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The role of science, technology and innovation in building resilient communities, including through the contribution of citizen science

Report of the Secretary-General

Summary

In this report, key issues concerning the role of science, technology and innovation in building resilient communities are discussed. The paper highlights the critical importance of building resilience for sustainable development. Resilient communities empower their members to absorb and adapt to shocks, have economies that can self-organize to continue functioning in times of crisis, and are able to carry out all their activities without harming the environment. Science, technology and innovation have a critical role to play regarding each of these dimensions. Digital technologies have empowered people. Innovation leads to economic diversification, which increases the ability of economies to adapt to shocks. New technologies could help to decouple economic development from environmental degradation. Citizen science uses new technologies to engage volunteers in performing tasks such as data collection in support of science. The technical challenges involved are related to data, underlying enabling technologies and the need for caution when using data acquired during citizen science projects. The social challenges that arise are linked to knowledge generation and use, given that resilience reflects social norms and competing interests within the community. There are also market challenges regarding scalability and sustainability, highlighting the fact that many technological solutions for community resilience are still at the prototype stage. Another key issue is the need to develop science, technology and innovation solutions that are resilient in themselves, given that disruption could be extremely harmful for communities. The report concludes by underscoring the key role of international cooperation and presenting policy suggestions for consideration.

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Introduction

1. At its twentieth-first session, held in Geneva, in May 2018, the Commission on Science and Technology for Development selected The role of science, technology and innovation in building resilient communities, including through the contribution of citizen science as one of its two priority themes for the 2018–2019 intersessional panel.

2. The secretariat of the Commission convened an intersessional panel meeting from 15 to 17 January 2019, in Vienna, to contribute to a better understanding of this theme and to assist the Commission in its deliberations at its twenty-second session. This report is based on the issues paper prepared by the Commission secretariat,[1] the findings of the panel, country case studies contributed by Commission members, relevant literature and other sources.

I. Context

A. Impact of shocks on sustainable development

3. People around the world are affected by shocks all the time: from economic crises to health emergencies, from social conflicts and wars to disasters caused by natural hazards. For example, outbreaks of diseases such as cholera and Ebola have affected thousands of people. In 2016, 180,000 people died as a result of conflicts.[2] In 2017, natural disasters affected more than 95 million people, causing over US$337 billion-worth of loss and damage.[3] Conflicts and disasters displaced 30.6 million people across 143 countries and territories.[4] Two recent broad-based economic shocks, in the form of the 2010–2012 European sovereign debt crisis and the 2014–2016 global commodity price realignments, resulted in economic slowdown, affecting jobs and the capacity of many Governments to provide better access to public services, including health and education.[5]

4. Moreover, global economic interdependence has created increasingly complex and unpredictable threats. Disasters caused by natural hazards lead to supply chain disruptions, often resulting in widespread damage and economic losses that could spread through industries and economies. Another complex threat is the risk of natural hazard-triggered technological disaster events, such as the Fukushima Daiichi nuclear power plant disaster, primarily initiated by the tsunami following the Tōhoku earthquake on 11 March 2011.[6]

5. Such shocks have a severe impact on progress towards sustainable development. Building the resilience of people, communities and countries is, therefore, critical for the implementation of the 2030 Agenda for Sustainable Development and the achievement of the Sustainable Development Goals.

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[1] The issues paper and all presentations and contributions to the intersessional panel meeting cited in this report are available at https://unctad.org/en/pages/MeetingDetails.aspx?meetingid=2026 (accessed 15 February 2019).

[2] World Health Organization (WHO), 2018, *World Health Statistics 2018: Monitoring Health for the [Sustainable Development Goals] SDGs,* Geneva.

[3] UNCTAD calculations based on data from the Emergency Events Database of the Centre for Research on the Epidemiology of Disasters, Université catholique de Louvain. Available at www.emdat.be (accessed 15 February 2019).

[4] Internal Displacement Monitoring Centre, 2018, *GRID 2018: Global Report on Internal Displacement*, Norwegian Refugee Council.

[5] United Nations, 2018, *World Economic Situation and Prospects 2018* (New York, Sales No. E.18.II.C.2).

[6] See https://ec.europa.eu/jrc/en/research-topic/technological-accidents-triggered-natural-disasters (accessed 21 February 2019).

B. Resilience, risk reduction and sustainable development

6. In preparing this report, the United Nations harmonized definition of resilience was employed. That definition was approved by the High-level Committee on Programmes of the United Nations System Chief Executives Board for Coordination, as part of an analytical framework for risk and resilience for the United Nations. According to the definition, which is contained in the report of the High-level Committee on Programmes at its thirty-fourth session, resilience is: "The ability of individuals, households, communities, cities, institutions, systems and societies to prevent, resist, absorb, adapt, respond and recover positively, efficiently and effectively when faced with a wide range of risks, while maintaining an acceptable level of functioning and without compromising long-term prospects for sustainable development, peace and security, human rights and well-being for all."[7]

7. The focus on community resilience places community members acting within their sphere of influence centre stage, taking into consideration their social interrelations and economic activities, as well as the assets and infrastructure at their disposal.[8] Given the three dimensions of sustainable development, a resilient community is one that is organized socially in a way that sufficiently empowers its members to be better able to absorb and adapt to shocks. Such a community must have a diversified economy that can adapt to changes in circumstances, self-organize to continue functioning in times of crisis and carry out its activities without harming the environment.

8. A critical consideration in building the resilience of communities is that they should be fully engaged in interventions, projects and strategies from the beginning. Engagement and participation must be promoted if communities are to be empowered to act quickly and to find solutions to their own problems.

C. The role of science, technology and innovation regarding resilience: a framework for analysis

9. Science, technology and innovation contribute to resilience by: empowering and giving a voice to people, including the most vulnerable; extending access to education and health; making possible the monitoring of environmental risks; connecting people; and enabling the development of early warning systems. Innovation drives economic diversification, which allows economies to adapt to shocks and to thrive. Innovation in infrastructure protects against failure and negative impacts on communities. Moreover, new technologies and innovative products and services could decouple economic development from environmental degradation, promoting environmental sustainability.

10. To facilitate a focused discussion, this report covers the following key aspects:

(a) Technology: rapid technological development opens new pathways for community resilience. While recognizing the importance of traditional technologies, this report focuses on market-ready new technologies in order to highlight recent developments and new opportunities;

(b) Science: diverse fields of science contribute to building resilient communities. This report acknowledges that fact, focusing on the use of indigenous knowledge and new ways to engage citizens in contributing to and participating in scientific research for resilience;

(c) Innovation: the report contains discussion of the systems characterizing the innovation process that contributes to community resilience, and of new approaches to innovation for resilience made possible by digital technologies.

[7] CEB/2017/6, p. 25.

[8] International Federation of Red Cross and Red Crescent Societies (IFRC), 2012, *Characteristics of a Safe and Resilient Community* (Geneva).

II. Technology for building the resilience of communities

A. Building social resilience

1. Reducing vulnerabilities and building capacities to cope

11. Poor access to health and education increases vulnerabilities. In this regard, modern information and communications technologies, such as satellite and mobile technologies, facilitate access to health-care services through telemedicine, including for rural and remote communities. New vaccines and strategies to control outbreaks of diseases, such as Ebola, also contribute to increasing community resilience. Drones are used to delivery vaccines and medical supplies to rural areas of developing countries.[9]

12. The use of computers, tablets and smartphones enables e-learning and gives access to relevant information in a timely manner, improving capacity to cope with shocks. For instance: mobile applications support education efforts aimed at building capacities to prepare for, cope with and recover from disasters; smartphones are used to record and disseminate videos via social media, showcasing ways in which community members can build their own capacities; and digital games have been used in computer simulation-based emergency response training.

2. Assessing, monitoring and managing risk

13. Reducing the risk of threats entails the ability to assess and monitor risks. Low-cost, open-source, ad hoc sensors complement monitoring networks (for example, river gauges and seismographs). One example in this regard is a project as a part of which volunteers install self-built gauges outside their homes to generate and transmit data to update fine dust maps.[10] Citizens also provide crowdsourced information, commonly known as volunteered geographical information, in the form of time-stamped and geolocated photographs and social media updates. Smartphones equipped with sensors (for example, cameras, accelerometers and microphones) can also be used for monitoring and scientific observation.

14. In addition to in situ sensors, environmental monitoring involves the use of satellites and drones for remote sensing. Satellite technologies are critical for disaster preparedness and emergency response. The cost of small-scale satellites is decreasing, rendering more affordable applications that use high-resolution imagery, for example, for monitoring land use and urban planning. Drones offer a low-cost approach to remote sensing. Such devices can be deployed in land-use monitoring and rapid mapping in case of emergencies, for example, in tandem with crowdsourcing platforms that allow live footage from drones flown during disasters to be tagged.

15. Crowdsourcing is also used to produce digital risk assessment maps. Examples in this regard include the United States Agency for International Development YouthMappers project,[11] an international network of universities mapping for resilience by creating and using open geographic data, and Community Maps,[12] an initiative offering participatory mapping services.[13]

16. A critical component of community resilience is the existence of local early warning systems connected to national systems. For example, in the United States of America, local

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[9] For example, Rwanda Biomedical Centre, 2016, Rwanda launches the first drone medical deliveries project, 14 October. Available at www.rbc.gov.rw/IMG/pdf/press_release_medical_drones_deliveries.pdf (accessed 15 February 2019); and Rosen JW, 2017, Zipline's ambitious medical drone delivery in Africa, *[Massachusetts Institute of Technology] MIT Technology Review*, 8 June. Available at www.technologyreview.com/s/608034/blood-from-the-sky-ziplines-ambitious-medical-drone-delivery-in-africa/ (accessed 15 February 2019).

[10] See https://luftdaten.info/en/home-en/ (accessed 15 February 2019).

[11] See www.youthmappers.org/ (accessed 15 February 2019).

[12] See https://communitymaps.org.uk/welcome (accessed 15 February 2019).

[13] See http://mappingforchange.org.uk/ (accessed 15 February 2019).

authorities disseminate emergency alerts received from the Federal Emergency Management Agency Integrated Public Alert and Warning System. Mobile technology provides new possibilities for early warning. For example, as a part of the Surveillance in Post Extreme Emergencies and Disasters early warning system, health workers use mobile telephones to send reports to a central database to enable the detection of common health conditions in an emergency.[14]

3. Responding to emergencies

17. Emergency response requires timely communication for coordination and action, and mobile technology offers new solutions in that regard. For example, rescue and relief workers can use mobile telephones or "wearable routers" to form a wireless local area network during emergencies. Mobile technology is also used to run interactive post-disaster surveys for damage or needs assessment. One example in this regard is the World Food Programme Vulnerability Analysis and Mapping project.[15]

18. As disasters unfold, citizens increasingly turn to social media to seek and share information. Local agencies use social media to involve community members as first-line informants and responders. This approach creates shared awareness and commits citizens to increase resilience. Agencies and non-governmental organizations monitor social media for situational awareness, including patterns of serious needs, available resources and deployed responses.

19. Data analytics and big data can also support emergency response. For example, during a typhoid outbreak in Uganda, the Ministry of Health used data-mapping applications to allocate medicine and mobilize health teams.[16] Studies on partnership with mobile operators have shown that aggregated and anonymized mobile telephone data can be used for rapid assessment of population movements after emergencies, improving disaster management.[17] Financial transaction data have been used to better understand peoples' economic resilience and to estimate economic loss at the local level due to a disaster, which could inform targeted emergency response.[18] Data analytics and big data also render assistance to communities more effective. One example in this regard is the World Health Organization dashboard system, which monitors health emergencies globally to inform action (for example, the 2018 Ebola outbreak in the Democratic Republic of the Congo, and the cholera outbreak of the same year in Zimbabwe).[19]

B. Building economic resilience

1. Increasing economic opportunities and diversification

20. Economic diversification is a strategy that is commonly pursued when seeking to build economic resilience. This is particularly the case in communities that need to manage fluctuations in resource abundance and economic activity, such as rural, tourism-based and coastal fishing communities. Nevertheless, economic diversification remains a challenge for poorer economies with low levels of productive capacity. In more technologically advanced communities, with broadband Internet connectivity and modern information and communications technology, new technologies (for example, artificial intelligence, big data and three-dimensional printing) could enable the development of new sectors. Economic diversification can also be the result of innovation in know-how, methods, procedures,

[14] See www.wpro.who.int/philippines/areas/emergencies_disasters/speed/en/ (accessed 15 February 2019).

[15] See www.wfp.org/content/2016-mobile-vulnerability-analysis-mapping-mvam (accessed 27 February).

[16] United Nations Global Pulse, WHO and Uganda, Ministry of Health, 2015, Data visualisation and interactive mapping to support response to disease outbreak, Project Series No. 20.

[17] United Nations Global Pulse and World Food Programme (WFP), 2014, Using mobile phone activity for disaster management during floods, Project Series, No. 2.

[18] United Nations Global Pulse and WFP, 2016, Using financial transaction data to measure economic resilience to natural disasters, Project Series, No. 24.

[19] Contribution from WHO.

norms and regulations. For example, changes in social norms to facilitate women's access to productive resources could lead to the creation of new businesses.

2. Access to energy and communications infrastructure[20]

21. Access to infrastructure, such as electricity and communications, is critical for communities' development and resilience. New technologies can offer an alternative solution to costly investment in such infrastructure. For example, rapid technological advances and cost reductions have enabled some developing countries, notably in Africa and Asia, to skip analogue landline infrastructure and move directly to digital mobile telecommunications. Several countries that had low levels of penetration of fixed and mobile telephones in the early 2000s, had, by 2017, exceeded the worldwide average of 108.9 mobile telephone subscriptions per 100 inhabitants.[21]

22. An example of the potential of new technologies for extending access to electricity is the development of decentralized renewable energy systems. An analysis using geospatial data shows that, to bring electricity to all households in sub-Saharan Africa by 2030, for several countries the most cost-effective mix of conventional and renewable energy technologies would be off-grid and mini-grid solutions employing solar photovoltaic technology.[22]

3. Financial inclusion and risk financing

23. A critical element of a resilient community is the capacity of its members to handle financial uncertainty. Although financial services facilitate this process, many rural and remote areas and vulnerable groups are underserved. However, the rapid adoption of mobile technology has paved the way for innovative financial technology services, particularly in Africa, such as the M-Pesa mobile banking system in Kenya, with important implications for financial inclusion. For example, countries in sub-Saharan Africa have the highest percentages of adults with a mobile money account, 21 per cent in 2017, as compared with 4 per cent for the world.[23]

24. Innovations such as weather index insurance have also benefited farmers in countries where agricultural financial markets are underdeveloped. Under the index insurance system, payments are made based on an objective index, such as rainfall measurements, that serves as a proxy for crop or livestock losses. Insurance companies use satellite imagery and computer models to create indexes as the basis for payments. However, despite their clear benefits,[24] the uptake of index insurance schemes in developing countries remains low. This is due, among other things, to a poor understanding of crop insurance, the inability to pay premiums and the failure in the past of models to properly estimate loss.

C. Building environmental resilience

25. Technology can be used to monitor terrestrial and marine ecosystems. For example, satellite data and machine-learning algorithms are used to track changes in tree cover and canopy density. Artificial intelligence could be used to cross-check information regarding logging licenses with data provided by geospatial mapping systems to monitor illegal activities. Drones have various applications in land and resources management, including

[20] Based on UNCTAD, 2018, Leapfrogging: look before you leap, December, UNCTAD Policy Brief No. 71 (UNCTAD/PRESS/PB/2018/8). Available at https://unctad.org/en/PublicationsLibrary/presspb2018d8_en.pdf.

[21] UNCTAD calculations based on data from the International Telecommunication Union.

[22] UNCTAD calculations based on data from the United Nations, available at https://un-modelling.github.io/electrification-paths-presentation/ (accessed 20 February 2019).

[23] Demirgüç-Kunt A, Klapper L, Singer D, Ansar S and Hess J, 2018, *The Global Findex Database 2017: Measuring Financial Inclusion and the Fintech Revolution*, World Bank Group, Washington, D.C., pp. xi and 19.

[24] See Skees JR, 2008, Innovations in index insurance for the poor in lower income countries, *Agricultural and Resource Economics Review*, 37(1): 1–15.

the dynamic monitoring of land use, land law enforcement and land development and consolidation. Geospatial technology is used in new remote-sensing sensors to measure components of the water cycle, ground sensor-based field instruments, cloud-based data integration and computational models and web geographic information system-based water information portals.

26. Modern information and communications technologies open up new opportunities for innovative niche products and services, such as nature-based tourism, that promote balanced interaction with nature. For example, geospatial information and communications technology applications can support nature-based tourism by facilitating eco-friendly outdoor activities such as hiking, mountain biking and canyoning. Eco-friendly sectors usually require more knowledge than traditional sectors; furthermore, in order to meaningfully engage community members, it is critical to build their capacity.

D. Characteristics of technological solutions

27. Effective solutions for building the resilience of communities using market-ready new technologies share several common characteristics in that they are:[25]

(a) Multipurpose: solutions are relevant and useful before, during and after emergencies, as well as in daily life. Examples in this regard include mobile telephones and smartphones, which are employed in a range of solutions, from disaster risk assessment and monitoring to emergency response and early warning systems;

(b) Easy to learn and use: for example, there is no need for formal training in the use of social media, making them useful for emergency response. Similarly, the operation and data formats of drones used for remote sensing have been simplified, enabling non-scientists to conduct aerial surveys;

(c) Scalable: they should grow to accommodate demand. Social media for emergency response provide scale and enable anyone to reach a large audience;

(d) Accessible and affordable: with regard to emergency response, low-cost mobile telephones have become more available. Drones have low operation costs, allowing for frequent missions, offer increased spatial coverage, do not require installation points and can be deployed rapidly.[26]

28. Many of these characteristics of technological solutions arise from information and communications technologies and the possibilities that they bring through digitalization and connectivity. Reductions in the cost of such technologies have democratized access thereto and allowed new actors and forms of innovation to emerge.

III. Science: harnessing indigenous knowledge and engaging with citizens to ensure their participation

A. Building synergies with traditional, local and indigenous knowledge

29. Building synergies with traditional, local and indigenous knowledge could lead to new scientific developments that contribute to building resilient communities. Indigenous knowledge is usually acquired through interaction with the natural ecosystem and through work to ensure the long-term survival of communities. Such knowledge contributes to efforts to: increase the resilience of communities in the face of common natural hazards (for example, floods and droughts) and in relation to their livelihoods (for example, agriculture, animal husbandry and wildlife management); sustain the traditional values of communities

[25] Based on American Red Cross and IFRC, 2015, A vision for the humanitarian use of emerging technology for emerging needs, p. 14.

[26] For example, see Vousdoukas MI, Pennucci G, Holman RA, Conley DC, 2011, A semi-automatic technique for rapid environmental assessment in the coastal zone using small unmanned aerial vehicles (SUAV), *Journal of Coastal Research*, Special Issue 64: 1755–1759.

and strengthen their identity; and promote the engagement of women and members of vulnerable groups, who are important elements in building resilience.

30. Support from Governments and the international community is often required when scaling up, adapting and making accessible such knowledge. One way to achieve those objectives is through online databases of traditional knowledge.[27] There is also a need for policies designed to ensure the continued intergenerational transmission of such knowledge systems within their communities of origin.

31. In some countries, scientific funding bodies have incentivized indigenous knowledge in addressing environmental challenges. For example, in South Africa, indigenous knowledge systems are one of the cross-cutting themes of the National Research Foundation Ten-Year Innovation Plan, which focuses, among other things, on climate change.[28] In Canada, the federal agency Polar Knowledge Canada is providing Can$8.1 million from 2017 to 2019 to fund projects using indigenous knowledge to promote sustainability and resilience regarding the impact of changing ice conditions.[29]

B. Citizen science for building resilient communities

32. Citizen science refers to the involvement of non-scientist citizens in the generation of new scientific knowledge. This approach combines the Internet, smartphones and social media with low-cost sensor networks to provide extensive, real time information. Citizen science can also serve to educate and empower communities and stakeholders that might otherwise be bypassed by more traditional methods of generation of scientific knowledge.

33. Such an approach has been adopted in risk management for some time. Bottom-up community-led projects, which would nowadays be classified as citizen science, were recognized as being hugely beneficial to capacity building as early as the 1980s. This approach is not restricted to disaster risk reduction. There are projects such as the Global Mosquito Alert Consortium, for the global monitoring and control of mosquito species known to carry diseases,[30] and the Earth Challenge 2020, the aim of which is to collect together more than one billion data points on air and water quality, biodiversity and human health.[31]

1. Types of citizen science

34. Citizen science could involve data collection, interpretation and analysis, and the dissemination of results. In many projects, the role of local stakeholders is strictly limited to information gathering. These “citizen sensors” are less involved in the aims and formulation of the project, but still can provide good quality data in data-scarce regions. More recently, the tendency has been to involve volunteers in all intellectual aspects of the citizen science project, with citizens defining the problem at hand and then collecting relevant information (for example, observations on streamflow, air quality, ground shaking and flood damage).

[27] For example, see Liu Y and Sun Y, 2004, China traditional Chinese Medicine (TCM) Patent Database, *World Patent Information*, 26(1), March: 91–96; Traditional Knowledge Digital Library, available at www.tkdl.res.in/tkdl/langdefault/common/Home.asp?GL=Eng (accessed 18 February 2019); Korean Traditional Knowledge Portal, available at www.koreantk.com/ (accessed 18 February 2019); and Genesys – the Global Gateway to Generic Resources, available at www.genesys-pgr.org/ (accessed 18 February 2019).

[28] See www.nrf.ac.za/division/funding/indigenous-knowledge-systems-iks-2019 (accessed 18 February 219).

[29] See www.canada.ca/en/polar-knowledge/news/2017/12/government_of_canadaannouncesfundingforscienceandtechnologyandkn.html (accessed 27 February 2019).

[30] For more information, see Tyson E, Bowser A, Palmer J, Kapan D, Bartumeus F, Brocklehurst M and Pauwels E, 2018, *Global Mosquito Alert: Building Citizen Science Capacity for Surveillance and Control of Disease-vector Mosquitoes*, April, Wilson Centre.

[31] See www.earthday.org/campaigns/earthchallenge2020/ (accessed 27 February 2019).

35. Receiving information and data back in a comprehensible manner serves as an incentive for citizen participation. For example, in hydrological projects, this process could take the form of irrigation requirements for farmers, modelled water uses and demand for policymakers, or flood vulnerability maps for the public.[32] Internet-based technologies create opportunities for user feedback and communication beyond the research project itself. Where information provision and citizen feedback are integral to project development, participation rates and levels of community buy-in are high.

2. Use of technology in citizen science

36. Many have equated the increase in the number of citizen science research projects with rapid technological development over the past 10–15 years. Small, inexpensive sensors are now widely available and easy to connect to smartphones, which are generally Internet-connected and come with sophisticated cameras as standard. These developments, together with advances in data processing and analysis, are opening new pathways for citizen science to improve resilience-building efforts on a community scale. New information and communications technologies have augmented the flow of knowledge and data, while the Internet of things allows for a much more interactive and dynamic approach to research design, knowledge generation and information provision at the community level. While it is sometimes challenging to integrate the newest forms of innovative hardware and software directly into resilience-building projects in least developed countries, promising opportunities nevertheless exist; for example, the use of new sensor networks and online maps for hydrological monitoring,[33] geological mapping[34] and risk mapping exercises.[35]

IV. Innovation: a mission-driven approach to resilience

A. Innovation systems for building resilient communities

37. Innovation systems for the creation of products and services for building resilient communities are usually mission-driven, meaning that innovation system actors pool resources to solve a particular social problem: for example, the need for multi-hazard early warning, immunization against new diseases, or functioning communication networks during emergencies. These innovation systems usually focus on later-stage deployment of traditional technologies (for example, vaccines and remote sensing) or market-ready new technologies (for example, smartphone applications and low-cost drones), in contrast with early-stage exploration and development of emerging technologies (for example, artificial intelligence and gene editing).

38. Citizens, civil society organizations, social entrepreneurs, educational organizations and local and national Governments are all actors in these innovation systems:

(a) Citizens are the final users of many resilience-building products and services and contribute key inputs regarding the problems to be addressed and the effectiveness and usability of proposed solutions;

[32] For example, see Paul JD, Buytaert W, Allen S, Ballesteros-Cánovas JA, Bhusal J, Cieslik K Clark J, Dugar S, Hannah DM, Stoffel M, Dewulf A, Dhital MR, Liu W, Nayaval JL, Neupane B, Schiller A, Smith PJ and Supper R, 2018, Citizen science for hydrological risk reduction and resilience building, *[Wiley Interdisciplinary Reviews] WIREs: Water*, January/February, 5(1).

[33] Buytaert W, Zulkafli Z, Grainger S, Acosta L, Alemie TC, Bastiaensen J, De Bièvre B, Bhusal J, Alemie TC, Clark J, Dewulf A, Foggin M, Hannah DM, Hergarten C, Isaeva A, Karpouzoglou T, Pandeya B, Paudel D, Sharma K, Steenhuis T, Tilahun S, Van Hecken G and Zhumanova M, 2014, Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development, *Frontiers in Earth Science,* 2: 26.

[34] Malakar Y, 2014, Community-based rainfall observation for landslide monitoring in western Nepal, in: Sassa K, Canuti P and Yin Y, eds., *Landslide Science for a Safer Geo-environment. Volume 2: Methods of Landslide Studies,* Springer International Publishing: 757–764.

[35] Rieger C, 2016, Demonstrating the capacity of online citizen science mapping software to communicate natural hazards and engage community participation, University of Lethbridge, August.

(b) Civil society organizations mediate between local government, technology developers and marginalized groups, and promote innovations that address their needs. These organizations can be instrumental in testing, promoting and disseminating innovations designed to benefit the most disadvantaged communities;

(c) Social entrepreneurs contribute to the innovation process by providing local solutions to local social, cultural and environmental problems. They help to build resilient communities by addressing existing vulnerabilities and by promoting sustainable transitions;

(d) Effective education systems increase the capacity of communities to learn, adapt to changes and to contribute to the innovation process of finding new and better solutions for risk reduction;

(e) Local governments provide local public services and goods that increase resilience (for example, education, health, transport and infrastructure against floods);

(f) National Governments are key to providing direction for the mission-oriented approach to innovation, contribute the required soft and hard public infrastructure, promote capacity building and foster the creation of linkages in the innovation system.

39. Effective innovation systems have robust and evolving linkages between all the above-mentioned science, technology and innovation stakeholders. One example in this regard is cooperation between science and technology groups and educational institutions to promote the popularization and dissemination of resilience knowledge.

40. An effective innovation system for building community resilience also requires an enabling environment. Infrastructure should be developed with specific emphasis on ensuring affordable access to information and communications technologies and overcoming digital divides. The regulatory and policy framework should provide a supportive environment to facilitate mission-driven and long-term planning by innovation actors. Coherence is needed between science, technology and innovation policies and policy areas such as public health and disaster risk reduction. Institutions and public authorities should engage the community in participating in the design and implementation of resilience-building innovations. There should be flexible access to finance for social entrepreneurs. Human capital should be nurtured through a strong focus on building the skills required to use enabling technologies, such as information and communications technologies, and on the dissemination of resilience knowledge through the education system. Social and cultural norms and practices should promote inclusive participation of women, youth and the elderly in the innovation process towards community resilience.

B. New innovation approaches for community resilience[36]

41. Pro-poor and inclusive innovation can increase community resilience by extending the benefits of innovation to previously excluded groups; either as consumers of new products and services or as participants in the innovation process. The focus is on developing low-cost products and services to serve untapped markets, such as low-cost medical products and mobile telemedicine in remote rural areas, and innovations that offer opportunities for people living in poverty to engage in small-scale trade to help increase their incomes.

42. Grass-roots innovation approaches seek to include local communities in the innovation process, which is critical for the engagement of community members in initiatives for building resilience. This is done through the involvement of grass-roots actors experimenting with alternative forms of knowledge-creation and innovation processes. For example, community-based disaster risk reduction systems usually engage the community in the development of monitoring and early warning mechanisms. Another example is the development of innovative mobile payment solutions, particularly for the

[36] This section draws on UNCTAD, 2017, *New Innovation Approaches to Support the Implementation of the Sustainable Development Goals*, UNCTAD/DTL/STICT/2017/4 (United Nations publication, New York and Geneva).

consumers at the base of the pyramid, using basic mobile telephone technology rather than smartphones. Grass-roots innovation initiatives, which operate in civil society arenas, are driven by social and environmental needs, based on mutual exchange and voluntary inputs from actors and local knowledge and often supported by funding in the form of grants.

43. The term “social innovation” refers to innovations in social relationships; practices and structures that are primarily designed to address social needs and improve human well-being. Some examples of social innovation for building community resilience include the provision of microfinance products to reduce the financial vulnerabilities of communities, the promotion of new local business ideas for diversification of livelihoods, and support for women's eco-entrepreneurship as an approach to sustainable local rural development.

V. Key challenges

A. Technical challenges: Data and underlying enabling technologies

44. Several gaps persist in data used to inform resilience-building that could be filled by citizen science data. To better leverage that data, there is a need for standards and frameworks that facilitate its collection and dissemination. For example, citizen science projects typically involve sensor-sourced data collection by non-scientists; therefore, the design of the sensor network need to be simplified to ensure consistent samples. The use of data could also be increased through its conversion between technologies, platforms and applications. For example, while the use of smartphones to photograph flooding extent and river level has the potential to form a very dense network of crowdsourced sensors, data conversion to input for mathematical models and provision of information back to volunteers (non-scientists) remain technologically demanding and are currently being developed.

45. In an additional challenge, the data in question are often not of sufficiently high quality for the purposes of the calibration and validation of mathematical models. One solution to this problem is to apply novel merging algorithms to create combined datasets, for instance between citizen science-collected rain gauge data and satellite precipitation products. However, guidance on the deployment, use and management of these data-collection services may be required.

46. In addition, the effects of decreased observational frequency, irregular availability and variable accuracy from sensor to sensor need to be quantified before the data can be used in mathematical models. These data uncertainties prevent the widespread use of citizen science data in resilience-building applications, such as operational early warning systems. The uncertainties should be taken into consideration, for instance, by providing uncertainty bounds. These could take the form of approximate percentage errors on river level as deduced with a smartphone camera. Despite the rapid technological advances, citizen science data are rarely presented in such a form due to the difficulties in uncertainty quantification.

47. With the use of social media for building resilience, issues related to the reliability of information, privacy and data protection require consideration. Data in general, either when used in humanitarian and disaster emergency contexts or in the context of preparedness, raise the need for operationally responsible approaches to providing safe data storage, privacy and anonymity.[37] In this regard, there is a need for prudent use of data and for action to protect citizens’ privacy.

48. Another challenge is that many top-down institutional resilience-building approaches have struggled to create actionable knowledge at a local level. For instance, river level and discharge monitoring are usually based on a sparse network of gauges that require extensive and technologically complex maintenance, confining its use to large,

[37] For example, see Office for the Coordination of Humanitarian Affairs (OCHA), 2016, Building data responsibility into humanitarian action. OCHA Policy and Studies Series Think Brief, May.

well-funded institutions and official government entities. This restriction often entails administrative and even legal issues over data access, which can frustrate community-level users.

49. The Sendai Framework for Disaster Risk Reduction 2015–2030 strongly advocates linking data collection and analysis and information dissemination via user-friendly online interfaces or applications. This approach supports the construction of people-centred decision and policy-support systems. Such platforms have been described as environmental virtual observatories,[38] which allow information to flow between multiple actors. These observatories highlight the ways in which data cogeneration potentially leads to the political empowerment of marginalized individuals and communities, and consequently have broad implications for resilience building and knowledge co-creation in developing countries.

50. Another challenge is access to communications networks and equipment at the community level. For example, in some regions, countries and demographic groups, when individuals have access to equipment, such as mobile telephones, there is a prevalence of older models that may not interface with the latest applications. From a technical perspective, regions with low Internet penetration can benefit from extensive mobile telephone coverage that enables sensor data transmission via text messaging. Another important component of the digital infrastructure is the presence of local businesses that can support and maintain it, both in relation to software and hardware. Therefore, there is a need for initiatives to foster and promote such businesses.

B. Social challenges: Knowledge generation and use

51. Community members have different levels of resilience, which are also affected by power relations. Therefore, resilience is not neutral but reflects social norms and competing interests within a given community. For example, technological solutions for community resilience should take into consideration the fact that, in many contexts, women and girls have limited access to technologies. Initiatives that build their digital skills and provide access to information and communications technology could empower women and girls and contribute to building community resilience. One example in this regard is a project focusing on the empowerment of women and youth in the economically disadvantaged area of Kibera in Nairobi, specifically by engaging the community in data and information gathering, as well as by providing training in information and communications technology and entrepreneurship.[39]

52. Projects for building community resilience are sometimes precluded by cultural differences between scientists and local stakeholders (for example, language, customs, hierarchies, gender and treatment of outsiders). Scientists usually view resilience building as a discrete undertaking within a wider project. They often focus on publications and grants and lack the time and resources to fully understand local language and dialects, social norms and livelihoods. Local stakeholders consider resilience building as having a measurable impact on livelihoods, but they may be mistrustful or resentful if previous interventions failed to produce tangible improvements.

53. In order to align these views, technology-driven projects to boost resilience should include a social science component to ensure that research project outcomes are actionable and have a measurable impact on local livelihoods. The establishment of regular scientist-local stakeholder meetings or workshops can also overcome both cultural challenges and trust issues. Such workshops could also include an additional training component, delivered by local project members in the local language, under the scientific direction of the project leaders.

[38] Karpouzoglou T, Zulkafli Z, Grainger S, Dewulf A, Buytaert W and Hannah DM, 2016, Environmental Virtual Observatories (EVOs): Prospects for knowledge co-creation and resilience in the Information Age, *Current Opinion in Environmental Sustainability*, February, 18: 40–48.

[39] See www.globalgiving.org/pfil/15295/projdoc.pdf.

54. Moreover, it is critical that the data and generated knowledge should be locally relevant and actionable. They should be transformed into useful output (for example, hazard maps relating to landslide or earthquake vulnerability) and communicated back to the affected communities. Sometimes, there is a mismatch between the amount of scientific knowledge produced to inform decision-making at the local level, and the low demand for that information due to the fact that local governments are prevented from acting upon it by existing policy, legal and regulatory frameworks.

C. Market and operational challenges: Scalability and sustainability

55. One challenge relating to innovation systems for building resilient communities is the fact that many solutions are not developed beyond the prototype phase. There is a gap regarding the move to service delivery models and the improvement of the link between prototyping and entrepreneurs who bring the product or service to the market. Another challenge is the engagement and coordination of efforts across different government areas, sectors and markets (for example, health, infrastructure and education), which are required to upscale solutions for resilience building that usually have multiple impacts in different areas of the Sustainable Development Goals.

56. In terms of the use of hardware such as drones and sensor networks, current operational deployments are relatively modest in scale. Challenges include deployment and data collection costs, which remain high in extremely remote and impoverished areas. Moreover, important application-specific requirements may not be properly met by using off-the-shelf components.

57. Standardization of tools and methods used in citizen science research projects could reduce the operational challenges involved in that regard. For example, initiatives such as CitizenScience.org[40] and CitSci.org[41] seek to build collaboration, community and credibility by harnessing the knowledge gained by practitioners and researchers across the field of citizen science.

D. Developing resilient science, technology and innovation solutions

58. Technological solutions should also be resilient themselves and those designed for emergency response should be able to withstand weather, wear and tear, pressure and damage. They should also be energy-efficient and should increasingly leverage innovative sources of energy, supported by a network of back-up products and services.

59. The quality, design, distribution, interrelation and operation of technological infrastructure affect the resilience of the infrastructure itself. Disruption of critical infrastructure, such as hospitals, transport, electricity and information and communications technology infrastructure, has major negative effects on the socioeconomic fabric of communities. The complex nature and high level of interconnectedness of many of these types of infrastructure make them vulnerable to chain reaction effects during a crisis. The shape and structure of infrastructure networks affect how resilient they are to shocks. Many infrastructure networks tend to be formed by continuously adding new segments to existing parts of the network that are already well connected. These networks are robust to random failure but vulnerable to failure on nodes with many links. For example, public transport networks are robust under random failure but vulnerable to targeted shocks that disrupt more highly connected nodes.[42]

[40] See www.citizenscience.org/about/ (accessed 27 February 2019).

[41] See www.citsci.org/CWIS438/Websites/CitSci/About.php?WebSiteID=7 (accessed 27 February 2019).

[42] Berche B, Von Ferber C, Holovatch T and Holovatch Y, 2009, Resilience of public transport networks against attacks, *The European Physical Journal B*, 71(1): 125–137.

VI. International collaboration

60. International collaboration plays a critical role in the provision of global science, technology and innovation that enables community-based technological solutions for resilience building. This collaboration generates information on cross-border natural hazards, such as weather events or disease outbreaks, which feeds into national and community-level services. For example, the World Meteorological Organization provides online information on tropical cyclones, heavy rain and snow, thunderstorms, gales and fog.[43] The United Nations Platform for Space-based Information for Disaster Management and Emergency Response makes available space-based scientific knowledge and technologies for disaster management.[44] In the area of health, the World Health Organization-coordinated Pandemic Influenza Preparedness Framework[45] for the sharing of influenza viruses and access to vaccines and other benefits enables the rapid collection and analysis of influenza viruses, increasing national preparedness capacities and equitable access to antivirals and vaccines.

61. Collaborative global research platforms advance the development of scientific tools that contribute to resilience. For example, Precision [Food and Drug Administration] FDA[46] connects experts around the world and provides tools, data and a framework for running community-based challenges on issues such as early detection during pathogen outbreaks. Collaborative platforms are also effective in engaging Governments and practitioners. Examples in this regard include: the 100 Resilient Cities[47] platform, which provides member cities with financial and logistical guidance and curated resilience-building tools and services; the Digital Humanitarian Network,[48] which leverages digital volunteers in support of humanitarian response; and the Humanitarian Data Exchange,[49] an Office for the Coordination of Humanitarian Affairs open platform for sharing data across crises and organizations.

62. National and international initiatives have been established to support public participation in scientific processes, mainly by initiating and supporting citizen science projects and carrying out research on citizen science. Such initiatives include the European Citizen Science Association, the Citizen Science Association and the Australian Citizen Science Association. In 2017, a network of networks entitled the Citizen Science Global Partnership was launched to promote and advance citizen science.

63. Development cooperation can build capacity in new technologies with potential to increase the resilience of communities. Statistics on official development assistance do not track the amount of bilateral assistance specifically targeting resilience, but the amount of official development assistance for economic infrastructure, which contributes to economic resilience, has increased from US$8 billion in 2000 to US$22 billion in 2016.[50] International collaboration also takes the form of provision of support for the intergovernmental disaster risk reduction and resilience building process.

64. Within the United Nations system, several agencies have programmes to promote science, technology and innovation solutions that contribute directly to building resilient communities. The regional commissions have promoted cooperation on science, technology and innovation for resilience. For example, the Economic and Social Commission for Asia and the Pacific has a programme on information and communications technology and disaster risk reduction covering resilience building, drought monitoring from space, regional cooperation on space applications and space and geographic information systems for disaster management. One good example of cooperation is the Regional Cooperative Mechanism for Drought Monitoring and Early Warning, through which participating

[43] See https://severe.worldweather.wmo.int/ (accessed 27 February 2019).
[44] See www.un-spider.org/ (accessed 27 February 2019).
[45] See www.who.int/influenza/pip/en/ (accessed 27 February 2019).
[46] See https://precision.fda.gov/ (accessed 19 February 2019).
[47] See www.100resilientcities.org/ (accessed 19 February 2019).
[48] See http://digitalhumanitarians.com/ (accessed 19 February 2019).
[49] See https://data.humdata.org/.
[50] See https://data.oecd.org/oda/distribution-of-net-oda.htm (accessed 27 February 2019).

countries are provided with timely and free access to space-based data, products and services and training and capacity-building support. The Economic and Social Commission for Western Asia has promoted resilience building by assisting in the development of national digital transformation strategies, including by addressing the links between information and communications technology and governance and conflict prevention. At the community level, United Nations country team members have used market-ready new technologies to implement early-warning and preparedness systems and develop national capacities to manage disaster risk, while providing expertise in fields such as vulnerability analysis and mapping and support for social protection systems.[51]

65. The United Nations Office for Disaster Risk Reduction is the United Nations system focal point for disaster reduction coordination and, as such, it: ensures synergies between disaster reduction activities and work in socioeconomic and humanitarian fields; and brings together representatives from science and academia with other stakeholders, including civil society and community-based actors, through the organization of regional and global disaster risk reduction platforms. The body also maintains the PreventionWeb,[52] an online disaster risk reduction knowledge platform, and develops products such as the Global Assessment Report on Disaster Risk Reduction through partnerships with the scientific community, civil society and the private sector.[53]

66. The United Nations Office for Disaster Risk Reduction Science and Technology Conference, held in January 2016, in Geneva, resulted in the endorsement of the Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030. The Roadmap includes expected outcomes, actions and deliverables under each of the priority of actions of the Sendai Framework. There are also several cross-cutting actions, such as capacity development, gender equity, citizen engagement, public-private sector partnership and coherence or alignment with other post-2015 global agendas such as the Sustainable Development Goals and the United Nations Framework Convention on Climate Change, which will need to be linked to other stakeholders' actions in the implementation of the Sendai Framework.

67. While these efforts by national and international actors have delivered concrete results, more needs to be done to leverage science, technology and innovation for community resilience, particularly in the context of frontier technologies and rapid technological change. For example, in order to raise awareness and build national capacities, there is the need to: actively promote practical cases of the use of new market-ready frontier technologies for community resilience through knowledge products and exchange activities; and promote new partnerships and international collaboration to build capacity regarding the use of these technologies for resilience, including through citizen science. More should be done to promote the engagement of women and youth in the development and implementation of innovative approaches to community resilience. The Commission on Science and Technology for Development can play an instrumental role in this regard, given its unique position in the United Nations system as the leading intergovernmental platform for addressing issues related to science, technology and innovation and development.

VII. Suggestions for consideration by Member States and the Commission on Science and Technology for Development at its twenty-second session

68. Science, technology and innovation play a critical role in building community resilience. Diverse fields of science generate new knowledge that improve understanding of the mechanisms and drivers of community resilience. New market-ready technologies create innovative opportunities for increasing economic, social and environmental

[51] See www1.wfp.org/resilience-building (accessed 20 February 2019).

[52] See www.preventionweb.net/english/ (accessed 20 February 2019).

[53] See www.unisdr.org/we/inform/gar (accessed 27 February 2019).

resilience, and new approaches to innovation can bring together non-traditional innovation actors to unite their efforts and pool their resources towards community resilience.

69. Member States may wish to consider:

(a) Fully supporting the development of science, technology and innovation solutions for building resilience, including by advancing the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 and the 2030 Agenda for Sustainable Development and the achievement of the Sustainable Development Goals;

(b) Designing and implementing science, technology and innovation policies that contribute to building resilient communities, including through the creation of an enabling environment for a mission-driven innovation system for resilience;

(c) Aligning science, technology and innovation policies with public health, disaster management and other relevant policies to make them responsive to building resilient communities;

(d) Adopting inclusiveness in formulating science, technology and innovation for resilience strategies. Science, technology and innovation solutions for building community resilience should be inclusive and should engage the participation of the poorest and most vulnerable. It is crucial to support the participation of local communities as co-creators of related innovations, including social innovations;

(e) Establishing or strengthening existing national platforms to ensure the more effective use of science, technology and innovation for resilience;

(f) Strengthening research programmes concerning root causes, mechanisms, and drivers affecting the use of science, technology and innovation for building the resilience of communities, in order to better guide effective science, technology and innovation-enabled interventions;

(g) Promoting the use of scientific tools to provide and share risk information at different scales before, during and after shocks, in order to increase resilience through improved preparedness and strengthened capacity to cope;

(h) Investing in enabling technology infrastructure, such as information and communications technologies and electricity, with a specific emphasis on ensuring affordable access and overcoming geographical, gender, generational and income digital divides.

70. The international community may wish to consider:

(a) Promoting and implementing participatory research methods and interdisciplinary and transdisciplinary scientific collaboration for increasing understanding of community resilience, taking into consideration integrated disaster reduction and sustainable transformations;

(b) Taking into account and systematically using traditional, local and indigenous knowledge as a part of scientific research focusing on community resilience;

(c) Developing an analytical framework for factoring natural hazard-triggered technological disaster event risks into strategies for building resilient communities;

(d) Leveraging private sector participation in the innovation cycle for the creation of new products and services for community resilience;

(e) Using mechanisms such as incubators, accelerators, innovation labs, marketplaces and inclusive, grass-roots and social innovations to promote the creation of new products and services for community resilience;

(f) Promoting an open dialogue on resilience between the scientific and technology sectors and policymakers, facilitating networking between them and creating and implementing a systematic framework under which resilience-related issues are taken into consideration as a part of planning and development based on scientific evidence;

(g) Promoting citizen science initiatives and building the capacity of communities and citizens to collect, use and analyse data through budget allocation, programme and project planning and execution, and the dissemination of citizen science outcomes in global forums;

(h) Embedding citizen science in the standard modalities to support the policymaking process through the application of science;

(i) Promoting the use of data acquired as part of citizen science initiatives in ways that respect citizen's rights, particularly privacy rights;

(j) Promoting the establishment of platforms for the coordination and compilation of data collected in citizen science projects to made be available for use in other development-related initiatives;

(k) Establishing linkages, programmes and projects between citizen science and the Sustainable Development Goals, including those relating to building resilience, in line with the priorities of vulnerable communities;

(l) Ensuring that science, technology and innovation for resilience and citizen science projects are documented and that their results are available in the public domain to facilitate community learning in other settings.

71. The Commission is encouraged to:

(a) Facilitate bilateral and multilateral North–South and South–South partnerships that help to build capacity for science, technology and innovation for resilience, including through citizen science;

(b) Promote various types of effective science, technology and innovation for resilient communities, share practical and advanced science, technology and innovation-based resilience experiences, cases and successful paradigms through various forms of international collaboration and exchange activities;

(c) Promote citizen science, including by using it as a perspective from which to contribute to priority themes;

(d) Guide the global community to adopt policies and strategies that encourage women and youth to participate in innovation approaches towards resilience, including through citizen science.