & Vasquez, 2022) as well as technical decision-making (Kabir et al., 2013; Bernhardt & McNeil, 2008). Together, these works form our understanding of the key gap that this research project fills.

The Global Infrastructure Resilience Survey (GIRS) is a global project to obtain qualitative evidence on the institutional factors that influence infrastructure resilience, and in doing so understand infrastructure management and utilise those learnings to inform national and international policy and investment decision-making in relation to infrastructure resilience. The survey builds on important development, engineering, policy, and academic efforts which together form a foundation for this exploratory and novel work. Broadly, the comparable existing efforts to evaluate infrastructure governance can be described in three categories: top-down, global governance indices; bottom-up national governance assessments; and project-specific infrastructure success evaluations. These types of efforts are expanded on below to better understand their strengths, limitations, and how they guide the GIRS development.

Most global initiatives to evaluate infrastructure management take a top-down approach, using globally available variables, to describe infrastructure management. Oftentimes, these methodologies indirectly describe infrastructure management by instead examining factors of suitability for infrastructure investment or a likelihood of positive infrastructure outcomes. These variables include information on financial returns, legal protections, regional/political stability, national credit ratings, corporate transparency, and consumer rights. The World Bank's Worldwide Governance Indicators (WGI) and the Global Infrastructure Hub's Infracompass tool are two examples of a top-down approach which produce national-level infrastructure management results comparable to those collected by the Global Infrastructure Resilience Survey (GIRS) project. The GIRS however, represents a bottom-up approach which assesses realised infrastructure resilience and the institutional challenges faced by individuals and operators within those infrastructure systems.

The Capacity Assessment Tool for Infrastructure (CAT-I) developed for the United Nations Office for Project Services (UNOPS) represents a bottom-up, infrastructure management assessment parallel but distinct from the WGI and Infracompass tools. Where it takes a focused approach on individual countries the GIRS attempts to demonstrate the value of investigating inter-comparable infrastructure management results at national scales and across the globe. Where the GIRS limits the number of questions in the public survey by necessity, the CAT-I contains hundreds of questions to be answered through interview or survey with specific experts. The produced dataset is extremely rich and has demonstrated uses in several developing nation case-studies, but the database is yet to achieve the geographic range and comparability for international, inter-comparable studies.

The academic literature describing infrastructure management assessments tends to focus on project specific evaluations describing Critical Success Factors (CSFs) as the factors influencing effective infrastructure management. CSF analysis is often employed in business and management approaches, and its academic application in infrastructure projects stems from goal setting and efficiency evaluations in private-public partnerships (PPPs). These PPP projects often identify governance, transparency, and regulatory hurdles as key impediments (Yihong et al. 2019; Budayan, 2018; Zakaria et al. 2017; Shi et al., 2016; Chang and Mills, 2016; and Mohammed and Alshaoush, 2018) for successful infrastructure projects. As these analyses are developed and assessed using different metrics and terminology, and across different scales and locations, many of the individual projects' outcomes are difficult to compare. To overcome this, and in an attempt to develop uniform, globally relevant terms, this literature review engaged in a preliminary Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) analysis, identifying, reviewing, and finally collating the CSFs of multiple relevant academic research papers resulting in the following summary categories:

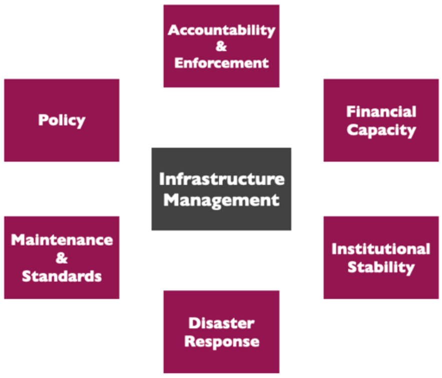
a. Policy
b. Maintenance and Standards
c. Accountability and Enforcement
d. Disaster Response Capacity
e. Financial Capacity
f. Institutional Stability and Capacity
g. Community Factors

This review of infrastructure success factors and the above categories form the basis for question development in this project's survey. See a detailed breakdown of the types of CSFs aggregated and their sources in Appendix A1.

3 Conceptualising the Global Infrastructure Resilience Survey

The Global Infrastructure Resilience Survey (GIRS) was designed to obtain qualitative evidence on the institutional factors that influence infrastructure resilience by capturing the reality of the impediments faced by infrastructure specialist in their day-to-day management processes. In its current form, it describes the foundations of the management institutions across several sectors and a range of infrastructure management components. The components of infrastructure management, while not a new concept, have been variably defined in works across the globe. Synthesising ideas from a wide range of academic work on the topic, we have decided to separate the components of infrastructure management into the following six categories which are seen as critical features of good infrastructure management:

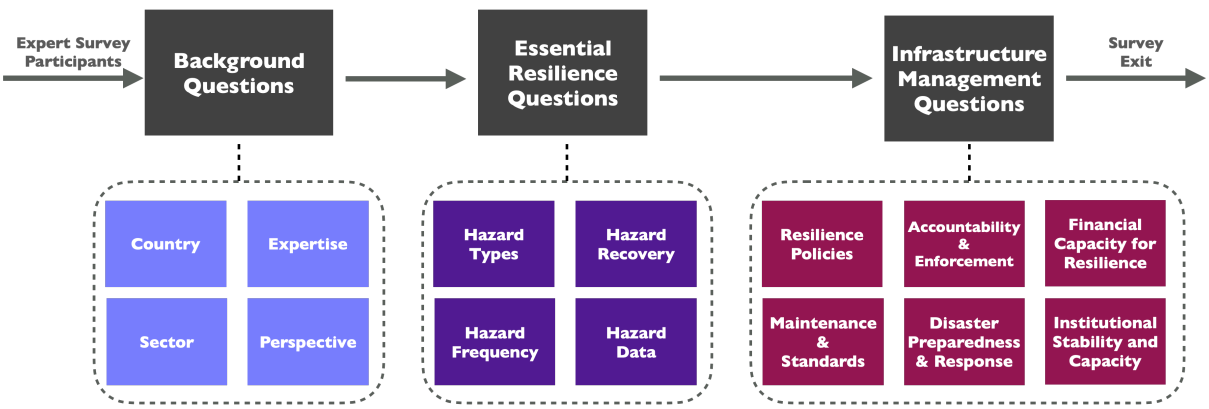
Figure 2- The Infrastructure Management Components assess by the GIRS.



For our research, we have adapted these constructs to address specifically infrastructure management which supports long-term resilience of infrastructure systems to hazards and shocks. While conceptually, few infrastructure managers would contest that each of these is important for a functioning system, the underlying mechanisms by which each of these acts on resilience is still obscured and this project is meant to act as a first attempt to illuminate the relationships between each from the perspective of the service provider (Wood et al., 2019; Linkov, 2018; Gasser, 2019).

To establish the relationships between infrastructure resilience and management, the survey is designed in three distinct steps, each with a greater need for technical specificity. Firstly, the survey collects fundamental information on sectors of expertise, nation(s) being described, and likely respondent knowledge, which enables the intended national and sectoral analyses of the GIRS. Secondly, the survey asks questions about hazard characteristics in the respondents' geography and sectors of expertise to ascertain resilience. The questions asked here are quantitative, but intentionally approximate and thus do not require supporting data or technical and detailed hazard knowledge. The final section of the survey is comprised of groups of optional infrastructure management questions covering the components highlighted in Figure 2. Respondents choosing not to respond can skip entire categories and complete the survey. The survey flow is designed to be increasingly technical allowing as much useable information as possible to be garnered even from respondents that do not complete the survey.

Figure 3-Conceptual overview of the survey demonstrating the types of questions asked.



Without a pre-existing vocabulary or causally described mechanism by which management influences resilience, this project took a data-led research approach. In qualitative analysis, this inductive research method allows for generative theory development meaning that the research project doesn't pre-suppose a hypothesis to test, but instead seeks to explore and explain a phenomenon by using collected data to define a new theory of relationship between the topics of interest–here infrastructure management practices and resilience. The grounded theory method (Glaser & Strauss, 2017) applied for this analysis establishes constructs (Figure 2) which are utilised into data collection, applied for analysis, and then iteratively assessed for goodness of fit. Within this project's lifecycle this took the form of review from an Expert Advisory Group, and a pre-pilot survey with a limited selection of nations.

Without the existence of an independently robust framework in academia to support Figure 2 the project relied on external advisors in the role of an Expert Advisory Group (EAG) to validate. The EAG was comprised of infrastructure experts from a range of sectors and fields of expertise, but importantly included those with backgrounds in management, survey design, and resilience. The list of EAG members advising on this project is available in Appendix A3. The EAG acted as an independent review panel for the survey's design and implementations and gave steering feedback which guided the project's questions, design, platform, and the goals of the ultimate results.

3.1 GIRS Implementation

3.1.1 Question Design

Foundationally, the survey was designed to ask simple questions that could be answered quickly and easily by infrastructure experts without external aid or data. Across the survey, both qualitative and quantitative questions were asked, with ranked, ordinal, and continuous data types being collected. For the infrastructure management questions using a factor analysis approach, the questions were often simplified to binary responses wherein each question highlighted the presence or absence of an attribute thought to support better infrastructure resilience. If the attribute was determined as present by the respondent, then questions about the attributes effectiveness were asked.

Table 1-Example of binary factor analysis showing the questions used to assess the Resilience Policies Component

Question	Response	Score
Do policies exist which explicitly support infrastructure resilience?	Yes	1
Do policies in your sector have clearly defined goals?	Yes	1
Are policies consistently implemented?	No	0
Are policies routinely reviewed and improved?	Yes	1
Are policies developed with stakeholder engagement?	No	0
Total Score		3
Max Possible Score		5
Policy Infrastructure Management Score		3/5
		0.60

Each management component is evaluated using this approach, though each has a different number of questions that were defined as relevant for the survey's scale by the EAG.

Table 2-Infrastructure management components assessed in the GIRS.

Infrastructure Management Component	Code	Number of Survey Questions
Infrastructure Resilience Policy and Planning	POL	5
Routine Maintenance and Standards Practices	MNS	11
Accountability and Enforcement Practices	AEN	6
Disaster Preparedness and Response	DPR	5
Financial Stability for Infrastructure Resilience	FIN	4
Institutional Stability and Technical Capacity	INS	7

Due to the survey's financial limitations and the cost of translation services the number of open-ended questions was limited, but open response data was collected to provide insight into the features of infrastructure management that this survey didn't capture. This was both to inform on features not considered, but also for how the survey might adapt for a successful future iteration.

3.1.2 Expert Sampling Approach and Outreach

From the initialisation of this project, the team identified and recognised the challenge in collecting a meaningful sample needed for this survey. An ideal sample would collect information for each nation and sector with the following attributes:

1. sufficient in number and geographic diversity to be representative of a wider population, nation, region, or group.
2. unbiased by management supervision
3. well-informed

To achieve the first key attribute and collect as much information as possible, from as wide a range as possible, the survey was implemented online and was accessible from both computers and mobile phones. In coordination with the wider CDRI Flagship report, the survey was presented in the six major languages of the United Nations: English, Spanish, French, Arabic, Chinese (Simplified), and Russian. In addition to minimising challenges to access, respondents were also financially incentivised to complete the survey.

To achieve the second key attribute and avoid the positive reporting biases associated with self-reported data in other global surveys like the Sendai Report, the survey chose to take an approach of anonymity for respondents–both regarding their identity and the specific institution they were describing. Through this we intended to minimise any expectation of repercussion with the intention of accruing the most honest responses possible.

To achieve the third key attribute, the survey targeted infrastructure experts in its distribution via the Coalition to Disaster Resilient Infrastructure network. To better understand the demographics and expertise of those responding, experts were asked to provide a descriptor of their profession and perspective. Facing the challenges of defining a useful sample head on, the project engaged in a pilot survey to guide trade-offs among questions, metrics, and realistic expectations of survey sampling.

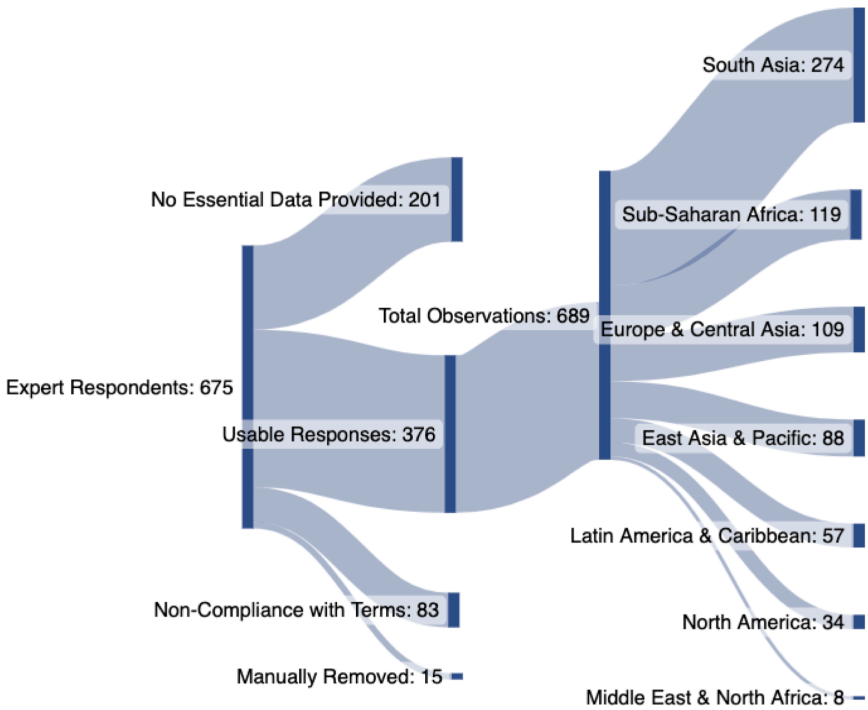
3.1.3 Testing and Validation of Methods

To validate the approach of the survey and the data collection tool, the team engaged in a pilot project across several nations deliberately spanning different geographic regions, languages, and national economic classes. For the pilot, results were solicited from infrastructure specialists in select countries and feedback on the survey tool was used to adjust the GIRS to increase its effectiveness. The process provided preliminary results that suggested that the survey could get results from experts and that questions were reasonable, useful, and understood by respondents. The pilot survey's response rate was approximately 33%, with the predominantly responding sectors being those of drinking water, wastewater, electricity, roads, and airports.

3.1.4 Features of the Survey's Sample

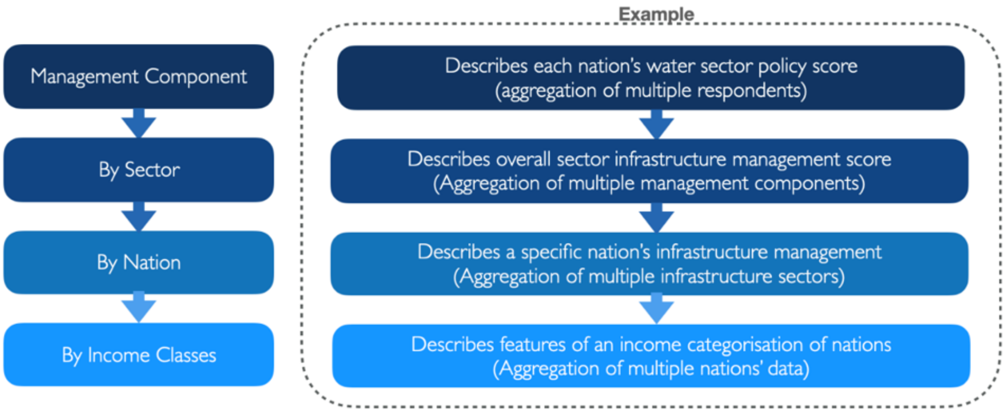
Respondents of the survey were able to provide information for up to two geographies, and in each of those, multiple sectors. Using this structure, experts typically provided 2-4 observations per response which resulted in a total of 689 observations used in the survey's analysis. These observations were derived from the 675 survey responses–some of which didn't provide the essential data (sector, geography, and at least one other data point), approval for compliance with the terms, and others that were manually removed (apparent reduplication of respondents). It is important to note that while the survey collected 689 observations for analysis, respondents were not tasked with answering every question and as such, the sample numbers for each questions vary individually and in some cases are substantially lower. Given limitations in sample sizes across sectors, the analysis focuses on the drinking water, wastewater, electricity, and road sectors, and primarily consolidates responses at an income-level stratification of high income, upper-middle, lower-middle, and low income nations following World Bank Classifications (WBG, 2022).

Figure 4-Sankey diagram summarising survey response cleaning and final classification of observations



From the data, lower middle-income responses comprise 54% of the total sample and dominate the survey by number. Many of these responses describe infrastructure in India and an analysis using equal weighting of respondents would skew towards Indian representativeness. To address this, the results use a data aggregation method which compiles data in the following order: by management component within a nation, then by sector within a nation, then cross-sectorally, nationally, and thereafter by income class. In this way, multiple respondents from a single country don't skew global results of aggregated indices as each country infrastructure management is ultimately given a single value. Figure 5 demonstrates the data aggregation approach used, where results can be extracted and analysed at and across any aggregation level.

Figure 5-Demonstrating data aggregation approach using an example.



3.1.5 Key Design Features of the Global Infrastructure Resilience Survey

The review process resulted in the current version of the Global Infrastructure Resilience Survey which includes the survey questions as well as notable survey features. These features are material to the survey's collection and are noted here as they could affect responses. The features were collaboratively decided on by the project's management, researchers, and EAG as the most likely to garner the responses needed despite their potential trade-offs. Below is summary of these features that are not addressed in the survey question design review or the analysis components.

a. Providing Multiple Country Responses

   To accommodate infrastructure experts that have multiple geographies of expertise, the survey enables respondents to select up to two separate geographies for which the survey platform readily duplicates questions. While some respondents may have expertise in more than two geographies, the survey is capped at two per response with concern for the survey becoming prohibitively long.

b. Optional Questions and Sections

   With the intention of the preventing the survey from being burdensome, most questions did not require answers and respondents were allowed to skip them. This was expedited in the specialist section on infrastructure management, where respondents could indicate their lack of expertise to be directed past an entire section. This approach meant that some questions had significantly fewer respondents than others.

c. "I don't know" Response Options

To reduce the cognitive need on respondents, many questions were asked such that respondents indicated only which attributes were present in the subject of the question. This approach meant that blank responses indicated that attributes were not present. To avoid false negatives using this approach, each question also included an "I don't know" option so that respondents could indicate any blank responses that shouldn't be assessed as a lack of attribute.

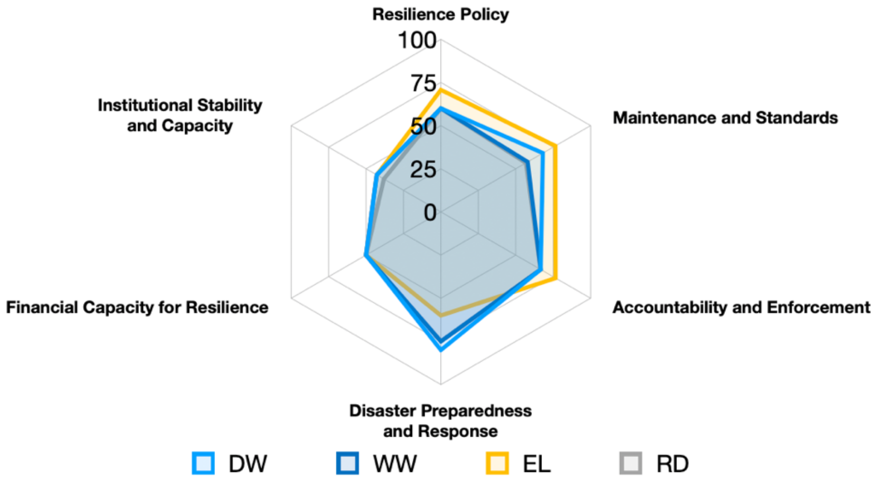
d. Response Incentives
To garner more responses, CDRI generously provided a financial incentive for respondents which was selected using a Lucky Draw method. In this method, two respondents were randomly selected to win $300USD each. The presence of a financial incentive may have influenced respondents' interest in completing the survey and thus required vigilance in data processing to avoid repeat respondents.

4 Key Learnings

4.1 Infrastructure Management

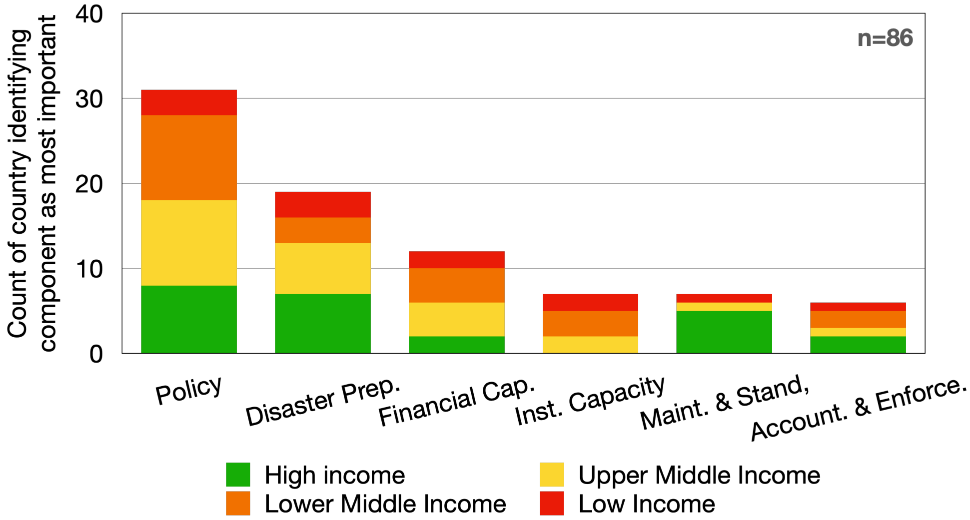
The Infrastructure Management score defined in this work is established as an index of the six infrastructure management components described in Figure 2. In Figure 6 below, we show the global scores for each of these management components by sector to understand which sectors tend to be the most well managed. Importantly, the results show two key findings: 1) firstly, that the wastewater and road sectors routinely score worse that the drinking water and electricity sectors across all infrastructure management components; and 2) secondly, that all sectors score relatively poorly in the Infrastructure Stability and Technical Capacity component. The remainder of this section explores the relationships and potential reasonings behind these.

Figure 6-Global sectoral infrastructure management index scores



Across the nations surveyed, the GIRS recognises that the hazards and infrastructure management challenges faced vary significantly by country and highlights those differences at a global scale below.

Figure 7-The infrastructure management components identified as most important at a national level

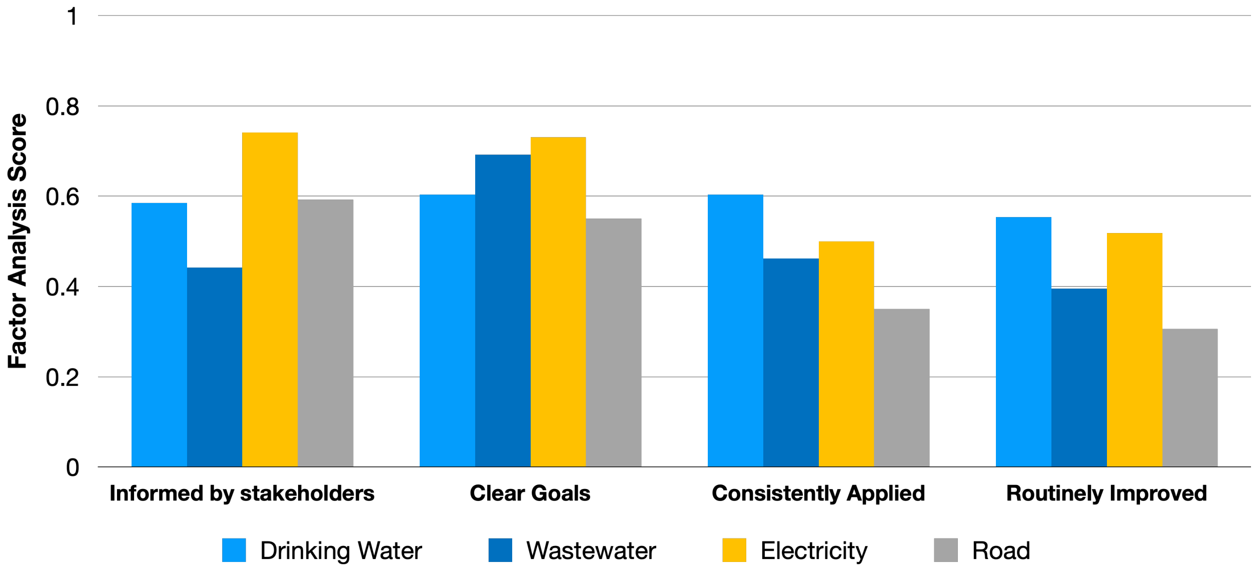


The results in Figure 7 (See Table 2 for expanded component names) show that in most nations, having stronger policies are seen as the most important infrastructure management development to ensure long-term resilience. The results demonstrate that primarily lower income countries see the need for institutional stability and technical capacity as a challenge, despite all sectors routinely scoring poorly in this management category (Figure 6). Conversely, higher income countries disproportionately identify having better maintenance and standards practices as the most important factor for them. Interestingly, no countries identified the need for collaborative societal and community engagement as the top priority for their infrastructure sectors.

4.1.1 Policy in the Road Sector

Despite stronger resilience policies being identified as the most important component of infrastructure management for future resilience, not all sectors consistently score highly in this category. The road sector for example, achieves the lowest score overall with more than half of responding nations identifying inconsistencies in how resilience policy is applied and describe the policies themselves as often outdate and/or not routinely improved. Figure 8 highlights specifically the areas in which the road sector policy could be made stronger, while recognising that its policies are seemingly well informed by stakeholders.

Figure 8-Survey results describing the global average scores for the Resilience Policy Component questions disaggregated by sector.

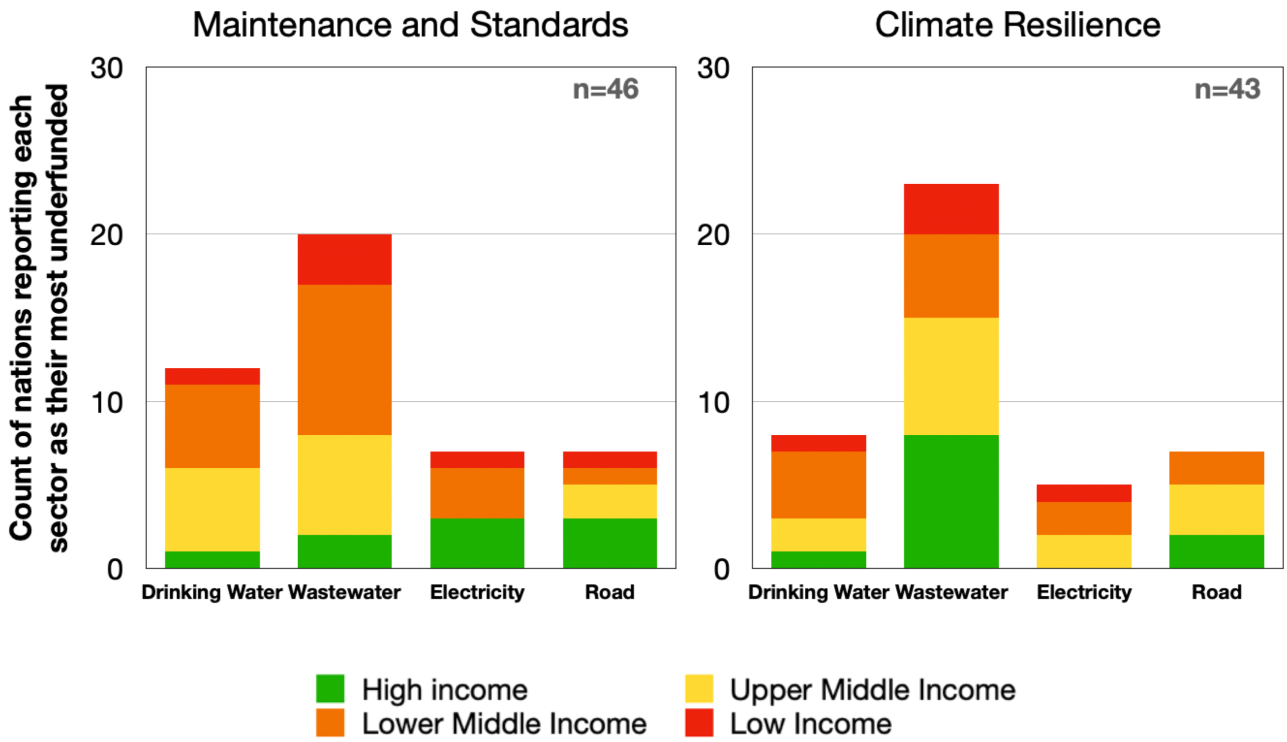


In highly networked infrastructure systems like roads, the inconsistent application of policies can result in complex inter-institutional and geographically diverse problems like unequal service quality, which can exacerbate existing socioeconomic weaknesses and unduly burden those most vulnerable. Inconsistently applied policies within a sector commonly stem from management fragmentation, a lack of policy clarity, and/or ineffective accountability mechanisms.

4.1.2 Challenges in Wastewater Infrastructure Management

The GIRS results highlight the wastewater sector as having the lowest index score and thus being most in-need for improvements in infrastructure management–especially due to its relatively weak score in its financial capacity for resilience component. The survey results indicate that experts find wastewater financing to be insufficient even to meet current needs–at only 30% of what is deemed adequate. The results also show that experts expect that trend to worsen in the future. This critical underfunding in the wastewater sector appears to be systemic in that most nations report it as their least funded sector, both for resilience and for routine maintenance and standards operations (Figure 9). Furthermore, the results identify that the wastewater sector demonstrates the lowest spending effectiveness of the surveyed sectors with only 37% of allocated funding not being lost to inefficiencies like misuse of funds and corruption.

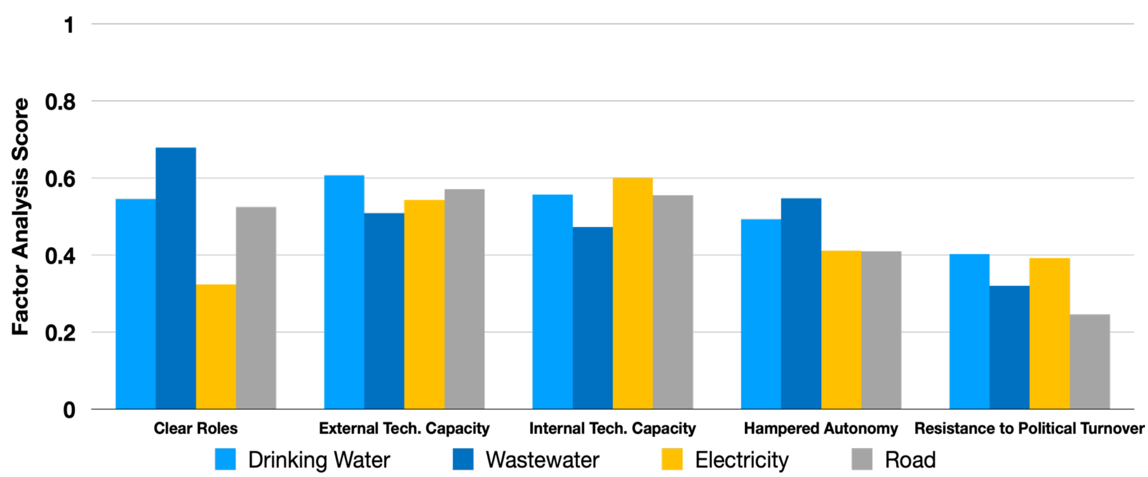
Figure 9-Funding inadequacy for routine maintenance and standards, and climate resilience



4.1.3 Cross-Sectoral Institutional Stability and Technical Capacity

The Institutional Stability and Technical Capacity component of the survey captures information on the ability of an institution to carry on its operations sustainably without external reliance or interference. The Infrastructure Management Indices presented in Figure 6 show that all the analysed sectors score relatively poorly in the Institutional Stability and Technical Capacity Component and to better understand this outcome, we explore the scores of the underlying questions below.

Figure 10- Global average scores for the Institutional Stability and Technical Capacity disaggregated by sector.



Across the questions used to develop the index score, sectors appear to score most poorly in their resistance to political turnover. Notably, the question identifies that most sectors are susceptible to significant policy, programmatic, and budgetary turnovers in response to political changes. This instability is sometimes used politically to curtail infrastructure benefits, extend budgets, and has even resulted in stranded utility assets. Conversely (though not considered in the survey), we recognise that cyclical, positive infrastructure outcomes, such as politically-driven road resurfacing campaigns, can also be a contributing factor underlying these scores.

The scores describing the clarity of institutional roles demonstrate the widest range, with the wastewater sector appearing to have roles and responsibilities of institutions that are most sufficiently clear and functional to avoid conflict between the sector's actors. For this question, the electricity sector reported an uncharacteristically low score considering its otherwise low deviations across other infrastructure management components. This could imply that while its Institutional and Technical capacity score is otherwise high, resilience benefits in the sector should not be attributed to uniformity or clarity in the electricity sector.

4.2 Expert Perceptions of Resilience

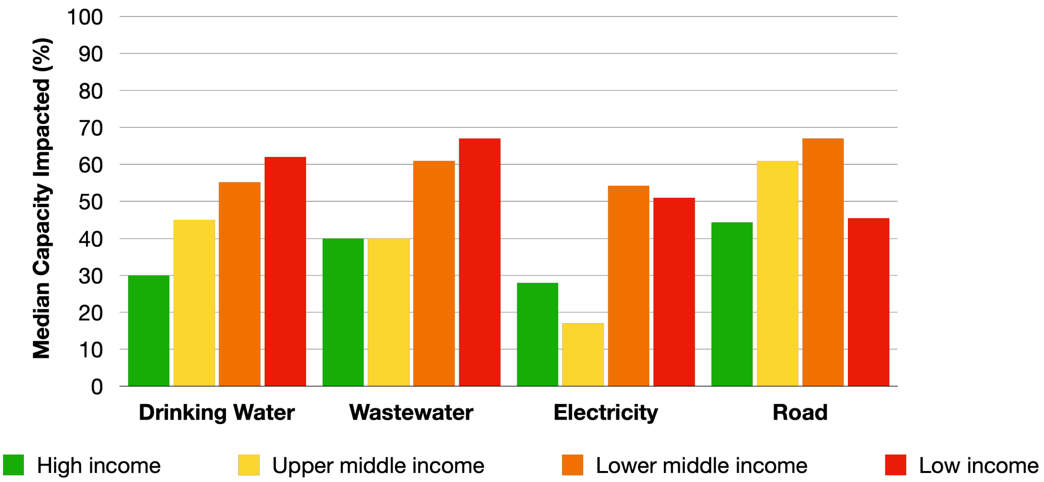
Understanding resilience is paramount for this research effort as the eventual goal of this work is to describe the relationship between it and infrastructure management. To accomplish this, the survey asks experts about their experiences with hazards to capture an understanding of resilience that is inexact but genuine. Guided by resilience metric research by Ouyang et al. (2019), Petit et al. (2013), Zobel et al. (2014), and Zobel (2011) we collect data about the non-physical features of sector resilience by asking about expert perceptions on: hazard impacts to operational capacity, the frequency of significant impacts, and the recovery time of systems.

Posing these questions to a broad range of experts across multiple geographies necessitates making unifying assumptions to ensure that responses are meaningful in comparing resilience. Key among these assumptions is how hazard impacts and recovery are defined. The challenge in defining similar impacts across this range of respondents is that it's a function of the combined effects of each respondents' hazards (type, intensity, duration, and frequency); assets (type and exposure); and their vulnerabilities (age and protections). To address this, the survey focuses on management actions as a metric for resilience, rather than physical factors like storms return period or the intensity of a drought. Instead, the survey asks respondents about "significant impacts," which are defined as "repercussions of natural hazards, which require exceptional management or actions beyond routine maintenance." Similarly, in defining system recovery, the survey asks about the return to "acceptable levels of service." This wording recognises that service quality varies significantly globally and that that there are several non-linear, or non-ideal recovery paths that return service to customers satisfactorily. The subjectivity of the survey questions allows for broader, qualitative data collection and below we share the learnings from the global dataset on Impact Capacity Losses, Impact Frequency, and Recovery Time.

4.2.1 Capacity Loss

The question of hazard impact posed in the survey collects information on proportional capacity loss in response to hazards which significantly impact a system or sector.

Figure 11-Median capacity loss due to significantly impacting hazards across sectors and income classes

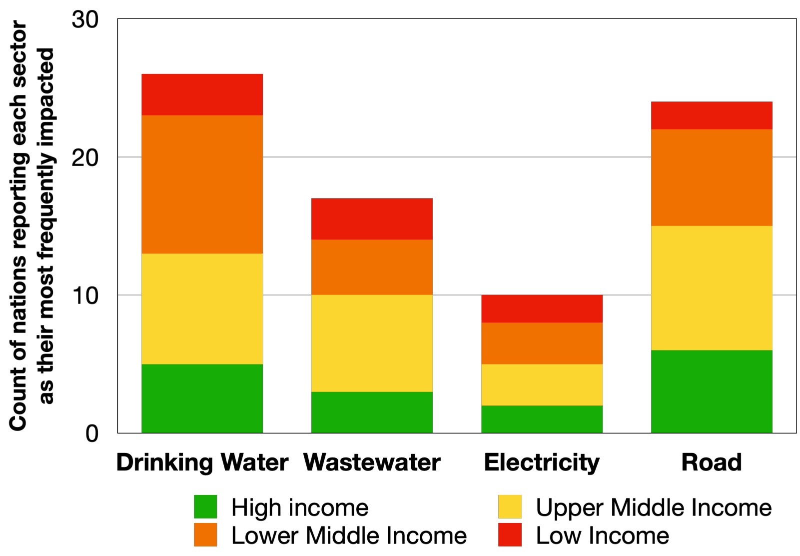


The results of the survey are broadly consistent with the widely held perception that infrastructure in lower-income nations faces greater risk and challenges from hazards. The survey results show that, on average, lower income nations face a 20% greater capacity loss in the face of significant impacts (dw-21%; ww-24%; el-30%; rd-4%). This trend is least pronounced in the road sector, where low-income nations report unexpectedly low capacity impacts relative to the trends in other sectors.

4.2.2 Impact Frequency

The frequency with which infrastructure is impacted is foundationally dependent on the hazard exposure of that sector or asset. Across the globe, nations face differential exposures to hazards and thus comparing sheer numbers of impacts can be misleading. Instead, we choose to normalise against other sectors in the same geography. Below is a qualitative assessment which aggregates information about which sectors are reported to be impacted the most in each nation.

Figure 12-Global survey data identifying which sectors are reported as most frequently being impacted by hazards.

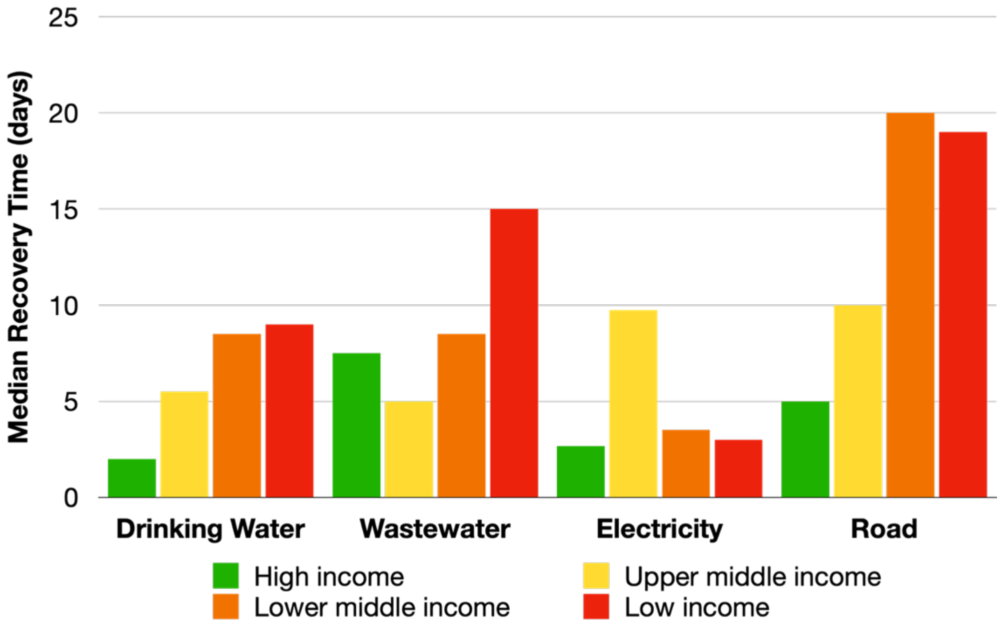


The survey results show that drinking water and road sectors are the most frequently impacted significantly by hazards. Conversely, the electricity sector is least frequently impacted by climate hazards. While the infrastructure sectors being considered here could be considered highly networked, it is likely that the electricity sector has some of the greatest redundancy relative to exposure.

4.2.3 Recovery Time

While the survey doesn't provide information on complex characteristics of infrastructure recovery– the methods, threshold metrics, or rate of recovery– it does inform on when systems attain a sufficient level of operation to return service to customers. In the survey, respondents were asked to identify the expected recovery time (in days) of their system/sector given a significant impact. The responses ranged from 1 to 1000 days, with any amount of time less than one day reported as 1 day.

Figure 13- Median recovery time due to significantly impacting hazards across sectors and income classes.



Across all sectors except electricity, we see the previously identified trend hold–where lower income nations face more negative outcomes. The survey results show that, on average, infrastructure systems in lower-income nations require 5 more days of recovery time in the face of significant impacts (dw-5; ww-6; el-3 fewer; rd-12). In the electricity sector, we see an unexpectedly high recovery time for upper-middle income countries, and this is strongly influenced by a single nation, Fiji, reporting a recovery time of 180 days relative to the average 9 days in the remainder of the category. Even while the theoretical removal of this outlying datapoint would significantly lower the upper-middle income electricity sector recovery times, the variation across income classes remains small. This indicates that unlike the other sectors surveyed, recovery time in the electricity sector is not very dependent on the nation's income class.

5 Key Limitations

Despite a robust and multi-pronged sampling method (Appendix A5), the key limitation of this survey lies in the inherent challenge of garnering a sufficiently large sample size to meet the survey's goals. More accurately, this can be distinguished into two categories of challenges: 1) defining the sample size relative to the population; and 2) capturing a sufficiently large sample to realise significance. More detail on secondary limitations of the survey like selection (expert sampling, online sampling, and language biases) and response biases (question categorisation and survey question design), can be found in Appendix 4.

5.1 Representativeness of Sample

In all public surveys, the sampled or surveyed population is a subset of the total population of interest. Ideally, the relationship between the sizes of the population and the sample is known and thus the surveys can describe what proportion of the population was sampled and how likely it is that the sample represents the views of the population. In the case of this survey, the population of interest (infrastructure experts) is necessarily broadly defined across several different occupations, all of which contribute meaningfully to infrastructure management:

1. National, Regional, and Municipal Government Official
2. Research Institute or Think Tank Researcher
3. Infrastructure Service Provider or Utility Provider
4. Non-Governmental Organisation Professional
5. Private Sector Consultant of Advisor
6. Financial Services Professional
7. Insurance and Reinsurance Professional
8. Technical Designer or Consultant (Engineering, Architecture, Construction)
9. Legal Sector Professional
10. Student
11. Other

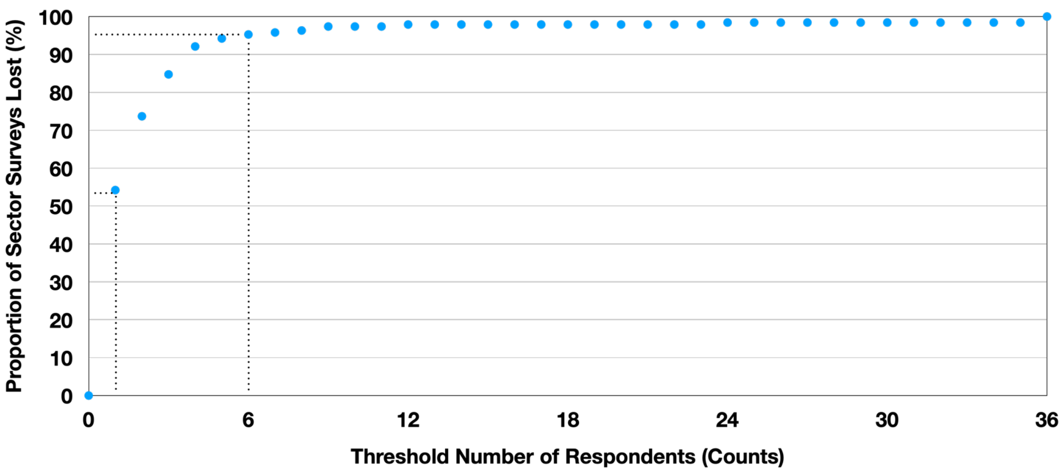
The intended respondent, "infrastructure experts," are loosely defined as we recognise that many experts in a field may carry different titles while all having useful insights. To accommodate and account for this in the processing of the results, the survey asks respondents to self-identify their profession and the perspective of their expertise. The decision to use this approach for the survey was collaboratively made by the project's management, researchers, and EAG as the most likely to garner the responses needed. The project aims to collect as many responses as possible to achieve a sufficiently large sample size in this research. Due to the broad definition selected for this research and the variability in defining these groups across these sectors and nations, the survey analysis has found it challenging to describe true population size of infrastructure experts (N), and thus has been unable to make claims of broader representativeness of this information.

5.2 Ideal Sample Size

Even without describing representativeness, a sample whose size is sufficiently large can describe significant trends in results. Typically, statistical best practices recommend that a sufficiently large dataset contain 36 independent samples at a minimum. Following this guideline, the survey would ideally collect 36 respondents for each sector resulting in a minimum of 144 responses per nation for the drinking water, wastewater, electricity, and road sectors. While in larger nations, this might seem a reasonable expectation, smaller nations may not have 144 experts across sectors who might feasibly answer the questions of the survey. Regardless of its size, many nations in the survey show only a few respondents, and even fewer provide sufficient relevant data to the key questions on infrastructure management.

One of the most pressing challenges of this research exercise has been garnering survey responses and determining the reasonable number of responses with which to draw conclusions. Figure 15 below shows the proportion of sector datasets that would be dropped from the analysis at different threshold of respondents. Importantly, the data shows that if the ideal standard of 36 respondents were to be upheld, only 3 sectors in the analysis would remain: India's drinking water, wastewater, and road sectors. The graph also shows that if the threshold was reduced to 6 respondents, the analysis would lose 95% of its data. There are reasonable arguments to be made about representativeness and the ability to draw fair averages and medians for respondent sizes below 3, but even at this low threshold, the survey stands to lose 85% of its data. Recognising this key limitation, the survey team and management had agreed that the survey's initial intent was ambitious given its financial and time limitations but that it is a successful pilot to inform the next iteration of the CDRI GIRS. With the intention of showcasing this survey as a proof-of-concept and pilot for future advancement, the analysis presents results with no minimum threshold. This approach allows the survey's data to demonstrate potential trends but remains too small a dataset with which to draw conclusive evidence.

Figure 14-Survey sectors which would be lost at different data requirement thresholds



Other infrastructure research surveys have skirted this problem using the expert sampling approach of in-depth interviews with verified experts. This expert sampling approach asserts that, especially in smaller nations, a large number of responses isn't necessarily required if the respondent is sufficiently knowledgeable. Because of the scale of the survey (global) and limitations in time, language, and budget, in-depth interviews with verified experts were not possible for the GIRS. In addition, the deliberate design choice to keep the survey anonymous means that expert responses, and thus their expertise, could not be verified. Future iteration of the GIRS will expand to more closely parallel other comparative survey work in the field like the Global Competitiveness Index and World Risk Poll. These projects garnered thousands of results (~14,000 and ~150,000 respectively) and have research teams and budgets which are larger, sometimes by orders of magnitude.

6 Ideas, Insights, and Future Analysis

Beyond the observations on infrastructure management components and resilience, the survey also provided a unique opportunity to understand aspects of infrastructure management that are critical, and yet beyond the scope of specific components or hazard impacts. The remainder of this section is comprised of a discussion of these findings and how they might be leveraged to achieve better outcomes both for infrastructure managers, as well as the future iterations of the GIRS survey.

6.1 Data Collection and Availability

Infrastructure managers require data both internal and external to their sector for robust decision making. This is most evident when considering climate and physical hazards but is also relevant to intersectoral assets that require joint coordination like hydroelectric dams or sub-terranean sewer lines that flow below road networks. To understand the magnitude of this challenge across sectors, the survey assesses data availability within a sector, the need for data beyond the sector for decision-making, and the existing accessibility of the cross-sectoral data.

Figure 15- Systems engaging in data management or expressing needs and access to external sectors' infrastructure data

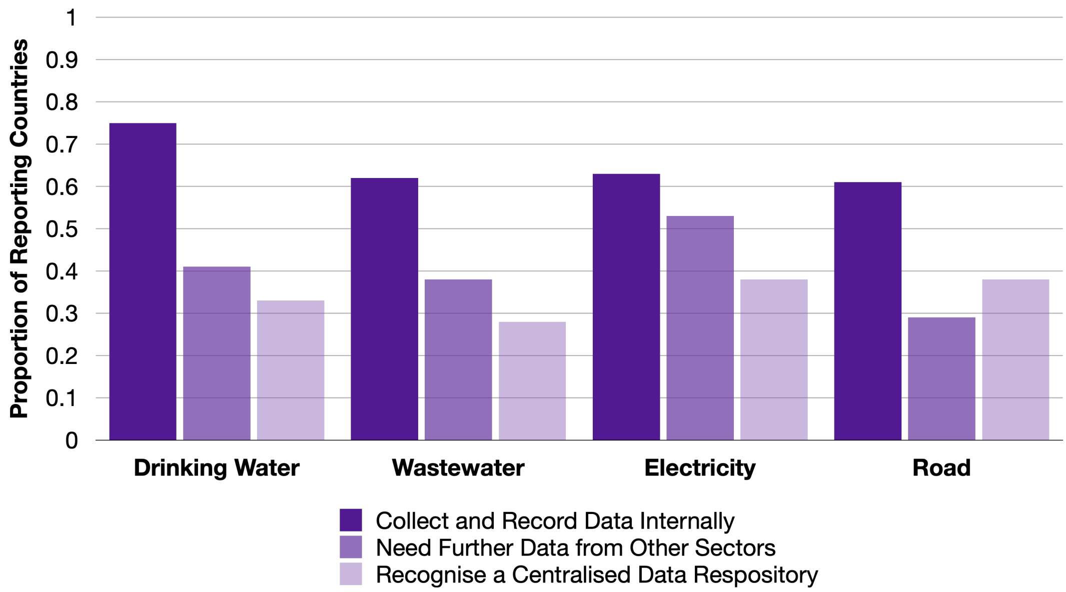


Figure 15 displays the results of these questions using the average proportion of each sector: 1) collecting and recording their data internally; 2) that needs extra-sectoral data that isn't readily available; and 3) that recognises a national-level centralised data repository which might house infrastructure data. While the income class data (not disaggregated) does show some trends where low-income nations appear to collect significantly less data in some sectors than others, Figure 15 expresses a wider sentiment echoed by infrastructure experts in their written responses—the need for wider data availability for intersectoral alignment. The results suggest that most sectors currently collect and record their own data internally, and thus data availability is unlikely the limiting factor in intersectoral coordination. Simultaneously, with this relatively widespread internal data collection effort, sectors recognise that most of their extra-sectoral data needs are unmet—on average across the sectors, less than half of crucial data needed for decision-making was readily available.

One solution to this need might be a centralised data repository or platform wherein infrastructure sectors report and deposit data that is relevant to other sectors for their decision-making. The survey's responses suggest that this approach is not yet ubiquitous but is already in place in several nations and sectors. The extent of effectiveness and use of these repositories is unclear from respondents, especially where respondents in the same sector and geography report juxtaposing information on its existence. While the survey's approach and the feedback from respondents would suggest that a centralised repository could positively impact infrastructure, we recognise that its structure and implantation, in the context of each country's enabling environment, would be a determinant in its ultimate use.

There are some prevalent challenges that we anticipate in the establishment and maintenance of any data repository related to data collection, data storage, and access. For data collection, we anticipate that the primary challenge in any context will be incentivising entities to share data in a timely fashion and to share it in a manner that is consistent with some established standard. For data storage, we anticipate challenges in maintaining a secure database, and questions of systems ownership like what entity bears the cost of storage and decides on data reporting, standards, and verification. Lastly and crucially, we anticipate challenges managing data access—most importantly, establishing which data should be used for common intersectoral or government-wide planning. Additionally, there will be needs for ensuring equitable access to data, as well as managing new data request and future needs.

6.2 The Opportunities for Future Analysis

Assessing the value and extent of centralised data repositories was a feature of the survey that was added late in its development. It was particularly added in response to expert feedback during the pilot phase of the survey and this feedback meaningfully shaped the outcome of the project's findings. Recognising the value of this open-ended data, the survey explicitly solicited infrastructure management solutions that respondents identified as just as important as the infrastructure management components selected for the analysis (Figure 2). Of the 378 respondents, 5% contributed alternatives which broadly fell into three categories.

1. The first category echoed the sentiment of the pilot survey in needing shared, robust means and methods of collecting, creating, and storing data like those for climate and population growth. One respondent concisely summarised this as a need for, "long term data collection/archiving strategies/standards and data sharing among multiple agencies (data about past disaster events, damage levels, maintenance records)."

2. The second category focused on better understanding the role of urban planning decisions—especially in relation to impervious surface, drainage, and green spaces around infrastructure assets.

3. The last category focused on community-level resilience and advocates for raising community awareness, greater household resilience to infrastructure impacts, and greater evaluation of community-level resilience.

These contributions raise interesting insights alongside the project's analysis. Firstly, the sustained interest in centralised data repositories give credence to the recommendation for greater implementation of infrastructure data repositories. The second finding appears to be a legitimate factor contributing to infrastructure management needs, but its addition to the survey raises a challenge: does the survey expand to survey urban planning entities alongside infrastructure sectors, or does it question sectors about the exogenous urban planning constraints that it faces? The last category, focused on community-resilience, likely does not fit within a future iteration of the Expert GIRS, but does motivate the need for a non-expert GIRS which can garner perspectives from communities or community-focused research and groups.

Similarly, to survey questions addressing important infrastructure management components, the survey also asked an open-ended question about which types of management violations impeded resilient outcomes but were not captured in the current survey. Of the 15 contributing responses, 47% of the respondents identified corruption and institutional non-cooperation as a key violation worth delving into further. If future iterations of the survey maintain anonymity for its respondents, capturing information on user experience of corruption may be feasible on a scale not seen before.

7 Conclusion

In conclusion, while the survey captured too limited a number of respondents to representatively describe global trends, the pioneering exercise of this work still serves as an important and educational pilot and a stepping-stone for the next iteration of the GIRS. By demonstrating preliminary findings in more than 80 countries, the work serves as a proof-of-concept that online outreach to infrastructure experts can be a successful in developing a far-reaching dataset across geographies, income groups, sectors, and languages. Given careful planning which might include larger datasets, or verifiable respondents, it confirms the opportunity for a secondary approach to understanding infrastructure management beyond top-down infrastructure governance datasets. Preliminary comparisons of the GIRS data with these datasets is ongoing, but initial findings suggest that in the top-down and bottom-up approaches do not always converge to similarly positive or negative results. Based on this pilot's sample sizes these results are inconclusive, which highlights the need for a further, more robust iteration of this work which can capture even more respondents.

As a proof of concept, many of the survey's findings confirm commonly held assumptions about infrastructure management like the importance of strong and lasting policies for building resilient infrastructure systems. The data also provides preliminary evidence to highlight comparative trends where it indicates that at the global scale, most nations see their drinking water and road sectors significantly impacted most frequently. The infrastructure management index results go on to suggest that the road and wastewater sectors are the most in need of management support given their relatively low scores in the Financial Stability for Resilience and the Institutional Autonomy and Technical Capacity components. In fact, based on the metrics of the survey, it appears that all sectors perform comparatively weakly in the Institutional Autonomy and Technical Capacity component—chiefly around issues of low resilience to political turnover and intuitional autonomies that are hampered due to existing agreements.

One of the findings routinely supported by respondent feedback is the opportunity for a centralised database which would, at a minimum, amass multiple sectors' information for intersectoral use. At a maximum, some experts view this database as a part of an institution that might also regulate data quality and access while ensuring uniform data use for planning across different branches of the government. The survey's responses show that this kind of repository already exists in some form for many actors, but its use isn't yet ubiquitous. Despite potentially broad support for this approach, there are several impediments that might hinder the implementation and usefulness of a data repository in different local contexts—most notably, these include incentivising data reporting at quality, maintaining a secure database, and the technical costs of hosting and administration.

While the potential takeaways from the survey are great, more than anything, the results demonstrate a need for greater qualitative data assessment in infrastructure management and resilience. Meaningfully for the survey, this applies both in terms of the number of respondents, but also in terms of greater depth of survey questions. For the former, the survey analysis recognises that with a greater number of respondents providing more statistically robust results would be easier and that the dataset would not be prone to skew due to individual outliers. For the latter, there is a case to be made that the inter-sectoral nature of the analysis sacrificed useful depth of questions for the ability to be widely applied across the globe. One possible improvement in future analyses might be the development of distinct sector-specific surveys, which ask questions that wouldn't be cross-applicable, but might elucidate more nuanced management constraints faced uniquely by sector actors. This sector-specific surveying approach may require more engagement but will also allow the next GIRS to focus its data collection efforts resulting in not only an improved number of respondents, but also in improved quality of responses. Of course, these potential improvements come with an associated cost to be considered. Regardless of whether the survey's questions or form changes in the future, engaging in a further iteration of the survey is imperative as it enables the tracking infrastructure management over time—the novel dataset idea that sparked this project's interest.

Appendix

A1. Critical Success Factors Contributing to Infrastructure Management Component

Summary Infrastructure Management CSFs	Study Source
Policy	
Project's Alignment with Political Objectives	3,4,7,6,10,13,14,15
Alignment of Long-term Policy Goals with Project Goals	4,6
Transparency in Project Procurement and Evaluation	7,8,10,12,13
Maintenance and Standards	
Extent and Transparency of Regulatory Hurdles	7
Stringency of Environmental Permitting Requirements	14,17
Accountability and Enforcement	
Burdensome Inter-Infrastructure Regulatory Requirements	7,18
Project Strategy Enforcement Capacity- Legal	3,6,7,8,9,15,16,17
Disaster Response Capacity	
Availability of Suppliers for Routine Operations	1,15
Availability of Historical and Future Data on Disasters	2,7,12,14
Financial Capacity	
Market Technology Stability	1, 4, 12,18
Favourability of Financing and Lending Policies	1,2,5,15
Institutional Stability and Capacity	
Autonomy in Decision-Making	4,7,8,10,18
Project Strategy Enforcement Capacity- Human	3,7,11,12
Coordination and Cooperation Capacity	4,7,8,11
Stable Political System	1,7,14,15
Community	
Project is Favourable in Public Perception	1,3,4,13,14,15
Public Trust in Project Implementing Body	3,7
Stable Macroeconomic conditions	1,4,6,16
Long-term Demand for Infrastructure Service	1,5,13,15

1- Mohhamed & Alshoush, (2018)
2- Budayan, (2018)
3- Zakaria et al., (2017)
4- Shi et al., (2016)
5- Sanni, (2016)
6- Chou et al., (2015)
7- Liu et al., (2015)
8- Hwang et al., (2013)
9- Ng et al., (2012)
10- Chou et al., (2012)
11- Meng et al., (2011)
12- Chan et al., (2010)
13- Li et al., (2007)
14- Jeffries, (2006)
15- Zhang & ASCE, (2005)
16- Jamali et al., (2004)
17- Jeffries, (2002)
18- Jolowo, (2014)

A2. Summary of Global Infrastructure Resilience Questions

	Summary List of Expert GIRS Questions
	Background Questions
A	Sector Expertise, Profession Background, and Perspective
B	Countries of Expertise (Primary and Secondary)
C	Hazard Resilience–Type, Impact, Recovery Time, Frequency
D	Infrastructure Data Availability
E	Relative Importance of Infrastructure Management Categories
	Policy
F	Policy Existence
G	Policy Attributes–Clarity, Application Consistency, Improvements, Stakeholder Engagement
	Maintenance and Standards
H	Maintenance Practice Existence
I	Maintenance Practice Attributes–Regularity, Formality, Clarity, Upgrades
J	Design Standards Existence
K	Design Standards Attributes–Climate-relevant, Flexible
L	Maintenance and Standards Development–Technically-grounded, Stakeholder-informed
M	Maintenance and Standards Financing–Adequacy, Dependability
	Accountability and Enforcement
N	Accountability and Enforcement Practice Existence
O	Common Types of Management Violations
P	Accountability and Enforcement Attributes–Investigations, Penalties, Timing, Equitability
	Disaster Response Capacity
Q	Disaster Preparedness and Response Practice Existence
R	Attributes of Disaster Response Plans–Early Warning Systems, Infrastructure Interdependencies
S	Data Availability and Utilisation for Disaster Planning
	Financial Capacity
T	Financial Capacity Supporting Resilience Existence
U	Financial Capacity Supporting Resilience Attributes–Current and Future Adequacy, Dependability
V	Effectiveness of Spending
	Institutional Stability and Capacity
W	Local Technical Capacity
X	Infrastructure Ownership and Operations
Y	Institutional Responsibilities, Roles, and Autonomy
Z	Institutional Stability to Political Turnover

A3. Expert Advisory Group Members

	Representing Institution or Background	Member
1	Co-Chair CDRI Executive Committee	Kamal Kishore
2	Lead Author - CDRI Flagship Report on Disaster and Climate Resilient Infrastructure	Andrew Maskrey
3	GCA - Global Centre on Adaptation	Nitin Jain
4	UNOPS - United Nations Office of Project Services	Scott Thacker and Geoffrey Morgan
5	UNDRR - United Nations Office for Disaster Risk Reduction	Abhilash Panda
6	OECD - Organisation for Economic Co-operation and Development	Michael Mullan
7	FCDO - Foreign, Commonwealth and Development Office	Mark Harvey
8	Global Infrastructure Hub	Thomas Maier
9	Willis Towers Watson	Matt Foote
10	Global Infrastructure Investor Association	Jon Phillips
11	Director of the National Integrated Planning and Programme Unit, Department of Finance - Government of Saint Lucia, St Lucia	Haward Wells
12	Resident Senior Fellow – IDFC Institute, India	Jagan Shah
13	Advisor, ADB Headquarters, Philippines	Balabhaskar Reddy Bathula
14	Haiti Representative, GeoHazards International, Haiti	Dr. Garmalia Mentor-William
15	Deputy Chief Executive, National Disaster Management Authority, Maldives	Umar Moosa Fikry
16	Infrastructure Specialist, ADB	Shinjini Mehta
17	Associate Director, International Research Methods, Pew Research Center	Patrick Moynihan
18	Senior Economist, World Bank	Jun Rentschler
19	Director, Arup	Juliet Mian

A4. Detail Review of Considered Survey Biases

A4.1 Selection Biases

A4.1.1 Expert population Bias

Inherent to this project's methodologies are two important kinds of selection bias. Firstly, as discussed in the Limitations section of the report, the Expert GIRS accommodates a deliberately broad definition of expert, which is self-described by respondents. A significant challenge with this inexact approach lies in the analysis of the survey's results. Most analyses developing statistical conclusions rely on the known or assumed relationship between the sampled population (n) and the total population of a system (N)–this information allows researchers to extrapolate findings and determine whether they are representative and significant. With the decision to solicit and accept expert responses without any strict definition, the total population of "infrastructure experts" (N here) becomes difficult to ascertain or estimate. Secondly, to reach these individuals, the project takes a joint Expert- and Snowball- Sampling approach in which we identify likely experts and expert associations, reach out to them to complete the survey, and ask them to disseminate the survey further across their networks. This approach selects for experts that are well known and connected to CDRI and the University of Oxford but may exclude experts from more local levels infrastructure management and thus introducing bias.

A4.1.2 Online Sampling Bias

Another bias of the collected data inherent to the online survey method is its exclusion of offline respondents. While there is an expectation that most infrastructure experts would have access to internet services via their institutions, this cannot be universally assumed. Especially in geographies where in-home broadband telecommunications are uncommon, online survey modes can lead to an exclusion of less advantaged populations. The anticipated outcome of this systematic exclusion is an under-representation of infrastructure services that serve less economically developed geographies and communities. In an attempt to mitigate this effect, the survey was designed and deployed for mobile phone access with the expectation that a wider range of socio-economic groups could reasonably engage through this channel.

A4.1.3 Language limitations

The results of this project are influenced because English is the primary language of this research's literature review and project analysis. For the PRISMA conducted, only research published in English was considered, likely meaning that the findings under-represent factors in countries where English is not the language of infrastructure management. Foundationally, this means that the summary categories established describing infrastructure management may not represent the factors in those countries.

While the Expert survey was translated across the six primary UN languages (English, French, Spanish, Simplified Chinese, Arabic and Russian) to be able to collect data from a range of nations, limitations in funding prohibitively restrict the use of open-ended questions which would require unpredictable translation of the results. This limits the ability of the survey to collect nuanced information describing infrastructure management. The survey does contain a limited number of open-ended questions meant to mitigate the effects of this limitation by directly collecting information on these complex interactions.

A4.2 Response Biases

A4.2.1 PRISMA Categorisation

The categories of the Expert GIRS were established based on the PRISMA analysis from 2019-2020 and already new work in the field lends insights into developing new categories (Boroto, 2022). In addition to this, the project recognises that the approach taken has inherent biases. Notably, the review only captured a selection of the existing and completed infrastructure projects published in English language journals. Of those, the PRISMA did not consider the quality of the papers reviewed but did note the absence of unsuccessful infrastructure projects in the published literature. Without information on those unsuccessful projects, it is possible that the Critical Success Factor summary categories miss important infrastructure management elements. With only closed-ended questions in the survey, this categorisation limits the kinds of answers respondents can give.

A4.2.2 Survey Question Design

Introducing response bias in survey design is inevitable, but through the guidance of the EAG and survey pilot process, the project has worked to identify and correct for the most significant of these. Despite this however, some known biases persist in the survey that are considered essential for the data collection:

Recall, recollection, or availability bias occurs when respondents provide information based on recent or memorable event occurrences rather than factual or quantitative data. In asking survey questions about hazard events, we anticipate that responses will be biased towards more memorable or impactful events.

Agreement bias occurs when respondents provide information to surveys which is disproportionately positive to either produce a positive survey outcome or to meet a perceived desire from the surveyor. This perception can stem from the wording of questions or a desired result from the perspective of the respondents. For the GIRS, this bias is of real concern if it makes respondents unable to identify shortcomings in infrastructure management. The project addresses this by removing charged or influential language from the survey questions and by providing anonymity to its respondents to avoid conflicts of interest.

Survey fatigue bias occurs when respondents speed through surveys by answering questions without due consideration, thus minimising the quality of the collected responses. This generates erroneous data which obscures results while being difficult to remove or account for. This occurs more commonly in surveys that are: a) long, or b) provide an incentive. The GIRS faces both of these challenges and to mitigate these them it: a) informs respondents of a "return" policy whereby respondents can leave and return to complete the survey within two weeks, and b) always provides respondents with an "I don't know" option which allows their rushed responses not to skew the bulk of considered responses.

A5. Survey Outreach

The survey was then openly piloted in 7 countries and feedback was collected on the survey's design. The countries selected were Chile, Fiji, Japan, Nepal, Singapore, St. Lucia, and Tajikistan, which were selected across a range of languages, continents, and socio-economic backgrounds to better understand how the survey would be received in each context. The piloting methods were varied dependent on stakeholder engagement and availability in each location, resulting in differing qualities in survey responses. Useful feedback and conclusions were drawn and applied in a secondary round of survey question improvements. In its current form then, the survey consisted of roughly 20 core questions on the respondent's background and their infrastructure's resilience, followed by a variable number of infrastructure management questions dependent on the respondent's expertise and appetite for questions.

The survey is being deployed using an online survey platform, Qualtrics, and it targets infrastructure experts as those with sufficient knowledge to answer questions in infrastructure management. The intended respondent, "experts" are loosely defined as we recognise that many experts in a field may carry different titles while all having useful insights. To accommodate and account for this in the processing of the results, the survey asks respondents to self-identify their profession and the perspective of their expertise. The decision to use this approach for the survey was collaboratively made by the project's management, researchers, and EAG as the most likely to garner the responses needed. The project aims to collect as many responses as possible to achieve a sufficiently large sample size in this research. To do so, we engage in seven different outreach strategies briefly described in Table 3 below.

Table A5-Survey Outreach Strategies Jointly Identified by the CDRI and UO teams.

	Strategy	**Description**
1	Social Media Outreach–Paid	Campaigns with online services able to directly advertise to sector experts for a cost. Facebook and Linkedin advertisements were evaluated as options during the pilot phase of the project.
2	Social Media Outreach–Unpaid	Social media posts from CDRI and the University of Oxford's organisational accounts.
3	CDRI Correspondence Outreach	Broad email outreach to a list of over 5000 specialised infrastructure-relevant individuals.
4	CDRI In-country Outreach	Targeted email outreach to volunteer infrastructure contacts in 62 CDRI member nations worldwide.
5	CDRI Internal Outreach	Campaign capturing dedicated answers from CDRI expert staff.
6	EAG Outreach	Campaign disseminated via EAG member networks leveraging global reach, range of sectors, and variety of perspectives.
7	Professional Infrastructure Bodies	Outreach via external professional groups and organisations in their media and newsletters. Examples of this include UNOPS, WFEO, and AWWA.

A5. Comparative Table of Similar Global-Level Surveys

Survey	Project Operators	Team Size	Languages	Survey Period	Number of Questions	Number of Respondents	Estimated Cost per Respondent
World Risk Poll	Lloyd's Registry and Gallup	5000 + Interviewers	Exhaustive	1 month per nation	75	154,195	$100
Global Competitiveness Report	World Economic Forum	7+ Researchers	42	1-4 months	80	14,303	Unknown
Global Infrastructure Resilience Survey	Coalition for Disaster Resilient Infrastructure	4+ Researchers and Staff	6	3 months	15-55	700	$137-242

A8. Preliminary Calculations of Alternative Confidence and Error Ranges

Expert - Max 162,000 per sector; 1,134,000 all sectors				
Confidence (Error)	**95% (5%)**	**90% (10%)**	**80% (20%)**	**50%(50%)**
Needed Respondents by Country by Sector	Max 379	Max 68	Max 10	Max 1
Respondents per Sector Globally	27,356	8,313	1,687	94
GIRS Total # of Respondents	191,493	58,187	11,811	658

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