



Research Paper

Disaster reconnaissance framework for sustainable post-disaster materials management

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ABSTRACT

A first foundational assessment is provided for disaster debris reconnaissance that includes identifying tools and techniques for reconnaissance activities, identifying challenges in field reconnaissance, and identifying and developing preliminary guidelines and standards based on advancements from a workshop held in 2022. In this workshop, reconnaissance activities were analyzed in twofold: in relation to post-disaster debris and waste materials and in relation to waste management infrastructure. A four-phase timeline was included to capture the full lifecycle of management activities ranging from collection to temporary storage to final management route: pre-disaster or pre-reconnaissance, post-disaster response (days/weeks), short-term recovery (weeks/months), and long-term recovery (months/years). For successful reconnaissance, objectives of field activities and data collection needs; data types and metrics; and measurement and determination methods need to be identified. A reconnaissance framework, represented using a 3x2x2x4 matrix, is proposed to incorporate data attributes (tools, challenges, guides), reconnaissance attributes (debris, infrastructure; factors, actions), and time attributes (pre-event, response, short-term, long-term). This framework supports field reconnaissance missions and protocols that are longitudinally based and focused on post-disaster waste material and infrastructure metrics that advance sustainable materials management practices. To properly frame and develop effective reconnaissance activities, actions for all data attributes (tools, challenges, guides) are proposed to integrate sustainability and resilience considerations. While existing metrics, tools, methods, standards, and protocols can be adapted for sustainable post-disaster materials management reconnaissance, development of new approaches are needed for addressing unique aspects of disaster debris management.

1. Introduction

The United States (U.S.) is one of the world's most disaster-prone countries due to its large size, large population, variable climatic regions, variable landforms, and high interventions to the natural environment. Multiple billion-dollar disaster events occur annually in the U.S. (EM-DAT 2023). These disasters not only result in losses of life and disruption of human activities, but also generate high quantities of debris and wastes that can extend over large regional scales. The increasing frequency and magnitude of disasters and commensurate

increases in the amount of post-disaster materials require significant action to provide sustainable management solutions (IPCC 2018, Derrible et al. 2019, USEPA, 2019). Similar to solid waste management, debris management hierarchy is categorized with source reduction and reuse identified as the most preferred options, followed by recycling/composting, energy recovery, and treatment and disposal as the least preferred options (USEPA, 2019). While the main characteristics of disaster debris and waste including the large material quantities, large areal extent, and high/rapid accumulation challenge waste management systems, these features are advantageous for beneficial reuse and

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recycling as well as energy conversion. The increasing frequency of disaster events, consistent generation of debris and waste materials from disaster events, availability of large quantities of these materials at disaster areas, and availability at remote disaster locations collectively support beneficial reuse of post-disaster materials. Reuse and recycling of disaster debris have been encouraged through various regulatory schema; however, landfilling remains as the main means used to manage disaster debris in the U.S. (USEPA, 2019).

The Sustainable Material Management Extreme Events Reconnaissance (SUMMEER) organization, established in 2020 with support from the U.S. National Science Foundation (NSF), has a mission of contributing to natural hazards research through training and reconnaissance with specific emphasis on sustainable post-disaster materials management. SUMMEER is one of the eight EERs supported by NSF, which are established to advance research in hazard mitigation to improve resilience and promote sustainability through post-disaster investigations with a focus on field data collection. Reconnaissance herein describes the field activities conducted to collect perishable in situ data and information. The reconnaissance activities are mainly conducted by EER members, mostly academicians with participation also from practitioners, specifically trained in such undertakings. The data obtained and analysis conducted typically are available openly for use by EER members as well as by other researchers.

The primary purpose of SUMMEER is to advance the state-of-the-art and the state-of-the-practice in sustainable management of post-disaster materials through pre- and post-disaster planning and reconnaissance activities including development of guidance documents; training stakeholders; facilitating data collection, archiving, and sharing; and supporting innovative research. The main objectives of SUMMEER are to: identify relevant information and data types and collect debris and waste data in response to extreme events; develop detailed guidelines and data standards for effectively collecting perishable multifaceted data for sustainable management of post-disaster materials; coordinate reconnaissance efforts to collect debris and waste data; develop training modules for effective reconnaissance activities and data collection approaches with a focus on promoting post-disaster material recycling and reuse; train stakeholders and establish a group of well-prepared individuals for sustainable post-disaster materials planning and reconnaissance; and broadly share and disseminate the data collected and data analyses conducted with stakeholders. The activities of SUMMEER serve to reduce the adverse impacts of the large quantities and wide varieties of debris and waste materials generated due to extreme disaster events.

Identification of post-disaster data needs and establishing associated reconnaissance activities are required to develop and support management actions that promote material recovery and create value from end-of-life materials. A workshop entitled “Disaster Reconnaissance for Sustainable Post-Disaster Materials Management” was organized by SUMMEER to address these needs. The workshop was held in September 2022 at California Polytechnic State University and included a total of 40 participants from the U.S. representing academia, industry, and state and federal agencies. The majority of the participants had engineering backgrounds, mostly civil, environmental, and construction engineering, as well as engineering geology. Other participants had social science, urban and regional planning, geography, environmental studies, and emergency management backgrounds. The participants had specific interests and expertise in waste management, geoenvironmental engineering, infrastructure planning, disaster logistics, hazard mitigation, remote sensing, geodesy, damage management, sustainability, and disaster management. This paper is intended to introduce and describe an important issue in solid waste management, specifically disaster reconnaissance for sustainable post-disaster materials management. Findings, an analysis framework, and recommendations from this workshop focused on disaster reconnaissance are presented herein.

2. Reconnaissance for post-disaster materials management

Field analysis is critical in the aftermath of disaster events as it is essentially not possible to artificially simulate in situ conditions theoretically in isolation or experimentally in the laboratory/test plots. In addition to the complex topology of post-disaster settings, conditions are highly and quickly variable across space and time. The data and information collected through reconnaissance are intended to better understand and define the post-disaster settings with respect to waste management activities and advance research on sustainable management of post-disaster materials.

2.1. Analysis

The main objectives of the Disaster Reconnaissance for Sustainable Post-Disaster Materials Management workshop were to (i) identify tools and techniques for reconnaissance activities, (ii) identify challenges in field reconnaissance, and (iii) identify and develop preliminary guidelines and standards. The workshop was organized to have presentations to the whole group and three dedicated breakout sessions for in-depth discussions of the three main themes. The presentations were selected to provide post-disaster materials and environmental management case histories from earthquake, storm, debris flow, flash flood, landslide, and wildfire events. In addition, a presentation was included on instrumentation, data acquisition and analysis techniques, and associated software required to document complex natural hazard events for hazard and disaster reconnaissance. Participants with diverse backgrounds were included to contribute complementary viewpoints to advance the complex subject of post-disaster materials reconnaissance. The information provided in the formal presentations at the workshop, the discussions during the workshop, and the reports from the three breakout sessions that aligned directly with the three workshop objectives were compiled and evaluated by the authors. Each breakout session included a team captain and a scribe. The breakout reports were submitted by the captains and/or scribes at the completion of the workshop within days. Analysis included the use of the breakout reports in conjunction with the information from the major disasters and data acquisition presentations to identify the most salient considerations on data needs, tools, and guidance for post-disaster materials management reconnaissance.

Reconnaissance activities were analyzed in twofold: in relation to post-disaster debris and waste materials and in relation to waste management infrastructure. Based on an extensive analysis of available literature, primary data needs for sustainable debris management were identified to be amount and composition of debris, availability of temporary disaster debris management sites, health and environmental impacts of debris, economics, social considerations, and funding policies (Jalloul et al. 2022). These interrelated data needs require assessment of post-disaster conditions with respect to both the characteristics of the debris materials and the available waste management facilities. In disaster waste management literature, available analyses on waste infrastructure mainly related to temporary debris management facilities. For comprehensive reconnaissance, all management infrastructure including transfer stations, recycling facilities, composting operations, incinerators and other energy conversion operations, and landfills need to be considered, as data on all management pathways are required for assessing and attaining sustainability. Further considerations beyond those identified from literature were included in the workshop to cover all aspects of sustainable post-disaster materials management.

In post-disaster materials reconnaissance, in addition to the data focus (i.e., materials and infrastructure), the timing of data collection activities is critical for acquiring perishable and non-perishable data to fully delineate post-disaster materials management including temporal variations. While debris and wastes are cleared relatively quickly throughout urban areas, and from roadways and other critical infrastructure in rural settings, debris may remain in place at temporary debris management sites (TDMs) for extended periods. Transfer of

debris and wastes to recycling/reuse operations, composting facilities, energy conversion operations, and/or landfills and other management facilities may occur over months and years. Overall, management operations may continue for extended periods. A four-phase timeline is required to capture the full lifecycle of management activities: pre-disaster or pre-reconnaissance, post-disaster response (days/weeks), short-term recovery (weeks/months), and long-term recovery (months/years). Timelines included in engineering extreme events reconnaissance activities typically are limited to the immediate aftermath of disasters and shortly afterward, hours/days to in some cases weeks (e.g., Bray et al. 2019, Wartman et al. 2020, Kijewski-Correa et al. 2021), which are not sufficient for post-disaster materials management reconnaissance.

2.2. Findings

A summary of the main findings from the workshop activities is provided in Table 1. The three main themes for reconnaissance activities are included with consideration of the materials and infrastructure attributes and the four timelines. The table includes general observations and specific reconnaissance activities. The four timelines, pre-disaster/pre-reconnaissance, post-disaster response, short-term recovery, and long-term recovery, are included in the table as appropriate for and considering the specific reconnaissance activities and constraints.

Several commonalities were observed in reconnaissance activities and needs related to methods and tools, challenges, and guidelines. Determination of debris characteristics was identified to be of high significance and relevance for all three aspects of reconnaissance. Both response and short-term reconnaissance are required to collect highly perishable data related to debris quantity, distribution, and overall areal extent. Monitoring debris quantities with continued, relatively high frequency long-term reconnaissance is needed to identify the full range of waste management operations used for a specific disaster event. This is particularly significant as debris and waste materials typically are stockpiled at temporary debris management sites for long durations prior to ultimate management actions. Also, record keeping and availability of information regarding the fate of post-disaster materials typically are highly fragmented with limited datasets on amount and type of materials managed. In addition, characterization of management facilities was included under all three themes studied at the workshop. Post-disaster systematic and targeted reconnaissance allows for determining distribution and fate of debris materials as well as assessment of waste management infrastructure.

Response and short-term reconnaissance are needed to identify the constituent components of the debris and waste materials as well as to detect hazardous constituents, whereas long-term reconnaissance provides the evolution of waste management operations identifying the different debris and waste streams managed using different approaches. Debris constituents and hazards data are perishable and require assessment over multiple timelines due to both changes in the composition of the debris materials and potential intra-debris interactions and interactions between the debris and the surrounding environment. Composition may change due to sorting and separation of individual constituents. Constituent-specific debris variations may include volatilization of chemicals, release of encapsulated gases and liquids, dissolution reactions, mixing reactions, decomposition and degradation of organic materials, and chemical/biochemical reactions. Highly volatile chemicals may be released quickly; depending on the level of damage, encapsulated gases and liquids may be released quickly or with low/no damage, diffusion can occur over long durations; and decomposition of the organics may be slow or rapid depending on the management option (e.g., exposed to the atmosphere in a TDMS or isolated in a landfill). Post-disaster debris operations such as demolition of heavily-damaged buildings and infrastructure may generate new pathways for release or mixing of contaminants that can only be effectively identified with in situ reconnaissance.

Table 1
Summary of Main Workshop Findings

Theme	Timeline ¹
Tools and Techniques	
Identify debris materials (quantity and composition); key for sorting, reuse/disposal decisions	PD, RE
Most perishable data: aerial or ground scans for debris material identification	RE, ST
Perishable data: access to disaster zone and management facilities	RE, ST
Perishable data: water/moisture content of debris	AL
Debris quantity needs to be determined quickly	
Debris surveys to establish baseline, and also after disaster, and after removal of debris	RE, ST, LT
Material flows data on fate of debris and associated management routes	AL
Scale of identification method needs to be appropriate for resolution needed:	RE, ST
• satellite-scale not sufficient for quantity/composition, can provide areal extent • scale can be refined over time • surveying tools, drones, LIDAR, smartphones, multispectral sensors; analysis can be scaled • community tools such as smartphones can provide variable and high number of perspectives	
Inventory and modeling tools for debris estimation; quantity, location, and spatial extent information	PD, RE, ST
Monitor evolution of debris removal, collaborate with debris contractors	AL
Detecting contaminants (solid, liquid, gas; biological, chemical), may need to be long/very long term for long-lived chemicals such as nuclear materials	RE, ST
Survey waste management infrastructure; capacity, materials accepted, damage in the disaster event	AL
Location of and access to waste management facilities	AL
Identify markets for reused/recycled materials, lifecycle assessment	AL
Need data processing methods for large time-sensitive datasets	
Need in situ sensors and/or remote sensing capabilities to assess debris contamination	
Need reconnaissance for debris quantity and composition for calibrating and verifying debris estimation tools and models; connect pre-disaster models with field	
Need reconnaissance for identifying impacts of disasters on waste management infrastructure and management routes	
Need tools for effective citizen science, community involvement	
Challenges	
Barriers to site access	RE, ST
Being the first onsite, interfacing with the affected population	RE
Time management, balancing data collection with need to re-open	RE, ST
Lack of detailed data on disaster-specific debris generation (amount, composition)	AL
Commingled debris, lack of sorting, identification of characteristics and composition of debris	RE, ST, LT
Ad-hoc debris operations, lack of well-defined networks	RE, ST
Access to/availability of reuse/recycling facilities for most commonly generated debris materials from different types of disasters	RE, ST, LT
Lack of streamlined standards for sampling/field measurements for debris characteristics and waste management infrastructure	AL
Access to/availability of post-disaster materials data and management infrastructure data from prior events	AL
Lack of plan for community to respond to disasters from post-disaster materials management perspective	AL

(continued on next page)

Table 1 (continued)

Need remote sensing for evaluating debris hazards	
Need automated systems to assess disaster impacts on waste management infrastructure	
Need long-term reconnaissance to assess management operations	
Standards and Guidelines	
Desktop survey, mapping/facility identification (materials and waste management infrastructure)	PR
Background data on site conditions	PR
Logistics, what happened and what data are needed	PR
Identify reconnaissance team(s) based on type of event, location	PR
Access protocols to disaster site	PR, RE
Protocols for contact with emergency agencies	RE
On the ground, network team members on site (social media)	RE, ST
Protocols to determine debris mass and composition	RE, ST
Data management (collection, analysis, integrity) procedures	AL
Protocols for contact with emergency agencies, regulatory agencies, debris contractors, waste managers	AL
Guidelines for selection of timeline-specific data collection methods and tools	AL
Specialty guidelines for assessment of different types of waste management infrastructure	RE, ST, LT
Data sharing and archiving standards	LT
Need development of listings of data needs – standardized and specific to disaster and location characteristics	
Need development of reconnaissance best practices databases	
Need diverse perspectives	
Need metrics to assess social impacts and equity of waste management pathways	

¹ PD: pre-disaster; PR: pre-reconnaissance; RE: response; ST; short term, LT: long term; AL: all.

Similar to the needs for identifying the characteristics of debris materials, the characteristics and state of the waste management infrastructure also need to be established. Pre-disaster reconnaissance provides the locations and operating conditions of landfills, composting facilities, incinerators and other energy facilities, and different types of recycling operations ranging from material recovery facilities to metal recycling operations, dedicated vehicle recyclers, appliance recyclers, and construction and demolition waste operations. Remaining landfill capacity typically is included in available landfill-specific information. However, such capacity describes the amount of available landfill air space for waste disposal throughout the remaining design life of the landfill in the long term and not the amount of waste disposal capacity available at a given time. Recycling capacity typically is limited to operational conditions with no means to process large added loads from disaster events. Response and short-term reconnaissance are required to establish the type and available capacity of waste management infrastructure. In addition, waste facilities can be adversely impacted by disaster events necessitating use of alternative facilities and approaches for post-disaster materials. Such information can be obtained using reconnaissance activities. To supplement existing waste facilities, temporary deployments may be used such as mobile incinerators, large-scale concrete/asphalt crushers, woodchippers, anaerobic digesters, gasifiers, and other temporary energy conversion or recycling tools as well as cleanup/remediation units. Short- and long-term reconnaissance are required to identify these operations and allocation of debris and wastes to these operations.

Reconnaissance for the state of waste management infrastructure includes, in the first place, establishing whether the facilities are operational in the immediate aftermath of a disaster in the response stage and then continued monitoring of the facility conditions over time. Structural damage to buildings and other infrastructure can be identified and assessed. Facilities such as landfills have unique characteristics and may experience various different types of damage including slope stability issues, subsidence, tears/cracking of liner/cover systems, erosion, translational mass sliding, wildfire damage, flooding, electrical system outages, and others. Reconnaissance over multiple timelines is required to identify the different damage mechanisms and effects on operations and also to identify damage-disaster correlations as well as to understand repair/recovery timelines unique to waste management infrastructure.

Access to waste infrastructure also is a significant management consideration in post-disaster settings and comprises highly perishable data. In particular, response and short-term reconnaissance are required for combined evaluation of transportation infrastructure, debris extent/distribution, and access routes to different management facilities and operations. Debris and waste materials may be left in TDMs for long periods of time and access to these facilities and to surrounding management infrastructure can be evaluated with long-term reconnaissance. While locations of temporary management sites may be established prior to disaster events, based on specific event characteristics, these sites may become inaccessible, and post-disaster reconnaissance is required to analyze the impacts of new sites and new transportation routes on sustainable management practices.

In addition, needs are identified for development of disaster event-specific data requirements, appropriate data collection tools, better data processing tools, and guidance for assessment of management pathways over variable timelines and with consideration to social impacts and equity considerations. Overall, databases need to be developed for reconnaissance best practices. Disaster debris management is not yet fully established and common language to facilitate information exchange between stakeholders as well as new metrics, descriptive of significant data needs and new data collection/analysis approaches, are required.

3. Reconnaissance framework and recommendations

The analysis and findings from the workshop were compiled and consolidated into a disaster reconnaissance framework. The proposed framework is presented in Fig. 1 in a structured listing of the main factors and actionable items for reconnaissance. The framework includes separate assessment for debris materials and waste infrastructure and includes categories for reconnaissance tools and techniques, challenges in field reconnaissance, and preliminary guidelines and standards. The elements in the figure need to be considered for all four relevant timeframes: pre-disaster or pre-reconnaissance, post-disaster response, short-term recovery, and long-term recovery. Overall, the analysis includes a 3x2x2x4 matrix to consider data attributes (3 – tools, challenges, guides), reconnaissance attributes (2 – debris, infrastructure and 2 – factors, actions), and time attributes (4 – pre-event, response, short, long). Various factors and action items are repeated horizontally as similar considerations apply to both debris materials and facilities as well as methods and tools. The repeated attributes are significant baseline requirements for reconnaissance for sustainable post-disaster materials management.

A three-step method is proposed to apply this framework. The first step includes decision-making/event selection to determine whether the unique attributes of the disaster event warrant deployment of a reconnaissance team. The reconnaissance objectives and scope are defined in this step including timeframe, investigation of debris materials and/or waste infrastructure, areal extent of coverage, and personnel. The objectives define the target data to be obtained and corresponding metrics/methods for research integrity considering associated costs. A

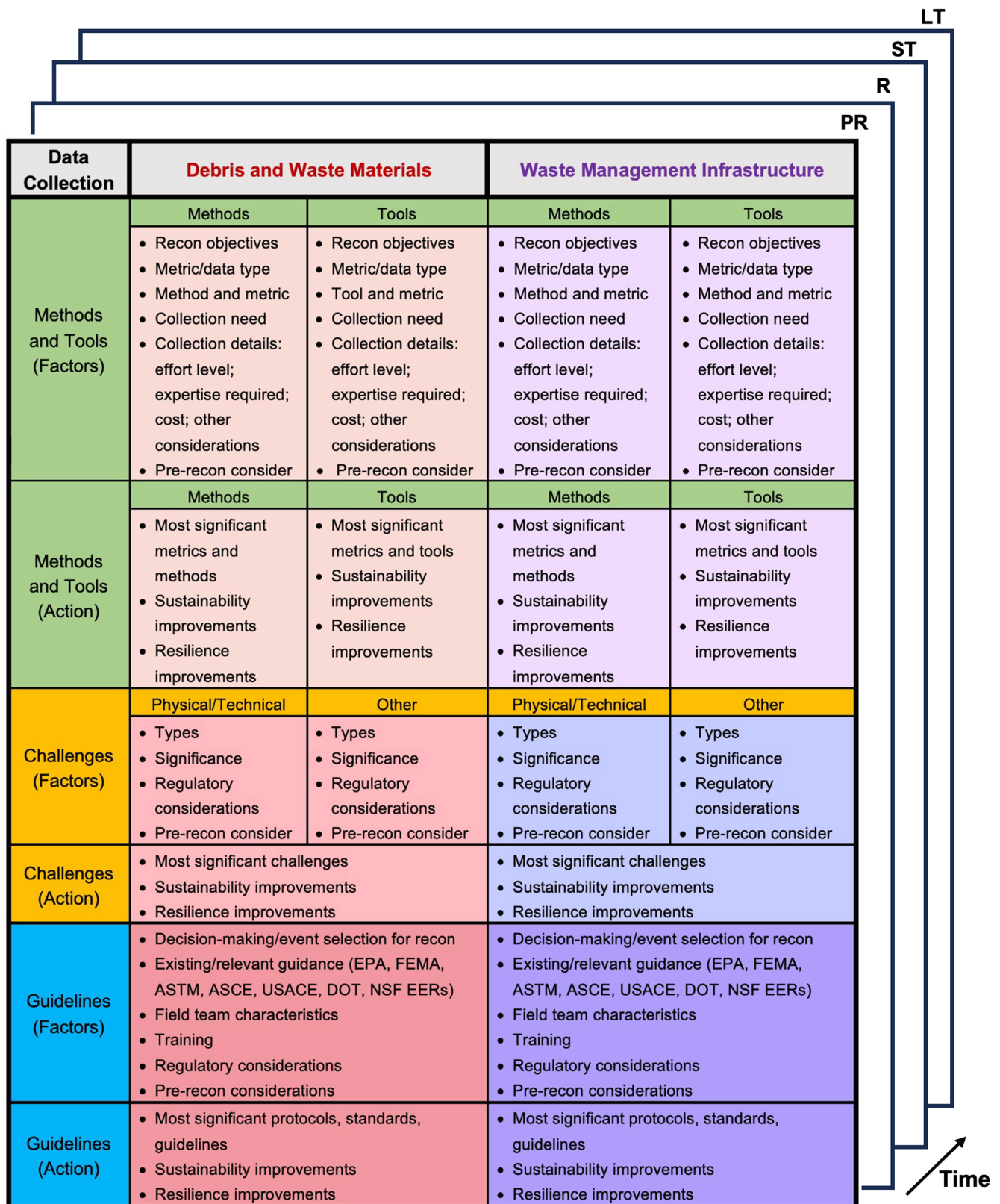


Fig. 1. Reconnaissance Framework (PR: Pre-Reconnaissance; R: Response; ST: Short Term; LT: Long Term).

preliminary scouting visit may be made to the disaster area to identify site conditions and access issues. The objectives and scope can be modified/amended during pre-reconnaissance as necessary. The second step includes summarizing expected relevant physical, technical, or regulatory challenges and strategy to overcome specific challenges that

may be encountered. Modifications may be made to objectives or scope based on the challenge assessment. The third step involves establishing specific guidelines for the field reconnaissance, within the context of existing standards and regulations, to collectively define timeline(s), equipment needs, expertise, personnel, and regulatory oversight to

ensure safe working conditions and reliable data collection, reporting, and archiving.

To properly frame and develop effective reconnaissance activities, the action elements for all 3 data attributes are proposed to have sustainability and resilience considerations. The post-disaster settings, in particular in the immediate aftermath of disaster events, have search and rescue followed by clearing of lifelines as the main priorities. The only priority associated with debris and waste materials is rapid removal with generally no priority for actions and operations for sustainable management or utility in developing resilience in the impacted area. Incorporating these concepts into reconnaissance objectives is recommended to advance disaster response and waste management activities.

Debris characteristics was identified as one of the most significant reconnaissance data types. Currently available tools for investigating physical characteristics (i.e., amount, extent, and composition) of debris and waste materials consist of ground-based or aerial geomatics technologies. Analysis tools and methods typically include 2D and 3D mapping and imagery and associated photogrammetry analysis. Terrestrial systems consist of surveying, Structure from Motion (SfM) photogrammetry, and 3D laser scanning (lidar) and aerial systems consist of aerial photography, SfM photogrammetry, and lidar. The aerial measurements can be conducted using near-surface (e.g., UAV) or far-field (e.g., satellite) equipment and systems. Terrestrial and aerial multispectral and hyperspectral cameras with discrete (relatively low number of) or continuous (relatively high number of) electromagnetic wavelength analysis bands, respectively, can be used to further investigate areal extent and distribution of debris masses and composition of debris and waste materials. Thermal images may provide assessment of moisture content or biochemical activity. Imagery-based mobile or handheld apps can be used to assess composition or quantity information. The condition of waste management infrastructure also can be evaluated using terrestrial or aerial geomatics. Aerial methods can alleviate access issues for data collection with consideration of appropriate measurement scales for reconnaissance objectives. Aerial methods also can assist reconnaissance activities in disaster areas within developing and underdeveloped countries. While the reconnaissance framework described is flexible and can be adapted to different post-disaster settings, the framework is also resource intensive, with full capabilities including personnel, tools, and methods not readily available in all settings. Globally available aerial data, for example, from satellites may be used to assess damage levels and extent and then used to estimate debris quantities. Similarly, aerial imagery may be used to identify locations for temporary or permanent storage and/or disposal of debris as well as locations where the maximum need exists or optimum conditions are present for reuse. International partnering may allow for conducting reconnaissance planning and missions when resources are not available in a given location.

Hazardous constituents and contaminants in debris can be identified mainly using collection of samples and laboratory testing. Standard test methods, practices, and guides available from ASTM International can be used: standards from D34 Waste Management committee for sampling and testing debris and waste materials and D18 Soil and Rock committee for sampling and testing soil/rock-like debris fields such as landslide masses, tsunami sediments, and flood sediments. Test protocols available from USEPA and other agencies also can be used. Existing methodologies can be used until specialized test protocols are established for post-disaster settings. Remote sensing using advanced imaging may be applicable to identifying contaminants or emissions from debris and waste masses. Pre-reconnaissance analysis and modeling using tools and databases available can provide understanding of chemical contamination and potential impacts on the surrounding environment.

Field data on types of materials present in the debris systems have direct relevance for sustainable management by providing information on materials that can be reused or recycled. Detailed debris characteristics data also allow for identifying materials appropriate for energy

conversion. Assessment of waste infrastructure with respect to generated debris characteristics can provide essential information for decision-making and aid in allocation of the debris materials to routes that valorize the debris materials. Requirements for additional capacity for reuse and recycling can be identified. Assessment of hazardous constituents also contributes to proper management of the debris by allowing for identification of separation or environmental cleanup/treatment options as appropriate. Monitoring evolution of debris and wastes in TDMSs can assist in determining potential environmental impacts of these sites including emissions to the atmosphere and leaching to the surrounding soils and subsurface as well as allow for timely allocation of debris to sustainable operations with respect to potential changes in material properties (e.g., decomposition of organic materials). Waste infrastructure data provide impacts of the debris materials on the management operations.

In addition, reconnaissance activities can advance debris modeling by allowing development of correlations between data obtained from reconnaissance and disaster characteristics (type of disaster and geographical setting) with specific considerations for compound and cascading events. Pre-disaster or pre-reconnaissance modeling can provide preliminary debris estimates. Field-obtained debris generation data (i.e., amount and extent) and specific characteristics information (i.e., type and composition) from reconnaissance missions can be used to calibrate and validate numerical models.

Post-disaster materials reconnaissance provides quantitative debris and management infrastructure data with standardized metrics and procedures. Connecting debris management information to the socioeconomic settings of the debris transport paths, temporary management sites, and final management facilities can allow for assessing equity and environmental justice aspects of the operations. Reconnaissance teams are recommended to have diverse participants representing technical science and engineering expertise, the ability to assess economic implications ranging from local markets to national and international markets, and include regulators and emergency managers to coordinate efforts as well as access information regarding management options, preferences, and routes.

The reconnaissance framework introduced herein is intended to be a flexible and standardized approach for acquiring field data that is consistent and reliable for advancing the sustainability and resilience goals of post-disaster materials management. This framework is conveniently organized into a 3x2x2x4 matrix format for ease of representation and interpretation. Future standardization of reconnaissance tools, methods, and approaches will provide consistency in global disaster reconnaissance efforts. Reconnaissance data are foundational for establishing the baseline in the state-of-the-practice as well as state-of-the-art of post-disaster materials management and identifying sustainable management routes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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