British Geological Survey

Geoscience for Sustainable Futures: our journey towards impact

BGS National Capability — Official Development Assistance Programme (NE/R000069/1)

Open Report OR/22/017

BRITISH GEOLOGICAL SURVEY

BGS NATIONAL CAPABILITY — OFFICIAL DEVELOPMENT ASSISTANCE PROGRAMME

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Geoscience for Sustainable Futures: our journey towards impact

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Front cover

The Sustainable Development Goals (from www.un.org/sustainabledevelopment/)

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The ODA-NC Geoscience for Sustainable Futures programme (2017–2021) involved around 170 staff from BGS and over 30 partners around the world. We are grateful to them all for their commitment to achieving the positive outcomes and impacts for development that are presented in this report.

Contents

FIGURES

TABLES

Executive summary

This report describes the BGS Geoscience for Sustainable Futures (GSF) National Capability (NC)/Official Development Assistance (ODA) programme. It used ODA funding to advance collaborative geoscience research and innovation to address challenges in lower- and middle-income countries. We describe the programme's progress towards achieving lasting change ('impact') in the contexts where activities were carried out. These activities were organised into projects under three research platforms (RPs) focusing on different development issues and working in different regions:

- RP1: integrated resource management in eastern Africa (addressing the UN's Sustainable Development Goals (SDGs) 2, 3, 6 and 12)
- RP2: resilience of Asian cities (SDGs 6, 11 and 13)
- RP3: global geological risk (SDGs 1, 9 and 11)

For each platform, a 'Theory of Change' (ToC) approach was used to plan and navigate the pathway to impact. This approach requires first analysing the institutional and environmental context of the location being considered, so that an impact objective may be defined. From this, the behaviour and capacity changes ('outcomes') that are expected to lead to that impact are identified. Those outcomes will rely on outputs such as reports, policy briefing notes, databases and web portals, which are produced by various activities, such as workshops, research and conference attendance. An idealised ToC is shown in Figure 1. The theories of change developed during the programme in this report are significantly more complex.

Figure 1 Idealised 'Theory of Change'.

As of 27 May 2022, the programme's outputs include:

- 96 peer-review journal articles
- 42 reports
- 8 book chapters
- 15 maps
- 14 technical products, databases and datasets
- 4 webtools

Around 200 engagement activities have also been undertaken.

To assess how much progress the RPs have made towards producing outcomes and impact, 'impact narratives' were prepared for each project and analysed to determine the types of outcome that had emerged or were emerging as of August 2021:

- conceptual: changes in knowledge, understanding and attitudes
- capacity (skills) strengthening: increased ability (of individuals and organisations) to conduct similar work in future
- enduring connectivity: changes to the existence and strength of networks of people and one-to-one relationships, and organisations who understand and can make use of the research
- instrumental: changes in policy and practice

While it is possible to point to many positive outcomes arising from the GSF programme (Table 1), we recognise the journey to impact is not yet over. The knowledge, skills and relationships developed will potentially contribute to further outcomes and impact after the programme ends.

Maximising this potential impact will depend on the steps taken by BGS staff and our partners in the coming months and years.

Numerous lessons have been learned during the programme about doing impact-focused research and using ToC. They point to the need for greater input from partners in:

- developing theories of change
- detailed stakeholder mapping
- emphasising knowledge brokering activities
- clear indicators of progress towards impact that can be monitored both during a project and after it ends

1 Introduction

The British Geological Survey (BGS) is a world-leading geological survey and global geoscience organisation focused on public-good science for Government and research to understand Earth and environmental processes (BGS, 2019).

Understanding of the geological environment underpins many aspects of international development, such as identifying and managing mineral resources and reducing disaster risk resulting from geohazards. For many years, BGS has undertaken projects in low- and middle-income countries around the world that aim to support development (e.g. geological mapping; strengthening capacity of geological survey organisations) and carrying out applied research.

From 2017 to 2021, the BGS increased the proportion of its research budget spent on Official Development Assistance (ODA) by establishing and delivering the Geoscience for Sustainable Futures (GSF) programme. This programme focused on contributing to the economic development and welfare of ODA eligible countries by working with governmental and academic institutions to address pressing geoscientific research challenges with direct connections to communities' needs.

2 Geoscience for Sustainable Futures

The United Nations' Sustainable Development Goals (SDGs) aim to end poverty, fight inequality and injustice, improve health and education and ensure environmental sustainability, with an emphasis on 'leaving no one behind' (UN, 2015). Many of the 17 goals address challenges that span the interface between the physical environment and human activities, and geoscience can play a crucial role in tackling these challenges (Gill and Smith, 2021) by, for example:

- ensuring access to sufficient and nutritious food
- identifying and protecting water resources
- developing sustainable cities
- tackling energy poverty
- understanding the impacts of environmental change
- increasing resilience to natural hazards

The aim of the Geoscience for Sustainable Futures (GSF) programme (2017–2021) was to deliver new data and research and strengthen geoscience-related capacity to support the delivery of multiple SDGs in three areas:

- supporting responsible use of natural resources in eastern Africa
- improving city resilience in India and south-east Asia
- improving resilience of communities to geohazards in hazard prone locations around the world

To do this, the programme was organised into three inter-connected research platforms (RPs) each focusing on one of these areas.

- RP1: integrated resource Management in eastern Africa (SDGs 2, 3, 6 and 12)
- RP2: resilience of Asian cities (SDGs 6, 11 and 13)
- RP3: global geological risk (SDGs 1, 9 and 11)

Central to the GSF programme's ethos was SDG 17: 'strengthen the means of implementation and revitalise the global partnership for sustainable development'.

Each RP undertook research and capacity strengthening activities in collaboration with local partners in a range of countries eligible to receive ODA funding. Each platform consisted of several tasks, which contributed to its overall aims.

As part of the UK's commitment to ODA, the GSF programme had to ensure it was fully ODA compliant. To do this, the programme followed guidance set out for similar research-for-development programmes, such as the UK Global Challenges Research Fund (GCRF). The guidance given by UKRI for the GCRF (UKRI 2016; 2018) states that projects should:

- seek to investigate a specific problem or seek a specific outcome that will have an impact on a developing country or countries on the OECD Development Assistance Committee (DAC) list of ODA recipients.
- provide evidence as to why this is a problem for the developing country or countries
- address the issue identified effectively and efficiently
- use the strengths of the UK to address the issue, working in collaboration with others as appropriate
- demonstrate that the research is of an internationally excellent standard
- identify appropriate pathways to impact to ensure that the developing country benefits from the research

The ability of a programme like GSF to contribute to lasting change requires involvement of diverse stakeholders. Partnerships with local organisations and national and international networks have been the foundation of the GSF programme. Besides their expertise, partners also bring a deeper understanding of the political, economic, social and institutional

characteristics of their own regions that will shape how change happens. This knowledge should therefore underpin impact planning and the RPs identified opportunities to bring partner knowledge and experience into the discussions about how impact could be achieved.

2.1 RP 1: INTEGRATED RESOURCE MANAGEMENT IN EASTERN AFRICA

Eastern Africa faces natural resource challenges due to exponential population growth, rapid urbanisation and economic development. This platform aimed to contribute to improved human welfare and future economic development by characterising resources in the context of a changing natural and social environment.

Key research themes included:

- understanding the links between geology, soils, water and agriculture to help tackle micronutrient deficiencies ('hidden hunger')
- investigating the diverse natural and anthropogenic stresses on groundwater resources, aiming to improve and ensure water security and quality
- assessing the location, extent and characteristics of critical metal resources, which are essential for use in many technologies, including those required for the energy transition

This RP's activities took place in Kenya, Malawi, Tanzania, Uganda, Zambia and Zimbabwe.

2.2 RP 2: RESILIENCE OF ASIAN CITIES

Asian cities are exposed to multiple natural hazards and environmental stresses, rapid urbanisation and significant uncertainty regarding their resilience to environmental change. This platform aimed to contribute to improving urban resilience by integrating geoscience knowledge in urban subsurface planning and decision making, and urban-catchment science, in India and south-east Asia.

Key research themes included:

- using data informatics, sensor technologies and modelling systems to:
    - improve integrated urban planning
    - identify new and economically viable uses of the subsurface and its resources
    - avoid conflicting and potentially harmful subsurface uses
- understanding the diverse stresses faced by cities and the suburban surroundings to help strengthen development of planned, resilient city networks

This platform worked in India, Malaysia and Vietnam with engagement in wider, regional networks.

2.3 RP 3: GLOBAL GEOLOGICAL RISK

Geological hazards, such as those associated with volcanic activity, earthquakes and landslides and their potential risk and impacts are of great concern for sustainable development. Understanding these dynamic processes and their effects and using this information to improve disaster (risk) management can increase the security and sustainability of development, and protect lives and livelihoods.

Key research themes included:

- characterising complex, multi-hazard processes in the Caribbean, eastern Africa and Asia
- integrating citizen science, innovative technologies and understanding of environmental processes, hazards and impacts to strengthen resilience
- providing information to governments, mandated authorities and non-governmental organisations (NGOs) involved in responding to disastrous or significant hazard events

The global nature of RP3 meant the platform was active in many counties including Ethiopia, Tanzania, India, Nepal and St Vincent and the Grenadines. The platform also engaged with wider regional and global networks.

2.4 COMPLEMENTARY ACTIVITIES

While the research conducted within the GSF programme was undertaken within the three RPs, there were also complementary, cross-cutting activities. The aims of these were to raise awareness of the role of geoscience in delivery of the SDGs and share learning from the programme with other geoscientists around the world.

Examples include:

- contributions to national and international committees and networks, focused on themes aligned to geoscience for sustainable development (e.g. the steering committee of the Global Network for Geoscience and Society; international meetings of the UNESCO International Geoscience Programme)
- publication of a book *Geosciences and the SDGs*, with 42 authors from across six continents (including 12 from BGS), examining how geoscientists can contribute to each of the 17 SDGs
- presentations and side events at national and international meetings, including an earth science-focused side event at the 2019 UN Forum on Science, Technology and Innovation for the SDGs

3 The journey towards impact

This report focuses on the outcomes and impacts of the GSF programme. These are the result of a large amount of work by around 170 BGS staff and their partners (Appendix C). In this section, the programme's approach to achieving impact through the use of the Theory of Change (ToC) approach is described along with the progress that has been towards achieving positive impact in the countries involved. This builds upon many collaborations that have resulted in numerous outputs. As of 27 May 2022, this includes:

- 96 peer-review journal articles
- 42 reports
- 8 book chapters
- 15 maps
- 14 technical products, databases and datasets
- 4 webtools

There were also around 200 engagement activities.

Achieving impact requires time; impacts may only manifest after a research programme ends. However, since research knowledge will exist beyond the life of a project, any outputs produced may potentially inform or change policy and practice long after the project ends (Shaxson, 2016). Specific actions, including stakeholder mapping and context analysis, can help to catalyse impact. This can inform impact strategies, ensuring that planning to support the generation of impact is embedded into project management, effective communication with stakeholders, and monitoring of progress. A ToC approach to planning and monitoring progress towards goals can support these actions.

In this section, we first describe the ToC approach and how we anticipated realisation of impact for each of the three research platforms (Section 3.1). We then discuss the progress made using a ToC approach and the evidence for this (Section 3.2). This enables us to characterise the outcomes of the GSF programme (Section 3.3) and describe potential future impacts after the programme ends (Section 3.4). Potential future impact and the steps that may be required to achieve and monitor progress towards this are discussed in Section 4.

3.1 THE 'THEORY OF CHANGE' APPROACH TO PLANNING AND MONITORING IMPACT

'Theory of Change' (ToC) is an approach or tool used in international development programming. It is a theory of how and why a set of activities will bring about certain changes in the short, medium and long term and lead to a desired goal. The ToC approach is implemented by first analysing the context to understand the problem to be tackled, so that a desired impact or goal can be articulated. From this, the behaviour and capacity changes ('outcomes') that are expected to lead to that impact are identified. In this context, capacity changes include changes to knowledge, skills, attitudes and opportunities. Behaviour changes are longer-term outcomes. This characterisation of a 'pathway to impact' is then used to determine the outputs (e.g. reports; policy briefing notes; databases; web portals) that will contribute to the desired outcomes and the activities (e.g. workshops; research; conference attendance) needed to deliver these outputs. This process is illustrated in Figure 1. Note that, while it is shown as a simple, linear process in Figure 1, the pathway to impact is usually significantly more complex.

Progressing from outputs to wider impacts on society often involves multiple stakeholders, institutions and projects and, therefore, will be outside the direct control of a particular project. The process represented in Figure 1 is therefore supported by the identification of key stakeholders (i.e. those who will have a fundamental effect on achieving the project's impact objective) who have the power to influence others or the project and have an interest in the work (either positive or negative). Critical reflection on the steps needed to extend a project's influence (e.g. through partnerships, diplomacy or knowledge brokering) can help increase the likelihood of impact in the medium to longer term.

Since ToC is a theory about how a change will happen, the assumptions that it rests on must be made explicit. For example, improved earthquake hazard information will lead to decision

makers being able to make decisions about how to manage that hazard, assuming they are able to access and use that information. Documenting these assumptions and tackling any issues that are identified is crucial to minimising barriers to impact.

Both development practitioners and academics have applied the ToC approach in diverse contexts (Vogel, 2012). The approach has several benefits, including:

- ensuring activities (and therefore ODA investments) are focused on delivering impact, with the design of appropriate pathways that consider factors within a project's spheres of control, influence and interest
- active identification of potential, unintended, negative consequences arising from the project's activities, and determination of appropriate mitigation steps to reduce harm
- the ability to define indicators and develop a monitoring plan to:
    - assess progress through the ToC
    - test assumptions
    - identify any required additional actions to catalyse movement from outputs to impact (e.g. using research outputs in diverse knowledge exchange activities)

The Economic and Social Research Council (ESRC) provides a non-exhaustive list of factors that support the generation of impact (ESRC, 2021) including:

- establishing networks and relationships with research users
- involving users at all stages of the research
- developing good understanding of policy and practice contexts

3.2 USING THE THEORY OF CHANGE APPROACH IN GEOSCIENCE FOR SUSTAINABLE FUTURES

In 2017, the GSF core team completed initial ToCs for the RPs, setting out how the planned activities would deliver impact (Figure 2, Figure 3 and Figure 4). Each ToC shows how activities or interventions (left-hand side of the ToC) were assumed to lead to a theorised network of outcomes (from left to right of the ToC), and progress to the desired, high-level impact (right-hand side of the ToC). High-level assumptions were also defined (Appendix A; Figure 4).

RP ToCs were used to reflect on the programme and to assess progress towards outcomes and impacts, although it could be argued they could have been revisited and reviewed more frequently, especially with partners.

Three years into the programme (2020), a Monitoring, Evaluation and Learning (MEL) group for the programme was set up. This led to a greater effort to understand the progress that was being made towards impact across the programme's activities and how this progress connected to the RP ToCs.

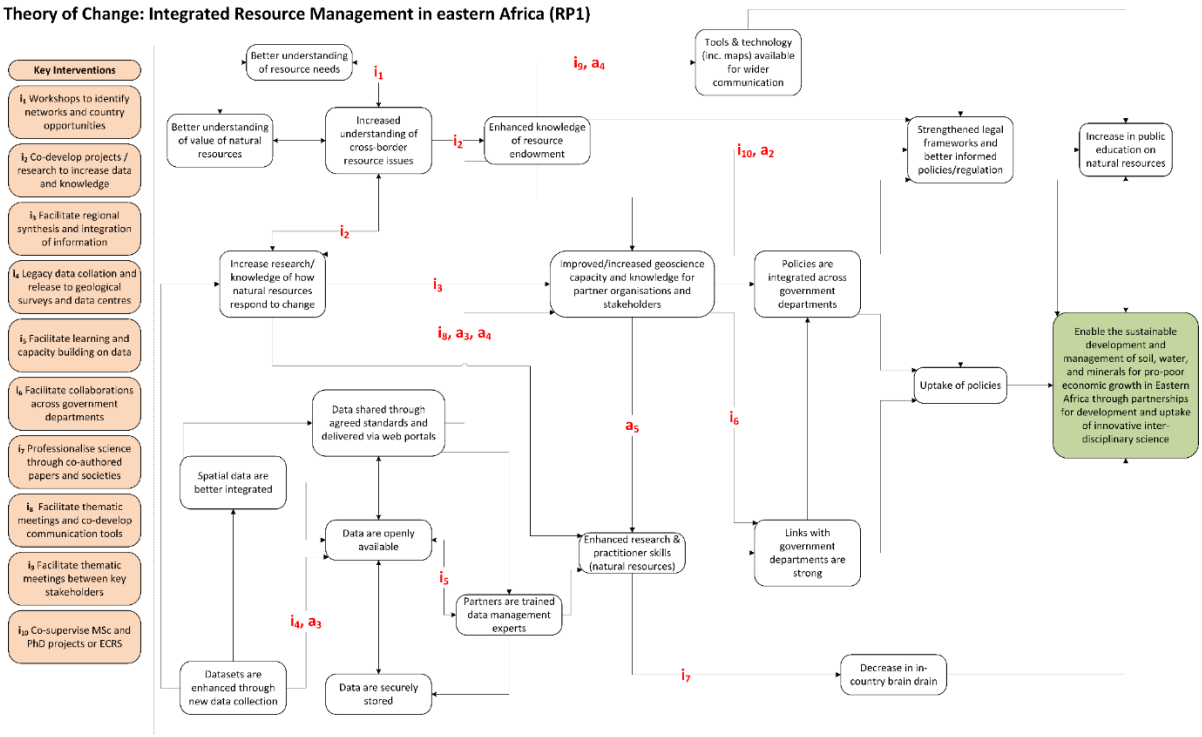

Figure 2 RP1 Theory of Change. Assumptions (a1–a5) are given in Table A1.

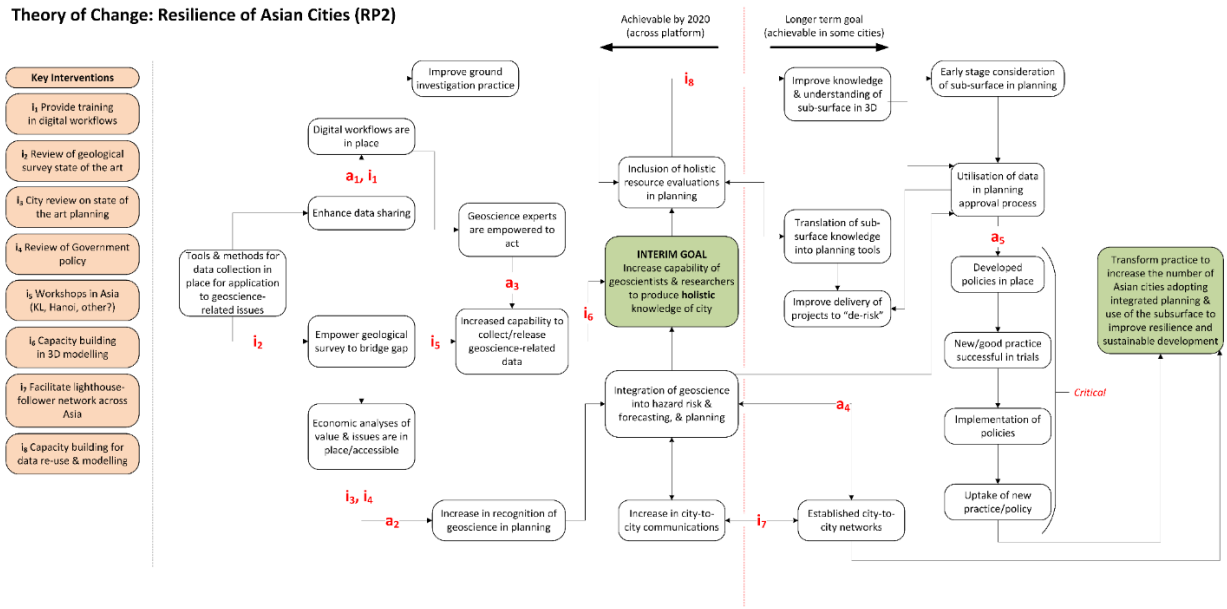

Figure 3 RP2 Theory of Change. Assumptions (a1–a5) are given in Table A2.

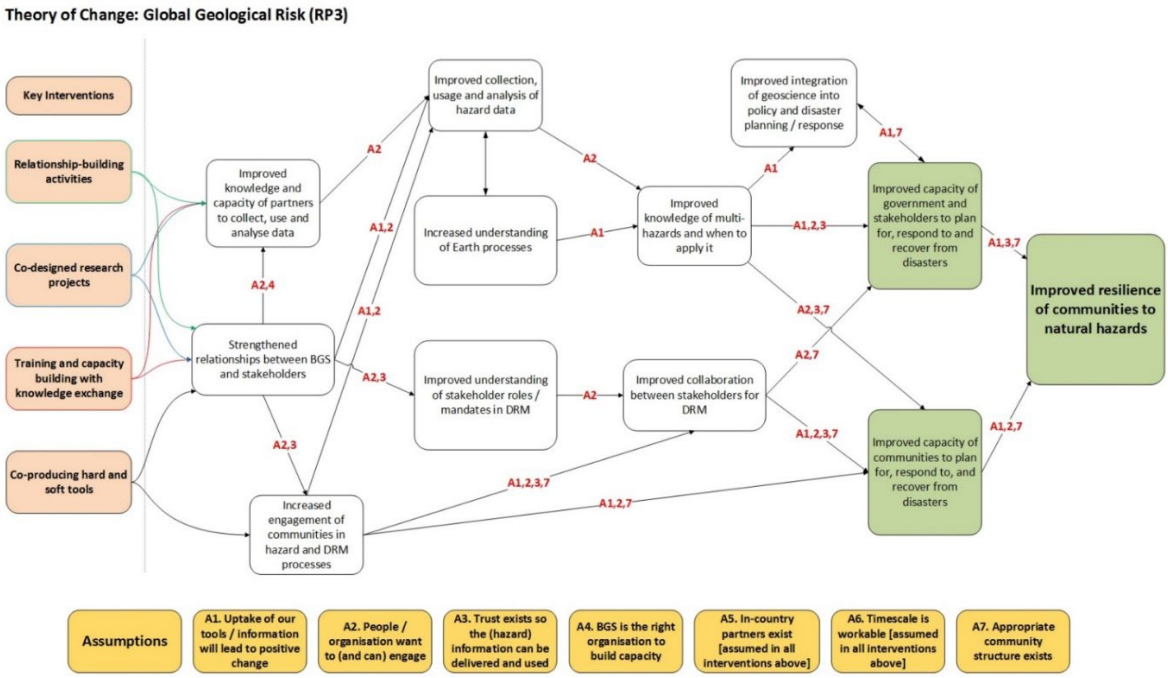

Figure 4 RP3 Theory of Change.

3.3 CHARACTERISING OUTCOMES OF OUR WORK

3.3.1 Types of outcome

Shaxson (2016) outlines four types of impact, which, in the context of the GSF programme and its use of ToC (see Sections 3.1 and 3.2), we refer to as 'types of outcome' or steps towards the high-level, development impact. These types of outcome are:

- conceptual: changes in knowledge, understanding and attitudes
- capacity (skills) strengthening: increased ability of individuals and organisations to conduct similar work in future
- enduring connectivity: changes to the existence and strength of networks of people and one-to-one relationships, and organisations who understand and can make use of the research
- instrumental: changes in policy and practice

A project may contribute to more than one of these four types of outcome and the delivery of one outcome may result in a cascade of others. For example, developing new understanding of a topic (conceptual) could result in changes to the way students are taught (capacity strengthening), which then contributes to a different professional standard or understanding of good practice in a region (instrumental).

3.3.2 Outcomes of GSF activities

To examine the outcomes of GSF, the MEL group designed a template to collect 'impact narratives' from each task contributing to the programme. This template (Appendix B) included questions on:

- work undertaken
- the most significant arising outcomes (with evidence)
- potential future impacts
- key learning

Task leaders were asked to complete and return the template, liaising with others as necessary. The information given was used to characterise the types of outcome achieved by each task, using the classification in Section 3.3.1. The results of this process are set out in Table 1.

In this section, we outline each task completing a narrative, grouped by RP, and the types of outcome achieved. In the following sections (Sections 3.3.3 to 3.3.6) a selection of examples from specific tasks is used to illustrate the types of outcome achieved. Where a task narrative is used to illustrate one specific type of outcome, this does not preclude it from making actual or potential contributions to other outcomes.

Table 1 shows the known, significant types of outcome arising from activities at the time that narratives were written (i.e. further outcomes may have been realised and/or observed since, or may be realised in the near future or longer term). For many tasks, there was limited active and systematic collection of evidence to support understanding of any outcomes and progression towards impact. Future programmes would benefit greatly from an improved approach to documenting evidence of impact.

Table 1 Summary of outcome types for tasks in GSF. **Research platform**	**Task name**	**Outcome type**			
		Conceptual	Skills strengthening	Enduring connectivity	Instrumental
RP1	A: support to African groundwater community	■	■	■	■
	B: mining practice and recovery of gold in Migori County, Kenya	■	■		
	C: critical raw materials in eastern Africa	■			
	D: using earth observation data for mining sites and their evolution in time along the Migori river catchment area	■			
	E: environmental geochemistry and health	■	■	■	
	F: effective and innovative ways of managing and delivering geodata	■	■		
	G: rural water supplies during drought in Ethiopia	■			
	H: real-time monitoring of faecally contaminated drinking water	■	■		
RP2	I: 3D Kuala Lumpur pilot study	■	■	■	
	J: Kuala Lumpur geology	■	■		
	K: south-east Asia urban geology partnerships	■	■	■	■
	L: east Asia materials flow analysis	■	■		
	M: earth observation for assessment and monitoring of the urban environment and hi8azards	■	■		
RP3	N: national landslide susceptibility modelling — Ethiopia	■			
	O: METEOR	■	■	■	
	P: myHAZ – a multi-hazard, citizen science app for St Vincent and the Grenadines (SVG)	■	■	■	■
	Q: Pathways to Action	■	■		
	R: geophysical technologies for landslide monitoring and early warning (India)	■	■		
	S: seismic hazard in Bandung, Indonesia	■			
	T: groundwater depletion (South Asia)	■		■	
	U: science into decision making in Ethiopia	■	■	■	■
	V: multi-hazards in the East African Rift	■	■	■	■
	W: volcanic event response	■		■	■
	X: global data and networks (volcanic hazards and risk)	■	■	■	■
	Y: opportunities and threats on small islands, examples from the UK Overseas Territories	■		■	■
	Z: hazard and risk data and evidence in Ethiopia	■	■	■	
	Total	**26**	**18**	**13**	**8**

3.3.3 Conceptual: changes in knowledge, understanding and attitudes

In Section 3.1, we noted that initial outcomes are often changes in capacity, including increased knowledge and understanding, or changes in attitude. Shaxson (2016) refers to these as 'conceptual' outcomes and we note from Table 1 that they are the most common outcomes of the GSF programme. Such outcomes often precede and underpin behavioural change, including implementation of improved policies or practices.

Examples of 'conceptual' outcomes are outlined in Sections 3.3.3.1 to 3.3.3.3.

3.3.3.1 CRITICAL RAW MATERIALS IN EASTERN AFRICA

BGS team:

- Eimear Deady
- Kathryn Goodenough
- Richard Shaw

Partner:

- Paul Nex (University of Witwatersrand)

Meeting the ambitions of the Paris Agreement requires sufficient raw materials to enable the energy transition. This is a significant opportunity for countries in lower- and middle-income countries that are rich in these resources, but requires operations to be responsible and as sustainable as possible.

This project investigated resources and value chains of some critical raw materials (including lithium) in eastern Africa. This information can be used by policymakers and investors to make informed decisions about the management of mining and mineral resources.

Work on lithium focused on Zimbabwe, with activities including:

- Fieldwork in:
  - the Kamativi region of Zimbabwe, to understand potential pegmatite resources in the area, in collaboration with Zimbabwe Lithium and Premier African Minerals and colleagues from the University of the Witwatersrand
  - the Harare and Masvingo areas of Zimbabwe, to understand pegmatite resources and mining in the area, in collaboration with Bikita Minerals and Prospect Resources and colleagues from the University of the Witwatersrand
- Workshops and engagement, including:
  - organising a workshop in Harare, bringing together representatives of organisations interested in lithium in Zimbabwe
  - engagement with the Zimbabwe Geological Survey and other organisations involved in the extraction of natural resources in Zimbabwe
  - presentations on lithium resources in Zimbabwe and more widely in Africa at the 9th International Symposium on Granitic Pegmatites, Ore Deposits Hub, Goldschmidt 2020 and 2021, and other online conferences
  - participation in an online workshop organised by the Centre for Natural Resource Governance (CNRG) Zimbabwe, on the lithium potential of Zimbabwe
- Preparing publications, including:
  - a report on lithium supply chains in Africa, to be published as an open report on the BGS website
  - a paper for *Canadian Mineralogist* on the geology of the Kamativi pegmatite

This work contributed to an improved understanding of the potential for Zimbabwe to make use of its lithium resources, particularly among those directly involved in the project workshops and attending the conferences noted above.

Further reading

SHAW, R A, GOODENOUGH, K M, DEADY, E A, and NEX, P. 2019. The Kamativi pegmatite: an opportunity for economic development in Zimbabwe? *The Canadian Mineralogist*, Vol. 57, 791–793. DOI: https://doi.org/10.3749/canmin.AB00023

GOODENOUGH, K M. 2020. Lithium pegmatites — an African story. *Ore Deposits Hub*. Available at: https://www.youtube.com/watch?v=x-L_EdxmWcY&t=12s

3.3.3.2 KUALA LUMPUR GEOLOGY (MALAYSIA)

BGS team:

- Marcus Dobbs
- Thomas Dodd
- Graham Leslie

Partners:

- Department of Minerals and Geosciences Malaysia – Jabatan Mineral dan Geosains Malaysia (JMG)
- —Kuala Lumpur City Hall – Dewan Bandaraya Kuala Lumpur (DBKL)
- Mass Rapid Transport Corporation (MRT)
- Public Works Department – Jabatan Kerja Raya (JKR)
- University of Malaya (UM)
- Universiti Tenaga Nasional (Uniten)

Cities and human settlements can be made more inclusive, safe, resilient and sustainable through better integration of geoscience with urban development. A key step in this process is developing a robust understanding of the geology within an urban environment and sharing this knowledge with appropriate stakeholders.

This task brought together a consortium of Malaysian geoscientists from government, industry and academia to develop a better understanding of the geology of Kuala Lumpur and share this with geoscientists working on the development of new urban infrastructure across the city and its surroundings.

This task involved:

- a desk-based study of published information on the geology of Kuala Lumpur
- a series of fieldtrips to outcrops in and around Kuala Lumpur (February 2018 to November 2018)
- discussion and debate among consortium members on various aspects of the geology of Kuala Lumpur at two workshops
- dissemination of new findings at conferences and through academic publications

Outputs from this task contributed to changes in knowledge and understanding of the underlying geology of Kuala Lumpur within the geological survey and amongst academics and consultants working in the city. For example, activities identified a major ductile shear zone in eastern Kuala Lumpur, with implications for subsurface development (e.g. excavation support; groundwater flow; geological boundaries; material re-use).

Activities also helped to characterise the heterogeneity of the Kenny Hill Formation, which comprises complex deposits beneath much of the city and surrounding areas. Improved understanding of the formation will help make the problematic ground conditions and geohazards that are associated with it more predictable, which will reduce the cost of developments and protect against geological risks.

A shared and increased understanding of the Kuala Lumpur geology has enabled the production of the first 3D geological model of Kuala Lumpur (‘3DKL’ v1.0). It has also helped to change attitudes, renewing an interest in the geology of Kuala Lumpur within Malaysia’s academic community, as evidenced by joint publications authored by JMG and the University of Malaysia.

Figure 5 Geoscientists from Malaysia and the UK. A visit to an outcrop of the Kenny Hill Formation, east of Kuala Lumpur International Airport. BGS © UKRI (2022).

Further reading

DODD, T J H, FATT, N T, ROSLE, Q A, MOHD NOH, M R, LESLIE, A G, DOBBS, M R, and GILLESPIE, M R. 2019. New insights into the sedimentology of the Kenny Hill Formation, Peninsular Malaysia. *Warta Geologi*, Vol. 45, 196–197.

HASLAM, R, and LESLIE, A G. 2019. Structural geology in the 21st century: the role of a modern geological survey. *Geophysical Research Abstracts*, Vol. 21, EGU2019-8223-1.

LESLIE, A G, DOBBS, M R, FATT, N T, ROSLE, Q A, MOHD NOH, M R, DODD, T J H, and GILLESPIE, M R. 2020. The Ukay Perdana Shear Zone in Kuala Lumpur: A crustal-scale marker of early Jurassic orogenic deformation in Peninsular Malaysia. *Bulletin of the Geological Society of Malaysia*, Vol. 69, 135–147. DOI: https://doi.org/10.7186/bgsm69202012

LESLIE, A G, FATT, N T, ROSLE, Q A, MOHD NOH, M R, DODD, T J H, GILLESPIE, M R, and DOBBS, M R. 2019. The Jalan Wangsa Thrust in eastern Kuala Lumpur; a marker for a major crustal boundary between the leading edge of Sibumasu and the Sukhothai Arc? *Warta Geologi*, Vol. 45, 174–175.

3.3.3.3 GEOPHYSICAL TECHNOLOGIES FOR LANDSLIDE MONITORING AND EARLY WARNING (INDIA)

BGS team:

- Jonathan Chambers
- Oliver Kuras
- Arnaud Watlet

Partners:

- ACWNA
- Amrita Centre For Wireless Networks and Applications
- Amrita University, Kerala, India

This project aimed to develop a novel geophysical monitoring approach in monsoonal, mountainous regions, helping to identify subsurface precursor processes to slope failure, hence improving early warning of moisture-induced landslide events.

A new geophysical monitoring system developed by BGS (PRoactive Infrastructure Monitoring and Evaluation, or PRIME) was deployed at the Munnar Landslide Observatory in Kerala, India. The system is designed as a low-cost, low-power, remote monitoring system that uses a mobile

phone network for telemetric control. It is ideally suited for deployment in resource-limited contexts with significant landslide hazards.

During the project, daily geophysical measurements were used to image the build-up of moisture in the slope during the monsoon season. This indicated an increased likelihood of slope failure.

The team engaged with Amrita University to co-design the deployment of the PRIME system in another location — Munnar— and the integration of geophysical monitoring outputs into landslide early-warning systems. Field visits supported this work, with the acquisition of additional geophysical measurements, geological mapping and soil sampling. The team also provided knowledge exchange and training activities at Amrita University, the BGS and via online sessions.

This project demonstrated the value of subsurface monitoring for improving landslide early-warning systems. It helped to change attitudes of project partners in India by increasing their understanding of the value of subsurface monitoring approaches (i.e. geophysics-based systems) to support landslide early-warning systems.

Figure 6 Geophysical technologies for landslide monitoring. A team member from Amrita University is being trained to operate the PRIME system at the Munnar Landslide Observatory. BGS © UKRI (2022).

Further reading

CHAMBERS, J, MELDRUM, P, WILKINSON, P, UHLEMANN, S, WATLET, A, SWIFT, R, INAUEN, C, GUNN, D, KURAS, O, BOYD, J, WHITELEY, J, HOLMES, J, RAMESH, M, THIRUGNANAM, H, BINLEY, A, and REEVES, H. 2019. Towards an improved geotechnical understanding of landslide hazard and slope stability from ground-based geophysical survey and monitoring. *AGU Fall Meeting 2019*, 9–13 December 2019, San Francisco, USA.

THIRUGNANAM, A, WATLET, A, SINGH, B, KUMAR, N, BRAHMANANDAN, D, RAMESH, M, SWIFT, R, INAUEN, C, MELDRUM, P, UHLEMANN, S, WILKINSON, P, and CHAMBERS, J. 2019. Monitoring slope subsurface dynamics with point sensors and geophysical imaging techniques for landslide early warning. *1st Indian Near Surface Geophysics Conference & Exhibition*, 28–29 November 2019, New Delhi, India. DOI: https://doi.org/10.3997/2214-4609.201979043

WATLET, A, THIRUGNANAM, H, SINGH, B, KUMAR, N, BRAHMANANDAN, D, SWIFT, R, INAUEN, C, MELDRUM, P, UHLEMANN, S, WILKINSON, P, CHAMBERS, J, and RAMESH, M. 2019. Deployment of an electrical resistivity monitoring system to monitor a rainfall-induced landslide (Munnar, India). *AGU Fall Meeting 2019*, 9–13 December 2019, San Francisco, USA.

3.3.4 Skills strengthening: increased ability of researchers and others to conduct similar work in future

Another outcome type linked to capacity change is the development and strengthening of the skills required by researchers and others to conduct similar work in the future. Each of the ToCs set out in Section 3.2 emphasises the need for skills strengthening to be external (i.e. with partners around the world, supporting them to fulfil their mandates). Skills strengthening may be a product of networks (see Section 3.3.5) and may also underpin behaviour change outcomes (as described in Section 3.3.6). We note that skills strengthening could also occur within BGS and evidence suggests involvement in GSF did support BGS staff to develop new skills and perspectives on science-for-development (Mills et al., 2022).

Examples of 'skills strengthening' outcomes are outlined in Sections 3.3.4.1 to 3.3.4.3.

3.3.4.1 Environmental geochemistry and health

BGS team:

- Olivier Humphrey
- Andrew Marriott
- Michael Watts

Partners:

- International Agency for Research on Cancer (IARC).
- Kenya Marine & Fisheries Research Institute (KMFRI)
- Kenyan Agricultural Laboratory Research Organisation (KALRO)
- Moi University (School of Public Health)
- University Eldoret (School of Environmental Sciences)

Advances in environmental geoscience lie at the nexus of geochemistry (soil; water; sediment), health (nutrition; toxicology; epidemiology) and agriculture (crops; livestock; fisheries). BGS and research partners are developing an integrated approach to risk assessment and public policy, with themes including:

- capturing and integrating soil geochemical processes across multiple scales
- developing predictive models of soil-to-plant micronutrient and environmental pathways of contaminant exposure to assess health consequences (e.g. oesophageal cancer incidence; soil erosion; input to lake environment)
- supporting policies in agriculture (e.g. agri-strategies; fisheries-aquaculture) and public health surveillance (e.g., geochemical maps; location of aquaculture cages)
- determining land–lake transfers via soil erosion and implications for loss of agricultural opportunity and sustainability of lake fisheries

This work combines data collection and analysis with stakeholder engagement activities. Partners across the eastern African region have been involved in all stages of the work. Skills have been strengthened in laboratory, field and data handling skills (e.g. using QGIS and R). When international travel was difficult during the COVID-19 pandemic, partners in Kenya continued fieldwork independently, drawing on previous training in Kenya. Partners have been closely involved in the write-up of the different datasets and associated publications, giving Kenyan partners the skills and track record required to participate as co- and principal investigators on grant proposals with BGS and other organisations.

Figure 7 Laboratory training at University of Eldoret. BGS © UKRI (2022).

Further reading

SAMOEI, D. 2017. A model for quality assurance, lab management and good laboratory practices for Africa. Available at: http://britgeopeople.blogspot.com/2017/10/a-model-for-quality-assurance-lab.html

WATTS, M, and OSANO, O. 2020. Continuing fieldwork in Africa despite COVID-19. Available at: http://britgeopeople.blogspot.com/2020/12/continuing-fieldwork-in-africa-despite.html

WATTS, M, MENYA, D, and OSANO, O. 2018. Geochemistry and health in the Kenyan Rift Valley. Available at: http://britgeopeople.blogspot.com/2018/11/geochemistry-and-health-in-kenyan-rift.html

3.3.4.2 EARTH OBSERVATION FOR ASSESSING AND MONITORING OF THE URBAN ENVIRONMENT AND HAZARDS (HANOI, VIETNAM)

BGS Team:

- Luke Bateson
- Tom Bide
- Teresa Brown
- Ekbal Hussain
- Carolin Kresse
- Joseph Mankelow
- Alessandro Novellino
- Evi Petavratzi

Partners:

- General Department of Geology and Minerals of Vietnam
- Hanoi People's Committee
- Ministry of Construction
- Vietnam National Space Center

The team used interferometric synthetic aperture radar (InSAR) — a form of satellite data — to analyse ground deformation (subsidence) between 2015 and 2021, aiming to understand the spatio-temporal characteristics of the ground deformation and its potential causes (e.g. groundwater abstraction; settlement). The project also used satellite data to assess construction material demands associated with urban growth between 1975 and 2020, integrating machine learning approaches.

This activity included the development and delivery of specialist InSAR and Google Earth Engine training courses to support skills transfer. These courses aimed to help scientists in Vietnam use, reproduce and update ground deformation maps, and create land-cover maps, respectively. Strengthening these skills enables future work on this research theme.

Further reading

BIDE, T, PETAVRATZI, E, BROWN, T, KRESSE, C, and MANKELOW, J. 2020. A case study for Hanoi, Vietnam: urbanisation and demand for construction materials. *British Geological Survey Open Report* OR/20/034 (unpublished).

NOVELLINO, A, BROWN, T J, BIDE, T, THỤC ANH, N T, PETAVRATZI, E, and KRESSE, C. 2021. Using satellite data to analyse raw material consumption in Hanoi, Vietnam. *Remote Sensing*, Vol. 13, 334.

3.3.4.3 MYHAZ — A MULTI-HAZARD, CITIZEN SCIENCE APP FOR ST VINCENT AND THE GRENADINES

BGS team:

- Melanie Duncan
- Anna Hicks
- Sue Loughlin
- Katy Mee
- Steve Richardson

Partners:

- NEMO: National Emergency Management Organisation, St Vincent and the Grenadines
- UWI-SRC: University of the West Indies Seismic Research Centre, Trinidad and Tobago

This project aimed to develop a citizen science smartphone tool, 'myHAZ', for residents of St Vincent and the Grenadines to share their observations of multiple natural hazards, environmental phenomena and their impacts.

Citizen science facilitates resilience building by enhancing citizens' understanding of hazards and risk, whilst also building trust and communication links between citizens, scientists, and authorities. The near-real time reporting of hazards within the app enables scientists and emergency managers to gain a rapid understanding of an evolving hazard event and its impacts, in particular for scientists who may be based remotely (i.e., the University of the West Indies Seismic Research Centre, UWI-SRC, are based in Trinidad and Tobago). Use of the myHAZ application is also encouraged during periods of quiescence, to help citizens grow in their awareness of subtle changes in their surroundings which may provide early warning to more significant events.

- The team developed the myHAZ system in collaboration with the National Emergency Management Organisation (NEMO) of St. Vincent and the Grenadines and the UWI-SRC. The system comprises three components: (1) a smartphone citizen science app; (2) a management dashboard for administering incoming observations; and (3) a web portal for visualising and downloading data collected by the app.

The team took an iterative approach to the design and development of myHAZ by gathering input and feedback from stakeholders (including:

- UWI-SRC
- NEMO
- other government departments in St Vincent and the Grenadines
- utility companies
- emergency services
- schools
- citizens

This involved three visits to the Caribbean (to St Vincent and the Grenadines and to Trinidad and Tobago) in March 2017, October 2018 and September 2019, interspersed with multiple design sprints at BGS.

The app has provided a formalised means for collecting observations of hazards across St Vincent and the Grenadines to be shared with scientists and emergency managers, providing them with a way to respond to observations by supplying further information and quelling rumours. Activities in this task also strengthened the knowledge and skills of both BGS researchers and early-career professionals in the Caribbean through shared fieldwork experiences, co-authored publications and on-the-job training and knowledge exchange.

Figure 8 Gathering feedback on the myHAZ app from communities around the island of St Vincent, September 2019. Photo Credits: Katy Mee, Steve Richardson, Anna Hicks © UKRI (2022).

Further reading

DUNCAN, M, MEE, K, HICKS, A, ENGWELL, S, ROBERTSON, R, FORBES, M, FERDINAND, I, JORDAN, C, and LOUGHLIN, S. 2017. Using the 'myVolcano' mobile phone app for citizen science in St Vincent and the Grenadines: a pilot study. British Geological Survey Open Report OR/17/045 (unpublished).

MEE, K, and DUNCAN, M J. 2015. Increasing resilience to natural hazards through crowd-sourcing in St. Vincent and the Grenadines. *British Geological Survey Open Report* OR/15/032 (unpublished).

3.3.5 Enduring connectivity: changes to the existence and strength of networks of people and organisations who understand and can make use of research

'Connectivity' — changes to the existence and/or strength of networks of people and organisations who understand and can make use of research — supports both conceptual and skills strengthening outcomes and is often necessary to change policy and practice. Enhanced connectivity and networks have been a key part and legacy of BGS's work in the GSF programme.

Examples of connectivity or network building/strengthening outcomes are outlined in Sections 3.3.5.1 and 3.3.5.3.

3.3.5.1 SUPPORT TO AFRICAN GROUNDWATER COMMUNITY

BGS team:

- Alan MacDonald
- Kirsty Upton

Partners:

- African Ministers Council for Water (AMCOW)
- International Association of Hydrogeologists (IAH)
- International Water Management Institute (IWMI)
- United Nations Educational, Scientific and Cultural Organization (UNESCO)

Management of groundwater is critical to the implementation of SDG 6 (clean water and sanitation) and there are several initiatives to help strengthen management and share good practice in Africa.

Despite the persistence of integrated water resources management, groundwater is often forgotten about and not properly considered in the thinking and planning of water resources. BGS is helping to strengthen groundwater governance in Africa through several pathways, including:

- providing support to policy development
- helping to build consensus across different stakeholders
- synthesising and supporting exchange of knowledge
- contributing to relevant networks

Examples of specific activities include:

- providing support to the African Ministers Council for Water (AMCOW) through collaborating with their Groundwater Desk Officer and Director of pPrograms, and contributing to several working groups
- contributing to the development of an integrated groundwater map for the Economic Community of West African States (ECOWAS), to be launched at the World Water Forum in 2022, in conjunction with:
    - AMCOW
    - Federal Institute for Geosciences and Natural Resources, Germany (BGR)
    - International Association of Hydrogeologists (IAH)
    - Office of Geological and Mining Research, France (BRGM)
    - UNESCO
- contributing to the 2022 UN World Water Development Report, which will have a focus on groundwater
- developing a map of groundwater salinity in conjunction with IAH
- writing a chapter on groundwater within a new textbook on catchment management

A key outcome of this collaborative work is the growth of AMCOW's groundwater programme (APAGroP) proof of concept, through the first two-year phase (2019–2021). This included engagement with the programme by Africa's ministers for water, working with AMCOW's technical advisory committee to increase buy-in from member states. Activities have contributed to a strong network of partners through APAGroP's working group and ensured incorporation of key groundwater resources into AMCOW's online knowledge hub.

BGS is supporting preparation for the second phase of work by helping to write a technical brief for the programme, outlining key priority areas and delivery mechanisms and presenting the programme to donors to secure future funding for groundwater activities in Africa. BGS is also co-authoring a White Paper on groundwater in Africa, to be taken to Africa's heads of state at the World Water Forum in 2022 (in progress).

Further reading

AMCOW GROUNDWATER PROGRAMME. Available at: https://amcow-online.org/initiatives/AMCOW-Pan-African-Groundwater-Program-APAGrop. This briefly explains the rationale, process, key activities and partners of the programme. BGS involvement started in 2016 through UPGro and continued through the GCRF Groundwater for Resilience in Africa Network and GSF.

3.3.5.2 SOUTH-EAST ASIA URBAN GEOLOGY PARTNERSHIPS

BGS team:

- Steph Bricker
- Diarmad Campbell
- Marcus Dobbs
- Andy McKenzie
- Keely Mills
- Martin Smith

Partners:

- Coordinating Committee for Geoscience Programmes in East and South-east Asia (CCOP)
- Department of Minerals and Geosciences Malaysia - Jabatan Mineral dan Geosains Malaysia (JMG)
- General Department of Geology and Minerals of Vietnam (GDGMV)
- Kuala Lumpur City Hall - Dewan Bandaraya Kuala Lumpur (DBKL)
- Mass Rapid Transport Corporation (MRT)
- Ministry of Natural Resources and Environment of Vietnam (MONRE)
- Public Works Department - Jabatan Kerja Raya (JKR)
- Universiti Kebangsaan Malaysia (UKM)
- Universiti Tenaga Nasional (Uniten)
- University of Malaya (UM)
- workshop participants from Thailand and Myanmar

Cities and human settlements can be made more inclusive, safe, resilient and sustainable through better integration of geoscience knowledge with urban development. A key step in this process is to enhance awareness among geoscientists of the role that geology can have in the urban environment and increase the number of geoscientists engaged in urban geology.

New research partnerships centred on urban geology have helped to raise the profile and awareness of urban geology in Malaysia and Vietnam and across the wider geoscience community in east and south-east Asia. These partnerships have been established with:

- Jabatan Mineral dan Geosains Malaysia (JMG, the Department for Minerals and Geosciences, Malaysia)
- General Department of Geology and Minerals of Vietnam (GDGMV)
- Coordinating Committee for Geoscience Programmes (CCOP)

For example, a joint CCOP/JMG/BGS urban geology workshop was held in 2019 with approximately 50 participants. This workshop was a contributory factor in the decisions by:

- JMG: to establish an environmental and urban geology cluster
- CCOP: to commission a survey of the urban geology capability and needs of member organisations and a desk-based review of the current state of the art within east and south-east Asia, Europe and North America
- CCOP and the China Geological Survey (CGS): to establish a joint research centre for urban geology and for JMG and GDGMV to join this group

Urban geoscience was also a theme for the regional conference GEOSEAS in 2018 and the focus for the 33rd National Geoscience Conference in Malaysia in 2021.

Figure 9 Participants of the CCOP-JMG-BGS urban geology workshop visit the Batu Caves during a one-day urban geology fieldtrip in greater Kuala Lumpur. BGS © UKRI (2022).

Further reading

MASS RAPID TRANSIT CORPORATION (MALAYSIA). 2019. Visit By Urban Geology 2019 Workshop Delegates. Available at: https://www.mymrt.com.my/events/visit-by-urban-geology-2019-workshop-delegates/

CCOP-BGS-JMG. 2019. Urban Geology Workshop. Available at: http://www.ccop.or.th/activity/436

INSTITUTE OF GEOLOGY MALAYSIA. 2021. NGC2020/21 Conference – Urban Geoscience. Available at: https://www.igm.org.my/component/rseventspro/event/101-33rd-virtual-national-geoscience-conference?Itemid=101

3.3.5.3 SCIENCE INTO DECISION MAKING IN ETHIOPIA

BGS team:

- Sue Loughlin
- Susanne Sargeant
- Charlotte Vye-Brown

Partners:

- Ethiopian government, humanitarian and development organisations
- international organisations and academia, including the following Ethiopian stakeholders:
    - Addis Ababa University
    - Ethiopian Civil Aviation
    - Ethiopian Red Cross
    - Ethiopian Roads Authority
    - Geological Survey of Ethiopia
    - Ministry of Mines
    - Ministry of Water
    - National Disaster Risk Management Commission
- NGOs, private sector and civil society

This project aimed to strengthen disaster risk governance in Ethiopia by creating space for dialogue and supporting scientific institutions and other governmental and non-governmental agencies and stakeholders to work together effectively.

In 2012, at the closure of the Afar Rift Consortium project, there was no mechanism for sharing of data or lessons learnt about the volcanic unrest and five volcanic eruptions in Ethiopia that

were monitored by the Afar Rift research project. Despite the adverse impacts of those eruptions, the knowledge of volcanic hazards and impacts in Ethiopia at a national level remained low.

Since that time, three workshops have been held in Ethiopia, in 2017 and 2019, bringing together scientific institutions and researchers in Ethiopia and local and national disaster risk managers, responsible government ministries, NGOs and other stakeholders affected by natural hazards.

- November 2017: this workshop discussed the current situation regarding geohazards in Ethiopia and possible ways for future action. The opening speech, by H E Mitiku Kassa of the National Disaster Risk Management Commission, highlighted the need to establish close links between relevant participants to adequately address disasters and emplace workable plans of preparedness and response
- January 2019: this workshop maintained engagement with individuals and organisations following the workshop in 2017, conducted a stakeholder mapping exercise and disseminated co-developed research results
- November 2019: this workshop focused on the theme 'From geohazard risk to action' and explored reducing and managing risks from geohazards to save lives and sustain growth in Ethiopia. It included talks from experts in other ODA-recipient countries (e.g. Nepal) to encourage South-South learning and partnership development

This project and its associated work helped to raise awareness of the occurrence, extent and consequences of geohazards in Ethiopia. Science diplomacy, sustained communication and collaborative working have strengthened disaster risk governance and institutional capacity for real-time monitoring and emergency response.

In 2017, the Ethiopian Natural Hazards Task Force was established, comprising:

- Addis Ababa University (higher education)
- Geospatial Information Institute and the Ethiopian Geological Survey (key government institutions)
- Ministry of Mines and Energy (responsible ministry)
- National Disaster Risk Management Commission (disaster management)

Two key outcomes of the workshop in November 2019 were the creation of a multi-stakeholder forum to improve interaction between scientists, practitioners and policymakers in Ethiopia, and the formation of a national repository and digital geohazard information centre to fill data gaps on geohazards and their impacts.

Figure 10 Scientists lead the discussion with stakeholders on priorities for future action in Ethiopia on geohazards and risk at the November 2019 workshop. BGS © UKRI (2019).

Further reading

RELIEFWEB. 2019. NDRMC Shifts from Crisis to Managing Geohazard Risks. Available at: https://reliefweb.int/report/ethiopia/ndrmc-shifts-crisis-managing-geohazard-risks

3.3.6 Instrumental: changes in policy and practice

Ideally, changes in capacity are followed by changes in behaviour, including both policy and practice change. Achieving these 'instrumental' outcomes may take longer than a project lifetime. However, where projects build on previous work and relationships or include key influential stakeholders from the outset, it may be feasible to realise this type of outcome before a project ends.

Examples of instrumental outcomes (or emerging outcomes, where there is evidence that BGS activities are contributing to policy or practice change) are outlined in Sections 3.3.6.1 to 3.3.6.3.

3.3.6.1 MINING PRACTICE AND RECOVERY OF GOLD IN MIGORI COUNTY, KENYA

BGS team:

- Tom Bide
- Clive Mitchell
- Barbara Palumbo-Roe
- Jeremy Rushton

Partners:

- Migori County Artisanal Miners Co-operative
- University of Nairobi (Department of Geology)

This project aimed to promote good practice for artisanal and small-scale gold mining (ASGM) in Migori, south-west Kenya, through collaboration with a local mining cooperative (Migori County Artisanal Miners Co-operative (MICA)) and the University of Nairobi (UoN).

ASGM is a major employer in Kenya (approximately 40 000 people) and produces five metric tonnes of gold per year. Improvement to ASGM practices has the potential to provide a significant boost to local economies, secure livelihoods and enhance the quality of life for many communities.

However, ASGM can also have significant negative environmental consequences. These can be through:

- release into soil and water of harmful chemicals used in processing, including mercury and cyanide
- poor water management practices
- incorrect storage and management of waste left over from the mineral extraction process

A key focus of the research was, therefore, to determine the particle size of gold in the region and provide evidence for a change in mining practice to help improve gold recovery rates, increasing income for ASGM communities and reducing the environmental impacts of mining.

In November 2019, a field team from the BGS and UoN, with the assistance of MICA, visited six mining sites in the Migori ASGM district. Samples of ore, crushed and milled ore, and sluice-box concentrates and tailings were collected from the ASGM sites. Samples of shaking-table concentrates, middling products and tailings were also collected from the MICA demonstration gold-processing plant. Petrographical and microchemical analyses were carried out to determine the shape and size of the gold, together with X-ray diffraction analysis, particle-size analysis and gold assays (a process to measure purity of items containing gold).

Analysis indicated that the use of sluice boxes is inappropriate for the recovery of gold, as the gold is too fine grained. The use of sluice boxes for the recovery of gold is widespread through Migori and over 80 per cent of the gold is consequently likely to be lost. Using shaking tables instead would dramatically increase gold recovery and revenues to the ASGM communities. Alternative methods such as shaking tables would also be more effective at reducing the environmental impacts associated with gold mining in the region.

Work is ongoing to support uptake of the research findings and effect a change in ASGM practices in mining communities across Kenya, and possibly further.

Figure 11 Sluice box, Kehancha ASGM site, Migori County, Kenya. Clive Mitchell © UKRI (2022).

Further reading

MITCHELL, C J, and BIDE, T. 2020. Artisanal and small-scale gold mining in western Kenya. Available at: http://britgeopeople.blogspot.com/2020/02/artisanal-and-small-scale-gold-mining.html

MITCHELL, C, BIDE, T, and ODHIAMBO, C. 2021. Recovering lost gold with improved efficiency, productivity and environmental impacts in Kenya. In: *2020 State of the Artisanal and Small Scale Mining Sector*. MCQUILKEN, J, and PERKS, R. (World Bank.) https://www.delvedatabase.org/resources/2020-state-of-the-artisanal-and-small-scale-mining-sector

MITCHELL, C J, PALUMBO-ROE, B, and BIDE, T. 2020. Artisanal and small-scale gold mining research field work, Migori County, Kenya. *British Geological Survey Open Report* OR/20/010 (unpublished). Available at: http://nora.nerc.ac.uk/id/eprint/528810/1/Migori_ASGM_fieldwork_report_OR-20-010.pdf

3.3.6.2 SOUTH-EAST ASIA URBAN GEOLOGY PARTNERSHIPS — GEOLOGICAL SURVEYS ACT (MALAYSIA)

Expanding on the example of urban geology partnerships in south-east Asia described in Section 3.3.5, work with Jabatan Mineral dan Geosains Malaysia (JMG, the Department for Minerals and Geosciences, Malaysia) has contributed to amendments being proposed to the Malaysian Geological Survey Act (1974). The amendment obliges those conducting site investigations to provide JMG with data, including borehole records. The director general of JMG, Shahar Effendi Abdullah Azizi, highlighted the importance of this amendment (Azizi et al., 2019) although it has not yet been given time in the parliamentary timetable.

Availability of such information can inform decision making, including that done by government agencies. This is illustrated in the UK context, where Environment Agency staff use open-access borehole data from the National Geoscience Data Centre on a daily basis to support their statutory function to protect England's waters and associated environments from pollution risk (Baker et al., 2021). Access to this data reduces the cost and improves the timeliness of decision making.

3.3.6.3 IMPROVING DECISION MAKING AND PRACTICES WHEN RESPONDING TO VOLCANIC EVENTS

BGS team:

- Brian Baptie
- Julia Crummy
- Fabio Dioguardi
- Melanie Duncan
- Sam Engwell
- Anna Hicks
- Sue Loughlin
- Richard Luckett
- Katy Mee
- Alessandro Novellino
- Lara Smale
- Pablo Tierz
- Charlotte Vye-Brown

(Selected) partners:

- ARISTOTLE
- European Emergency Response and Coordination Centre (ERCC)
- European Natural Hazards Scientific Partnership (ENHSP)
- Institut Teknologi Bandung, Indonesia
- International Committee of the Red Cross
- National Emergency Management Organisation, St Vincent and the Grenadines (NEMO)
- National Institute for Seismology, Volcanology, Meteorology and Hydrology, Guatemala *(*INSIVUMEH*)*
- National Coordinator for Disaster Risk Management, Guatemala *(*CONRED*)*
- Resilience Development Initiative, Indonesia
- Seismic Research Centre, University of West Indies, Trinidad (UWI-SRC)
- UK Foreign, Commonwealth *&* Development Office (FCDO)
- UK Cabinet Office
- Washington, Toulouse and Darwin Volcanic Ash Advisory Centres
- other UK Government *d*epartments (e.g. Ministry of Defence*;* Department for Transport*;* Defra*;* Government Office for Science)
- many other UK and international research partners

BGS responds to volcanic events (including unrest and/or eruptions) worldwide, including in countries eligible to receive ODA. The team involved in this project provided scientific evidence and advice to a range of UK government departments, embassies and overseas territory administrations to support decision making at all scales on issues aligned to humanitarian response and the effective management of mitigation measures. Support is also given to long-term scientific partners in regions such as eastern Africa and the Caribbean when requested during volcanic events, for example the 2021 eruption of La Soufrière in St Vincent and the Grenadines.

Activities within this project, together with associated and preceding work, have raised awareness and understanding of volcanic hazards and risks in government departments, humanitarian responders and NGOs, and the potential transboundary, systemic and cascading impacts arising from volcanic events. This informed FCDO/NGO decision making on themes including staff safety, funding prioritisation, governance and shelter locations.

This work supports both immediate and longer-term practice change by ensuring access to relevant expertise and changing perceptions of who to engage with during future volcanic events (e.g. advocating for closer engagement with volcanic observatories). Engagement with international science networks underpinned this work. These networks included:

- volcano observatories
- volcanic ash advisory centres
- NERC Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET)
- the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)
- Global Volcano Model network)

Figure 12 Fuego, Guatemala. BGS provided advice during the 2018 eruption of Fuego. © Joel C Gill (2018).

3.4 PROGRESS THROUGH OUR THEORIES OF CHANGE

Acknowledging that our journey to impact transcends the life of the GSF programme, this section describes the progress made towards delivering the ambitions of the three ToCs introduced in Section 3.2. Using the narratives described in Section 3.3, we reviewed the outcomes described in each completed narrative and mapped these to the three ToCs (Figure 2, Figure 3 and Figure 4). We document the results of this process in Sections 3.4.1 to 3.4.3, demonstrating that each research platform progressed from producing outputs to the stated outcomes believed to contribute to impact. The letters A, B, C […] Z relate to the tasks listed in Table A3.

3.4.1 RP1: integrated resource management in eastern Africa

The ToC for RP1 (Figure 2) had a desired long-term impact of *'*improved community welfare and sustainable economic development in eastern Africa*'*. While no single interim ambition was articulated, a key outcome along the pathway to this long-term impact is 'improved/increased geoscience capacity and knowledge*'*, with multiple pathways running through the ToC feeding into and/or out of this outcome.

Overall, the RP1 narratives suggest success in achieving this interim ambition, with several examples of activities improving conceptual understanding and strengthening skills in the region. For example, a cluster of activities contributed to the outcomes of 'increased knowledge of eastern African geoscience resources' (A; B; C; E; G; H) and 'improved methods in place for data capture and storage' expressed in the ToC (E; H).

3.4.1.1 FUTURE PLANS

RP1 had a large geographic and thematic scope, as evidenced by the narratives summarised in Table 1 and the detailed examples in Sections 3.3.3 to 3.3.6. Progression through the ToC to achieve regional impact (as opposed to localised impact) and see improvements across a range of geo-resources (as opposed to a focus on one natural resource) requires 'bridging' activities and outputs. Active knowledge brokering could help to unite different strands of work, bringing this to key audiences for reflection and/or action.

There is potential for increased contributions to the outcome of 'improved translation of data into user-friendly formats' stated in the ToC. This is an important step in ensuring 'improved knowledge' extends beyond the geoscience community to also inform and support broader decision making.

3.4.2 RP 2: resilience of Asian cities

The ToC for RP2 (Figure 4) had a desired long-term impact of 'improved resilience and more sustainable development of Asian cities through better understanding and management of the land and subsurface'. The ToC included an interim ambition of 'increasing the capability of geoscientists and researchers to produce holistic knowledge of the city', expected to be realised by the end of the four-year programme.

Overall, the RP2 narratives suggest that this interim ambition was achieved in both Kuala Lumpur (Malaysia) and Hanoi (Vietnam).

- Activities in Kuala Lumpur involved geoscientists from the region to ensure a positive legacy of a community capable of producing and contributing to holistic knowledge of the city. The activities resulted in:
    - generation of new knowledge
    - new systems for collecting and using data
    - new skills in the geoscience community
    - strengthened networks (I; J; K)
- In Hanoi, activities also strengthened networks, developed new skills and generated new understanding; collectively, these delivered the interim ambition (K; L; M).

The success of RP2 in reaching its interim ambition was supported by a focused geographical scope and close coordination by different activities. Specific activities focused on building and supporting networks supported the sharing of lessons learnt from other activities with a wider audience.

3.4.2.1 FUTURE PLANS

The RP's ambitions included informing planning and shaping policy development and implementation. Progression through the ToC may benefit from engagement with additional partners, including those involved in policymaking and influencing communities. BGS participants in RP2 also indicated the benefits of strengthening links to academic departments, to support research design and delivery.

3.4.3 RP 3: global geological risk

The ToC for RP3 had a desired long-term impact of 'improved resilience of communities to natural hazards'. While no single interim ambition was articulated, two key outcomes along the pathway to this long-term impact included 'improved capacity of government and stakeholders to plan for, respond to, and recover from disasters' and 'improved capacity of communities to plan for, respond to and recover from disasters'.

The RP3 narratives suggest that several activities, particularly those building on existing relationships and research programmes, contributed to the intermediate outcome of 'improving governments' capacity to plan for, respond to and recover from disasters' (e.g. O; P; U; W; Y). Work aligned closely to targets embedded within the UN Sendai Framework for Disaster Risk Reduction (UNDRR, 2015), including understanding hazard characteristics, strengthening the science/policy interface and improving hazard monitoring — all of which contribute to achieving the intermediate outcome of an improved government-level capacity.

Some (albeit fewer) tasks contributed to the second intermediate outcome of 'improving community-level capacity'. For example, the myHAZ project (P) includes a mobile phone application that citizens can interact with to increase their capacity to plan for, respond to and recover from disasters. While there is less evidence that BGS activities improved these capacities at a community level, but this is not surprising. Our primary partnerships are with research and government agencies and, therefore, most of our activities will contribute to improved capacity at a policy and governance level or within agencies (both governmental and non-governmental) that themselves work with communities.

3.4.3.1 FUTURE PLANS

As discussed in Section 2.3, RP3 had a wide geographical scope, with activities in multiple countries (e.g. Ethiopia; Nepal; St Vincent and the Grenadines) and engagement in regional and global networks. Understanding how the intended impact of 'improved resilience of communities to natural hazards' happens in any of these individual locations, given their unique political, economic, social, legal, technological and environmental contexts, may be better served by country-specific ToCs. This would also facilitate the monitoring of progress towards impact in each location, as well as allow clearer identification and articulation of stakeholders and audiences.

4 Continuing our journey — potential future impact

4.1 IMPACTS E XPRESSED IN THE RP TOCS

As set out in Section 2, the three RPs aimed to improve:

- community welfare and sustainable economic development in eastern Africa
- resilience and more sustainable development of Asian cities through better understanding and management of the land and subsurface
- resilience of communities to natural hazards

Throughout Section 3, we described outcomes that, while important and impactful, do not yet reach the level of ambition stated at the start of this programme. Our journey to impact is currently dominated by conceptual outcomes (Table 1) with many examples of skills strengthening and connectivity outcomes but few instrumental outcomes at this stage.

4.2 FACTORS NEEDED FOR FURTHER IMPACT

For these outcomes to develop and contribute to socio-economic development impacts, three factors are needed (associated recommendations are detailed in *italics* in Sections 4.2.1 to 4.2.3):

- time
- further actions and interventions by those undertaking activities contributing to the GSF programme
- further actions and interventions by other, external individuals and institutions

4.2.1 Time

Changes in policy and practice and the cascading benefits of their implementation do not always occur within the lifetime of a research project; they typically take three to five years, with some variation depending on the type of funding received. It is feasible that research commenced during or contributed to through the GSF programme will go on to achieve greater impacts than currently observed.

To ensure our journey to impact is fully understood and opportunities for action and learning within future programmes are not missed, ongoing monitoring is needed. There should be clear mechanisms for information and analysis from this monitoring to feed into the management and planning of future activities.

4.2.2 Further actions via GSF

For many of the activities within the GSF programme, there are ongoing opportunities to develop and expand research and share and translate knowledge, including its application to new contexts. Many of the descriptions of 'potential future impacts' set out by those completing narratives of their journey towards impact (see Section 3.3.2) are within the BGS teams' sphere of control and influence, given access to the necessary resources. For example:

- improved accessibility of information
- linking with other stakeholders working on a particular theme to support research uptake
- work being known and used by policymakers
- replication in new contexts

To ensure our work progresses along its journey to impact and we maximise opportunities within our sphere of control and influence, it is advisable that project teams include those with knowledge-brokering experience from the outset and set aside resource for knowledge-brokering activities. Including an 'impact champion' on the management team, who is tasked with supporting projects to push beyond outputs, may facilitate a more systematic and comprehensive approach to impact.

4.2.3 Further actions by external parties

We recognise that our contribution to impact exists within a complex ecosystem of projects and decision-making processes. Impact therefore depends on factors outside of our control and influence. A ToC approach, together with comprehensive stakeholder and context mapping, supports our understanding of who may contribute to the delivery of impact and how. This provides an opportunity to build broad, multisector, multidisciplinary partnerships with key individuals and groups from the outset, thus increasing our sphere of influence (assuming positive and respectful working relationships).

To ensure our work progresses along its journey to impact and we increase our sphere of influence, it is advisable to build in detailed context and stakeholder mapping from the outset. From this analysis, we should build diverse project partnerships or opportunities for engagement, including a wide range of organisation types.

4.3 IMPACTS FROM IMPROVED USE OF TOC APPROACHES

Potential for future impact can also be increased by improving our use of ToC approaches. While not a comprehensive list, we suggest there are a few ways this could be done.

Platform-level ToCs are not always enough to support planning and monitoring of impact. In some contexts, national or task-level ToCs would enable the identification of relevant stakeholders, integration of relevant context and monitoring of indicators. Strategic thinking around the most appropriate scales for a ToC would benefit future programmes.

ToCs need more input from partners to ensure pathways to change are rooted in a comprehensive understanding of the political, economic, social and cultural contexts, and that desired impacts and outcomes align with national development and organisational priorities.

The stakeholders mentioned in or needed to deliver specific outcomes should be considered**.** Detailed stakeholder mapping to understand who is required to support achievement of outcomes and who is the focus of capacity and behaviour changes should be completed.

Indicators for key outcomes within a ToC should be defined to support effective monitoring of impact and testing of the ToC.

ToCs are intended to be live documents so should be revisited frequently, ensuring regular updating and testing of assumptions or identification of new ones.

5 Concluding remarks

The GSF programme used ODA funding to advance collaborative research and innovation addressing challenges in low- and middle-income countries. Working with a wide range of partners from across sectors, countries and disciplines, we aimed to develop and use geoscience knowledge to improve:

- community welfare and sustainable economic development in eastern Africa
- resilience and sustainable development of Asian cities through better understanding and management of the land and subsurface
- resilience of communities to natural hazards

Collectively, these impacts deliver enhanced economic and social development and enrich the lives and livelihoods of those in ODA-recipient countries.

While we can point to many positive outcomes of the GSF programme across four broad categories (conceptual; capacity strengthening; instrumental; enduring connectivity), we recognise that our journey to impact is not yet finished. The knowledge, skills and networks developed and supported in the life of the programme will exist and can be applied beyond its formal end date. Leveraging and maximising impact will depend on the steps taken by BGS staff and our partners in the coming months and years.

Our activities sit in a complex and dynamic ecosystem of other actors and initiatives, meaning this progression to impact is not entirely within our control or influence. There are opportunities, however, to support activities to progress towards impact. A ToC approach, together with comprehensive monitoring, evaluation and learning, will support the design and implementation of follow-up activities and the monitoring of progress towards our end-goal.

The GSF programme provided an opportunity for BGS to develop significant experience of using ToC approaches and how to use them effectively. This should benefit future, impact-focused and international work undertaken by the organisation.

References

AZIZI, S E B H, LING, N-L, SIA, S-G, and ISMAIL, B. 2019. The changing role of geological surveys in Malaysia. *Geological Society London Special Publications*, Vol. 499, 85–97. DOI: https://doi.org/10.1144/SP499-2019-55

BAKER, G, BLOODWORTH, A, CONDON, D, GOODENOUGH, K, FALLAS, H, MILLS, K, PINNICK, J, REES, J, SARGEANT, S, SMITH, N, STEPHENSON, M, and WRAGG, J. 2022. Delivering a 21st century geological survey: BGS evidence report (evaluation period: April 2016 to March 2021). *British Geological Survey Internal Report* (unpublished).

BGS. 2019. BGS Science Strategy 2019–2023: Gateway to the Earth. Available at: https://www.bgs.ac.uk/download/bgs-science-strategy-2019-2023-gateway-to-the-earth/

ESRC. 2021. Defining Impact. Available at: https://www.ukri.org/councils/esrc/impact-toolkit-for-economic-and-social-sciences/defining-impact/

GILL, J, and SMITH, M (editors). 2021. *Geosciences and the Sustainable Development Goals*. Sustainable Development Goals series. (Springer Nature.)

MILLS, K., SARGEANT, S., GILL, J., DOBBS, M., 2022. Geoscience for Sustainable Futures: results of the internal staff survey. *British Geological Survey Internal Report* IR/21/030 (unpublished).

SHAXSON, L. 2016. Achieving policy impact: guidance note. Available at: https://www.gov.uk/research-for-development-outputs/achieving-policy-impact-guidance-note

UKRI. 2016; 2018. Official Development Assistance — Global Challenges Research Fund Guidance. Available at: https://www.ukri.org/wp-content/uploads/2020/10/UKRI-271020-GCRFODAGuidance.pdf

UN. 2015. Transforming Our World: The 2030 Agenda. Available at: https://sdgs.un.org/2030agenda

UNDRR 2015. Sendai Framework for Disaster Risk Reduction. Available at: https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf

VOGEL, I. 2012. Review of the use of 'Theory of Change' in international development. Available at: https://www.theoryofchange.org/pdf/DFID_ToC_Review_VogelV7.pdf

Appendix A Theory of Change assumptions for RP1 and RP2

Table A1 Assumptions underpinning the RP1 ToC. The final column SoE is the strength of evidence when the assumptions were identified. This has been given a RAG status.

#	Assumption	Evidence	SoE
a_1	Data exists and, where it does, it is accessible and useful. Data holders/custodians are willing to share.	Reviews, workshops, MoUs*. Some data has been shared with us already.	
a_2	City wants to engage with the process. There is buy in/collaboration between the city and the private sector (and BGS).	MoUs. Partners have agreed to co-host and co-design workshops. City plans are smart, integrated and driven by the SDGs.	
a_3	The geological surveys have the resources and funding to build capacity in urban research/geoscience.	MoUs and existing engagements in-country. Some existing data.	
a_4	City-to-city peer learning and translation of good practice occurs; there are no barriers to this interaction.	Existing Asian professional networks (e.g. CCOP/IOORC). High-level city cooperation (e.g. through British Council). Stakeholders operate at a national scale.	
a_5	BGS will be the main geoscience influence for changes in policy and practice (e.g. not countries such as Japan, China).	Limited. BGS offers capacity building.	

*Memorandum of Understanding.

Table A2 Assumptions underpinning the RP2 ToC. The final column SoE is the strength of evidence when the assumptions were identified. This has been given a RAG status.

#	Assumption	Evidence	SoE
a_1	Sustainable development is a driver for country/regional economic growth and social change.	Regional development and country strategies; reporting to UN; current NGO agendas.	
a_2	Receptive and engaged government departments that willingly work together; no issue with silos.	Existing policies and implementation plans; good practice across government departments (there are lighthouse examples).	
a_3	Data are available and can/will be shared freely by/amongst stakeholders.	BGS experience is both positive and negative with regards to this (country/government department dependent), but have research partners and key links.	
a_4	Information technology infrastructure is in place alongside policies to store or release data.	Evidence of use of cloud technologies and use/development of web portals. Investment into this technology by World Bank and DfID.	
a_5	Research partners exist and are willing/motivated to join with BGS ODA programme through a consortium approach.	Co-development of current projects, existing partnerships from personal to institutional level. MoUs*/research agreements/contracts exist. Depth of relationships and mutual respect.	
a_6	Opportunities arise and there is buy-in for disciplinary and regional integration of data and good practice.	Interdisciplinarity is a valued activity and projects can embrace new science research opportunities.	

* Memorandum of Understanding.

Appendix B Narratives template

This proforma was used to collect the information described in Section 3.3 of this report.

Research Platform *(Please select one)*	RP1	RP2	RP3
Task Name			
Authors/Contributors			
Overview *An overview of the project and why it matters. What societal challenge/s did this project try to address? (approximately 150 words)*			
	Relevant Sustainable Development Goals (if known):		
Partners *Which organisations were involved?*			
Research and/or Activities *Please provide a summary of what you did in this Task – the research or stakeholder engagement that was conducted through ODA funding.*			
Impacts (External and Internal) *These can take many forms, including changes in capacity, practice, culture, and policy, as well as academic impact (shifting understanding and advancing scientific method, theory, and application).* *Avoid generalised or exaggerated statements about your impact. Be careful not to oversimplify the links between the research activity and the subsequent impact (recognising that scientific research may be one of many factors or sources of knowledge that contributes to a decision being made or an action taken by NGOs, Government etc).*	**To date, what have been the main impacts that the research and/or activities within this Task contributed to?** • • *Where possible, please include any quantitative / qualitative supporting evidence*		
	What do you anticipate the biggest impact of this Task being 5-years from now? Do you have any ideas of how BGS could monitor that?		
Further Reading *Links to any published evidence that explains the research or activities completed (e.g., journal publications) or demonstrates impact*			
Learning *To increase the likelihood of impact, what would you do differently next time (at least one thing) and why?*			
Associated Projects and Funding *Please list any projects or additional funding sources that have supported this work, and should be acknowledged*			
Contact Name (Task Lead)			
Contact Email (Task Lead)			
Key Project Image/s	If you have an image or graphic that could be used to illustrate this project and its impact - please insert it here, with a caption and credit.		

Appendix C Task narratives – journeys to impact

Table A3 A summary of all the narratives used to inform this report.

Code	Task title	Task aim	Narrative authors
RP1: integrated resource management in eastern Africa			
A	Support to African groundwater community	Groundwater management is at an early stage in many parts of Africa, partly due to the low levels of development. However, management of groundwater is critical to the implementation of SDG6 and there are several initiatives to help promote management and share good practice. Despite the persistence of integrated water resources management, groundwater is often forgotten about and not properly integrated into thinking and planning of water resources. In this project, BGS is providing support to a number of pathways for good groundwater governance: • support to policy development • consensus building • knowledge synthesis and exchange • supporting networks These include developing a new pan-African groundwater programme through the African Ministers Council for water, synthesising existing data to provide policy-friendly summaries of groundwater.	• Alan MacDonald • Kirsty Upton
B	Mining practice and recovery of gold in Migori County, Kenya	This project aimed to promote good practice for artisanal and small-scale gold mining (ASGM) in Migori in south-west Kenya through collaboration with local mining cooperative Migori County Artisanal Miners Co-operative (MICA) and the University of Nairobi. ASGM is a major employer in Kenya (estimated 40 000 people) and produces five metric tonnes of gold per year. Improvement to ASGM practices has the potential to provide a significant boost to local economies, securing livelihoods and enhancing the quality of life for many communities. However, ASGM can also have significant negative environmental consequences. This can be through the release of harmful chemicals used in processing (including mercury and cyanide) into soil and water, poor water management practices and the incorrect storage and management of waste left over from the mineral extraction process.	• Clive Mitchell

Code	Task title	Task aim	Narrative authors
C	Critical raw materials in eastern Africa	Global net zero ambitions are dependent upon resources of the raw materials that are required for the energy transition. The World Bank has recognised that this represents a significant opportunity for developing countries that are rich in these resources, but that there is a need for mining to be done in the most sustainable way possible. This project aimed to investigate resources and value chains of some critical raw materials (chiefly lithium and graphite) in eastern Africa, in order to provide meaningful overview information for investors and policymakers. This information can then be used to make informed decision about management of mining and mineral resources.	• Kathryn Goodenough
D	Using EO data for mining sites and their evolution in time along the Migori river catchment area	This task aimed to improve understanding of the monitoring of mineral resource exploration and mining, from concept to closure, using earth observation tools.	• Claire Fleming • Alessandro Novellino
E	Environmental geochemistry and health	The programme of work addresses RP1: resource security in East Africa, specifically work package 1: agriculture and nutrition. Key advances in environmental geoscience lie at the nexus of geochemistry (soil, water, sediment), health (nutrition, toxicology, epidemiology) and agriculture (crops, livestock, fisheries). BGS and research partners are developing an integrated approach to risk assessment and public policy, including: • capturing and integrating soil geochemical processes across multiple scales • develop a predictive model of soil-to-plant micronutrient and environmental pathways of contaminant exposure to assess health consequences (e.g. oesophageal cancer incidence, soil erosion and input to lake environment) • support policies in agriculture (e.g. agri-strategies, fisheries-aquaculture) and public health surveillance (e.g. geochemical maps, location of aquaculture cages) • determining land/lake transfers via soil erosion and implications for loss of agricultural opportunity and sustainability of lake fisheries	• Olivier Humphrey • Andrew Marriott • Michael Watts
F	Effective and innovative ways of managing and delivering geodata	This project focused on effective and innovative ways of managing and delivering geodata that contributes to social and economic structural transformation, wealth creation and poverty reduction. The project facilitated ODA partners in realising the value of their data assets through the development and population of effective digital data workflows. We leveraged our networks, such as OneGeology, to enable ODA partners to utilise geospatial technology and computing systems to accelerate the dissemination of essential geoscience data for the benefit of society. Using modern data translation techniques (e.g. scanning and digitisation) and new information delivery methods appropriate to ODA partner infrastructure (e.g., mobile apps, interoperable web services), new and innovative digital access solutions have been developed that enable geoscience data to be embedded in policy development and wider ODA-related research.	• Patrick Bell

Code	Task title	Task aim	Narrative authors
G	Rural water supplies during drought in Ethiopia	This work examined the performance of rural water supplies during one of the worst droughts in Ethiopia since the 1980s to see which performed best. The work was joint with UNICEF in Ethiopia and the results used to help learn lessons to plan future more resilient rural water supply interventions.	• Donald John MacAllister • Alan MacDonald
H	Real-time monitoring of faecally contaminated drinking water	Globally, two billion people consume water contaminated with faeces. This exposure increases the incidence of infectious disease such as diarrhoea, which alone results in more than half a million deaths per year in low- and middle-income countries. Recent BGS sensor research has focused on on-site testing using portable tryptophan-like fluorescence (TLF) sensors that require no reagents and provide instantaneous readings. TLF sensors have the potential to be used for real-time microbial risk screening of drinking water supplies.	• Alan MacDonald • James Sorensen
RP2: Resilience of Asian Cities			
I	3D Kuala Lumpur pilot study	Cities and human settlements can be made more inclusive, safe, resilient and sustainable through better integration of geoscience into the urban development process. A key step in this process is to enhance awareness of urban geology among non-geoscience decision makers, so that inherent subsurface risks and benefits are understood and accounted for during planning, design and construction. Three-dimensional geological models are an effective tool for geologists to communicate with geoscience stakeholders in government and industry during this process. They can also provide a framework to enable geological data and information to be integrated into building and city information models, thus facilitating more sustainable infrastructure and utility asset management.	• Helen Burke • Marcus Dobbs • Tom Dodd • Richard Haslam • Rhian Kendall • Ken Lawrie • Graham Leslie • Nikki Smith • Steve Thorpe • Rowan Vernon
J	Kuala Lumpur geology	Cities and human settlements can be made more inclusive, safe, resilient, and sustainable through better integration of geoscience in urban development. A key step in this process is to develop a robust understanding of the geology within an urban environment and share this knowledge with geoscience stakeholders.	• Marcus Dobbs • Thomas Dodd • Graham Leslie
K	South-east Asia urban geology partnerships	Cities and human settlements can be made more inclusive, safe, resilient and sustainable through better integration of geoscience into the urban development process. A key step in this process is to enhance awareness among geoscientists of the role that geology can have in the urban environment and increase the number of geoscientists engaged in urban geology.	• Steph Bricker • Diarmad Campbell • Marcus Dobbs • Andy McKenzie • Keely Mills • Martin Smith
L	South-east Asia materials flow analysis	This task used satellite data to assess geohazards (e.g. subsidence) in Hanoi (Vietnam) and construction material demands associated with urban growth.	• Luke Bateson • Tom Bide • Teresa Brown • Ekbal Hussain • Carolin Kresse • Joseph Mankelow • Alessandro Novellino • Evi Petavratzi

Code	Task title	Task aim	Narrative authors
M	Earth observation for assessment and monitoring of the urban environment and hazards	This work investigates supply and demand of raw materials used in construction and infrastructure in Vietnam. Rapid urban expansion has caused an increasing strain on raw materials that are required for construction and for the manufacture of everyday items that are now considered essential for maintaining quality of life. If flows of raw materials are constrained then growth can be adversely affected, costs of building essential infrastructure can increase and feedstocks for manufacturing and industry may be restricted. This can also lead to illegal mining operations to fulfil demand, which can, in turn, cause great harm to the environment. To mitigate this and to ensure that raw materials are sourced sustainably in adequate quantities and are effectively used and recycled, it is important to understand how they flow through society, from source to end use and waste management. Mapping material flows and stocks at city level provides essential background information on raw material availability and use, and identifies risks and supply disruption issues that can be mitigated by tailored interventions. The outcomes of material flow analysis can assist effective decision making and planning of urban development projects. This research improves the understanding of materials flows associated with rapid urban expansion in Asian cities.	• Tom Bide • Teresa Brown • Carolin Kresse • Joseph Mankelow • Alessandro Novellino • Evi Petavratzi
RP3: Global Geological Risk			
N	National landslide susceptibility modelling, Ethiopia	Building on work carried out for the World Bank by BGS producing hazard and risk maps for a series of countries in sub-Saharan Africa. The aim of this project was to strengthen the collaboration with IGSSA in order to produce a national scale map of landslide susceptibility that was more tailored to the specific processes taking place in Ethiopia than the World Bank one. The initial focus was to increase the current inventory of landslides using literature and online imagery (GoogleEarth) to validate the current World Bank susceptibility model and assess what the areas of improvement were. Using additional data, the final aim was to create a more detailed map of landslide susceptibility in collaboration with Getnet Malwa at IGSSA.	• Dave Boon • Roxana Ciurean • Claire Dashwood

Code	Task title	Task aim	Narrative authors
O	METEOR	Multiple hazards cause an increased impact on populations. Mainstreaming disaster risk management into planning systems of governments and large organisations can reverse the trend of rising cost from disasters in terms of death, damage, and destruction. Many developing countries lack the tools, expertise, and data to factor the potential risk of disasters into their investment decisions. METEOR provided openly available national-scale exposure data for all ODA countries, produced through a rigorous methodology tested and validate in Nepal and Tanzania. The project combined satellite imagery and detailed structural engineering data to understand delineated building construction type and to model the vulnerability of the exposure to flood and seismic hazards, with landslide and volcanic hazards identified as of greatest importance to Nepal and Tanzania respectively. New national-scale hazard data were generated and the impact of the multi-hazards on exposure was assessed with the aim to assist in DRM to lessening the impact of these hazards on the populations.	• Kay Smith
P	myHAZ – a multi-hazard, citizen science app for St. Vincent and the Grenadines (SVG)	This project aimed to develop a citizen science smartphone tool for residents of St Vincent and the Grenadines to share their observations of multiple natural hazards and environmental phenomena and their impacts. Citizen science facilitates resilience building by enhancing citizens' understanding of hazards and risk, whilst also building trust and communication links between citizens, scientists and authorities. The near-real time reporting of hazards within the app enables scientists and emergency managers to gain a rapid understanding of an evolving hazard event and its impacts, in particular for scientists who may not be based on island (e.g. the UWI Seismic Research Centre, which are based in Trinidad and Tobago). Use of myHAZ is also encouraged during periods of quiescence to help citizens become more aware of more subtle changes in their surroundings which may provide early warning to more significant events.	• Melanie Duncan • Anna Hicks • Katy Mee • Sue Loughlin • Steve Richardson
Q	Pathways to Action	This project aims to identify hazard and risk communication pathways during active and latent periods. By characterising both formal (e.g., from NEMO to local communities) and informal (e.g., between friends/neighbours/via social media) flows of communication within and between communities, we hope to develop understanding of what components of the communication and the landscape it moves through affect sense making, promote learning and prompt risk-reducing action.	BGS: • Melanie Duncan • Alex Hall • Anna Hicks • Sue Loughlin • Hazel Napier UWI-SRC: • Stacey Edwards • Pat Joseph • Richie Robertson • Alia Juman • Thalia Thomas

Code	Task title	Task aim	Narrative authors
R	Geophysical technologies for landslide monitoring and early warning (India)	This project aimed to develop a novel geophysical monitoring approach in monsoonal, mountainous regions, helping to identify subsurface precursor processes to slope failure, hence improving early warning of moisture-induced landslide events. A new geophysical monitoring system (PRIME), developed by BGS, was deployed at the Munnar Landslide Observatory (Kerala, India). The system is designed as a low-cost and low-power remote monitoring system using the mobile phone network for telemetric control and is therefore ideally suited for deployment in developing countries with significant landslide hazards. During the project, daily geophysical measurements were used to image moisture build-up in the slope during the monsoon season, which indicated an increased chance of failure and highlighted the benefit of subsurface monitoring for improving landslide early-warning systems.	• Jonathan Chambers • Oliver Kuras • Arnaud Watlet
S	Seismic hazard in Bandung, Indonesia	This project aimed to aimed to resolve a scientific dispute on the activity of the Lembang Fault, which lies along the northern margins of Bandung city in Indonesia. This matters because the Lembang Fault is the principal source of local seismic hazard to the city. Additionally, we sought to engage the local art community in a creative discussion on the topic of 'seismic hazard, people and topography'.	• Ekbal Hussain
T	Groundwater depletion (South Asia)	Intensively cultivated areas in South Asia are crucial for regional food security and have a long history of major surface and, more recently, groundwater development. Managing groundwater exploitation is critical to agricultural viability.	• Donald John MacAllister • Alan MacDonald
U	Science into decision making in Ethiopia	In 2012, at the closure of the Afar Rift Consortium project, there was no mechanism for sharing of data or lessons learnt about the volcanic unrest and five volcanic eruptions in Ethiopia that were monitored by the research project. Despite the adverse impacts of those eruptions the knowledge of volcanic hazards and impacts in Ethiopia at a national level remained low. Since that time, a series of workshops have been held in Ethiopia, designed to bring together scientific institutions and researchers in Ethiopia with local and national disaster risk managers, responsible government ministries, non-governmental organisations and other stakeholders impacted by natural hazards. The project aimed to encourage scientific institutions and disaster risk governance and support institutions to work effectively together through influencing these organisations and creating space for dialogue.	• Sue Loughlin • Susanne Sargeant • Charlotte Vye-Brown
V	Multi-hazards in the East African Rift	Natural hazards and their impacts do not respect country boundaries. The East African Rift presents similar opportunities and challenges along its length. We have collaborated with partners in Ethiopia, Tanzania, Malawi, DRC and Rwanda.	• Melanie Duncan • Sue Loughlin • Charlotte Vye-Brown

Code	Task title	Task aim	Narrative authors
W	Volcanic event response	BGS responds to volcanic events (unrest and/or eruption) across the world in a variety of different ways. We provide authoritative scientific evidence and advice to UK Government departments, embassies and overseas territories' administrations to ensure UK citizens and interests, including humanitarian and diplomatic needs, are supported and mitigation measures are well-managed. We also contribute to COMET, the International Disaster Charter and other requirements. Events are inherently multi-hazard and lead to complex and cascading impacts. This task is underpinned by our international science networks (volcano observatory and volcanic ash advisory centres; COMET; IAVCEI; GVM network) and our experience of volcanic events and their impacts. We will also support long-term scientific partners during events, especially in East Africa and the Caribbean region, when requested. There are many requirements during emergencies and we aim to ensure that consistent, authoritative and timely scientific evidence supports decision making at all scales and in different nations and jurisdictions. Since October 2020, we have also been providing a 24/7 emergency response service (commissioned) for the European Response and Coordination Centre (ARISTOTLE European Natural Hazards Scientific Partnership), which also focuses on humanitarian needs.	• Brian Baptie • Julia Crummy • Fabio Dioguardi • Melanie Duncan • Sam Engwell • Anna Hicks • Sue Loughlin • Rich Luckett • Katy Mee • Alessandro Novellino • Lara Smale • Pablo Tierz • Charlotte Vye-Brown
X	Global data and networks (volcanic hazards and risk)	Global data and networks include several activities related to improved understanding of volcanic hazards and risk. Building on the GVM GAR2015 indices, we aimed to develop new methods for gathering global data on volcanic activity and build networks on volcano reporting. Understanding risk is a priority for the Sendai Framework for Action. Assessing risk at the global scale is critical to informing understanding of progress towards disaster risk reduction and sustainable development. Several stakeholders, including UK Government, are increasingly monitoring multi-hazard activity across the globe to ensure they can make anticipatory and timely decisions about potential humanitarian crises, systemic risks and the health and wellbeing of their residents overseas. Currently FCDO funds BGS to provide input to one such monitoring activity (the International Natural Hazards Forward Look), which is designed to increase situational awareness amongst Government partners to potential humanitarian crises. BGS currently is the only provider of a summary of global volcanic activity and impact.	• Fabio Dioguardi • Melanie Duncan • Sam Engwell • Anna Hicks • Gareth Jenkins • Sue Loughlin • Katy Mee • Lara Smale • Ashley Patton • Pablo Tierz Lopez • Charlotte Vye-Brown

Code	Task title	Task aim	Narrative authors
Y	Opportunities and threats on small islands, examples from the UK Overseas Territories	The UK Overseas Territory of St Helena, Ascension and Tristan da Cunha in the South Atlantic consists of two isolated islands and a third archipelago. Two of the three islands are volcanoes with potential to erupt so pose a risk to the highly exposed populations that inhabit them. Taking a multi-disciplinary approach is essential for sustainability and resilience in these locations where resources (including access to potable water) are limited, transport is essential for supplies, and emergency transport off-island cannot be immediately provided. This task has built on previous work on Ascension and Tristan da Cunha to explore how earth science research can be integrated with conservation and ecological research to inform and enhance existing natural hazard planning and risk management initiatives. There is an objective to develop a 'virtual observatory' for Ascension and Tristan da Cunha but despite submission of proposals, funding has not yet been made available.	• Anna Hicks • Sue Loughlin • Richard Luckett • Charlotte Vye-Brown,
Z	Hazard and risk data and evidence in Ethiopia	Since 1900, an estimated 405 000 fatalities have been caused by natural hazards in Ethiopia, with 80 million people affected and total damages more than US$1500 million (EM-DAT, 2019). An absence of accessible and reliable data about several frequent hazards in Ethiopia, including ground fissuring, rifting and volcanic hazards (e.g., gas emissions; ground deformation; volcanic earthquakes; volcanic ash; lava flows, etc.) has led to a lack of awareness of the risks they pose. Records of the impacts and consequences of these hazards are also not easily available and, in many cases, have not been recorded at all. We are developing understanding, knowledge and data related to multi-hazards in this volcanic environment, including: • earthquakes • volcanic ash • ground fissuring • lava flows • landslides • flooding • groundwater • past hazardous events and their impacts With our Ethiopian partners, we are designing and populating new databases and resources to enhance and share knowledge widely and give new insight into rapid and long-term changes and consequences in a rift environment.	• Rachel Bell • Julia Crummy • Sam Engwell • Ekbal Hussain • Sue Loughlin • Richard Luckett • Pauline Smedley • Pablo Tierz • Charlotte Vye-Brown