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Transdisciplinary interventions for environmental sustainability

Ghina Chammas [a], Sammy Kayed [a], Anwar Al Shami [a], Wassim Kays [a], Michele Citton [a], Mohamad Kalot [a,1], Elie Al Marj [a], Marwan Fakhr [a], Nadine A. Yehya [b,2], Salma N. Talhouk [c], Mahmoud Al-Hindi [d], Salah Zein-El-Dine [e], Hani Tamim [e], Issam Lakkis [f], Majdi Abou Najm [g,3], Najat A. Saliba [a,h,*]

[a] American University of Beirut, Nature Conservation Center, Lebanon
[b] American University of Beirut, Suliman S. Olayan School of Business, Lebanon
[c] American University of Beirut, Department of Landscape and Ecosystem Management, Faculty of Agriculture and Food Sciences, Lebanon
[d] American University of Beirut, Department of Chemical Engineering, Maroun Semaan Faculty of Engineering and Architecture, Lebanon
[e] American University of Beirut, Department of Internal Medicine, Faculty of Medicine, Lebanon
[f] American University of Beirut, Department of Mechanical Engineering, Maroun Semaan Faculty of Engineering and Architecture, Lebanon
[g] American University of Beirut, Department of Civil and Environmental Engineering, Maroun Semaan Faculty of Engineering and Architecture, Lebanon
[h] American University of Beirut, Department of Chemistry, Faculty of Arts and Sciences, Lebanon

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ABSTRACT

This paper presents a case study of a transdisciplinary research based on an ex-post assessment of the environmental and socio-behavioral contexts of solid waste management in Lebanese peri-urban communities. Lessons learned are compiled into the Transdisciplinary Interventions for Environmental Sustainability conceptual framework. The approach starts with building a team of researchers and non-academic partners, continues with co-creating solution-oriented knowledge, and ends by integrating and applying the produced knowledge. The co-created knowledge includes the environmental and socio-behavioral ex-post assessment's results. The former reveals low air pollution levels, evidence of waste-related water contamination, and higher self-reported frequencies of ill-health symptoms and diseases closer to the landfill. The latter indicates that the community's perception about waste production differs from the real accounting of generated waste. Nine lessons are identified: (1) inherent common interest between the researchers and the community, (2) flexible interdisciplinary research team, (3) representative citizen committee, (4) contextually-informed outreach coordinator, (5) iterative research process accounting for the shifting socio-political context, (6) common expectations of the research process, (7) boundary objects leading to spin-off activities in the same setting, (8) effective communication strategy, and (9) ex-post assessment of subsequent societal and scientific impacts. The non-phased framework links all nine pointers in a logical order to ease scalability. The study answers a global need for a unified, clear, broadly adopted framework for transdisciplinarity and a deeper understanding of factors ensuring full-circle knowledge co-creation in waste-related contexts in the global South. The study offers managerial and research implications and suggests avenues for further research.

1. Introduction

Solid waste management (SWM) intersects with sanitation, public health, climate change, poverty reduction, and sustainable resource production and consumption, is grounded in local economic, socio-cultural, and political contexts, and is directly linked to 12 out of the 17 Sustainable Development Goals (Rodić and Wilson, 2017). Solid waste (SW) mismanagement is a global multidimensional issue (de Souza Melaré et al., 2017), usually more pronounced in low- and middle- income countries (LMICs) comprising the global South (Aparcana, 2017; Ferronato and Torretta, 2019). A wide range of literature-reported factors from more than

* Corresponding author at: American University of Beirut, Nature Conservation Center, Lebanon.

E-mail addresses: gc18@aub.edu.lb (G. Chammas), natureprj@aub.edu.lb (S. Kayed), aa267@aub.edu.lb (A. Al Shami), naturevillage@aub.edu.lb (W. Kays), mc106@aub.edu.lb (M. Citton), mkalot@kumc.edu (M. Kalot), mf90@aub.edu.lb (M. Fakhr), nyehya@ucdavis.edu (N.A. Yehya), ntsalma@aub.edu.lb (S.N. Talhouk), ma211@aub.edu.lb (M. Al-Hindi), sz01@aub.edu.lb (S. Zein-El-Dine), htamim@aub.edu.lb (H. Tamim), il01@aub.edu.lb (I. Lakkis), mabounajm@ucdavis.edu (M. Abou Najm), ns30@aub.edu.lb (N.A. Saliba).

[1] Present address: Kidney Institute, Kansas University Medical Center, 3901 Rainbow Blvd., Mail Stop 3033, Kansas City, KS 66160, United States.

[2] Present address: Public Affairs and Marketing, University of California Davis, 4900 Broadway St., Suite 1200, Sacramento, CA 95820, United States.

[3] Present address: Department of Land, Air and Water Resources, University of California Davis, 1 Shields Avenue, PES 1110, Davis, California 95616, United States.

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thirty urban areas in twenty two LMICs influence individual elements (generation; collection, transfer, and transport practices; treatment; disposal; recycling) and aspects (technical; environmental; financial; socio-cultural; institutional; legal) of SWM systems. Examples are increased waste generation, financial burden on the municipal budget, limited information, scattered responsibilities among various ministries and agencies, and lack of community awareness and participation in SWM or incentives for behavior change (Guerrero et al., 2013). It has become commonly accepted that SWM systems overlooking social priorities are doomed to fail (Ma and Hipel, 2016; Zurbrügg et al., 2012). Research shows that public acceptance and empowerment in planning and implementation are as important as the economic and technical aspects of SWM (Marshall and Farahbakhsh, 2013). Also, social and behavior change is key to a functional waste system which drove international financial organizations and funding agencies to support the design of incentives and awareness campaigns centered on waste reduction, source-separation, and reuse (USAID, 2019; World Bank, 2019). Those are all effective measures to reduce community and workers' exposure to health hazards (Thakur et al., 2018; Triassi et al., 2015). Hence, SWM requires a holistic approach, characterized by cross-fertilization of environmental and social perspectives, as well as participatory strategies bringing researchers, public authorities, policy makers, community leaders, and lay citizens, together to cooperatively create knowledge and solutions across the wide range of waste-related elements (Soltani et al., 2015). This knowledge co-creation process (co-design, co-production, and co-dissemination) is complex as it involves ongoing reflection among all participants with iterative feedback loops (Mauser et al., 2013; Yokota et al., 2018).

The concept of knowledge co-creation is based on the recognized theoretical framework of transdisciplinarity, which has been increasingly popular for addressing complex, socio-environmental problems involving multiple scientific disciplines and diverse societal actors (Crosby et al., 2018). Moving beyond cooperation of disciplines (multidisciplinarity) and integration of disciplines (interdisciplinarity), transdisciplinarity represents one of the highest degrees of integration on the continuum of these research approaches (Thompson et al., 2017).

Projects integrating university researchers and communities in a transdisciplinary fashion are believed to empower communities, increase their motivation to collaborate, enhance the sustainability of interventions, and help build capacity to address future problems (Fam et al., 2017; Moser, 2016). However, transdisciplinary research (TDR) remains hindered in three ways.

First, recent reviews on transdisciplinary case studies concluded that concepts and methods of knowledge co-creation processes lack clarity (Leemans, 2016; Yokota et al., 2018; Zscheischler et al., 2017). In fact, while previous studies offer insight on the various challenges faced during knowledge co-creation, they suggest different and sometimes incoherent stratagems for project design to address those challenges. Although TDR has gained popularity, there is still no common glossary, nor consensual coherent research framework (Lotz-Sisitka et al., 2016; Temper and Del Bene, 2016; Thompson et al., 2017). Indeed, TDR has accumulated an exhaustive list of terms, including "interdisciplinary participatory research" (Kwok and Ku, 2008), "multidisciplinary participatory action research" (Graef and Sieber, 2018), "community-based participatory research" (Kwan et al., 2017), and "mode-2-knowledge production" (Thorén and Breian, 2016). Moreover, studies have stressed the need for a unified, clear, broadly accepted and adopted methodological TDR framework (e.g., Moser, 2016; Tejada et al., 2019; Zscheischler et al., 2017). However, an extensive range of frameworks is still used for knowledge co-creation. These include practice-oriented design principles to assess ideal TDR (e.g., Lang et al., 2012; Luthe, 2017), a framework of transdisciplinary outcome spaces proposing a backcasting guideline for research design focusing on three desired outcomes (situation, knowledge, and learning) and the research-practice interface (Mitchell et al., 2015), and a framework to compare transdisciplinary projects according to knowledge type and type and level of actor involvement at different stages (Hoffman et al., 2017). These frameworks typically consist of three to four broad phases, moving from problem definition, to conducting collaborative research, and applying results. Yet, these tend to overlap in practice, with no clear link between their sub-phases (Thompson et al., 2017; Wang et al., 2019). This lack of conceptual clarity impedes scientific communication (Tejada et al., 2019). As explained in Tress et al. (2005), clarity is important to "compare and evaluate the outcomes of different research approaches" (p.481). Hence, the current process of "rhetorical mainstreaming" of transdisciplinarity is misguided and could marginalize researchers (Jahn and Keil, 2015). Besides, TDR is devoted to integrating knowledge of various disciplines and stakeholders, yet, establishing coherent and reproducible methods remains challenging given the diversity of methodological designs for knowledge integration (Thompson et al., 2017). As explained by Athayde et al. (2016), different academic disciplines still use multiple methods to collect, analyze, organize, and present research findings. Brandt et al. (2013) suggest developing a set of accepted and standardized methodological tools, to ensure higher efficiency and effectiveness and increase the repeatability of TDR. Particularly, Athayde et al. (2016) recommend a mixed method approach, combining quantitative, qualitative, and participatory methods such as participatory mapping and ethnography to attend to the epistemological specificies of each academic discipline.

Second, most of the current integrated research only describes the early stages of co-design, focusing on "framing of problems" (Adler et al., 2018; Leemans, 2016), "social capital and partnerships with mutual trust" (McKee et al., 2015) "scaling" (Fraser et al., 2006), "accountability", "ownership" (Lang et al., 2012), as well as "priorities and needs" (Moser, 2016; Yokota et al., 2018). Yet, very few have used case studies to discuss co-design, co-production, and co-dissemination in a comprehensive, bottom–up manner (Leemans, 2016; Yokota et al., 2018).

Third, the majority of TDR has been conducted in the North Americas, Europe, and Oceania (e.g. Brandt et al., 2013; Goven et al., 2015; White et al., 2019; Yokota et al., 2018), with noticeable absence of such studies in LMICs in the Middle-East – particularly in terms of SWM. As such, key factors that influence knowledge co-creation in waste-related TDR in the global South remain vague. In addition to literature-reported inherent challenges in TDR such as disagreement on a common language, lack of integration of disciplinary and practical knowledge and methods, power asymmetries, and unbalanced ownership (Hoffman et al., 2017; Reed and Abernethy, 2018) that ipso facto occur in the global North and the global South alike, a special consideration of context-based influences is required in the global South due to their complex socio-political and economic contexts (Tejada et al., 2019). In their study, Lang et al. (2012) pointed out fundamental differences among TDR conducted in different cultural contexts and identified a critical need to better understand how the compiled principles and challenges manifest under different context conditions. More recently, Tejada et al. (2019) examined five TDR projects involving North-South collaborations. Specific context-related limitations were faced during implementation in Burkina Faso, Palestine, and Cuba, including weather conditions, water shortages, invasive pests and pathogens, political instability, poor relationships between the researchers and the communities, and administrative bureaucracy (red tape issues) with regards to funding and procurement. The researchers concluded that the integration process in TDR sets its own pace according to local realities. The importance of context in SWM in the global South is no exception. SWM is not always granted high priority by national and local policymakers due to other issues of social and political interest that take precedence and leave little budget for SWM (Leitol, 2014; Mmereki et al., 2016). Besides, there is still an ongoing reliance on the global North for solutions to local problems. As such, researchers like Reidpath and Allotey (2019) call for the need to promote homegrown, contextually-driven research in the global South, borne out of the reality of non-northern contexts to complement knowledge and scientific evidence generated in the global North and ensure sustainable solutions.

The paper fills these gaps by proposing a non-phased, process-oriented framework linking, in a logical order, lessons drawn from an applied transdisciplinary case study based on an ex-post reflection of an assessment of the environmental, social, and behavioral contexts of SWM in Lebanese peri-urban communities. The approach, labeled Transdisciplinary Interventions for Environmental Sustainability (TIES), informed by the collaboration among the American University of Beirut and communities in Lebanon, provides a suitable reference frame for managers and academics in designing, implementing, managing, and evaluating TDR in environmental management. TIES would be particularly beneficial to SW managers due to the sector's heavy reliance on multiple fields of knowledge and the need for sustained community inclusion in planning and implementation.

TIES' case study context will first be described. Then, the processes and outcomes of the transdisciplinary work will be expanded upon and the key lessons learned will be summarized, by reflecting on the experiences gained and challenges faced during the Project. Last, a conceptual framework, including contextually-informed guidelines that provide insight into successful design, implementation, management, and evaluation of transdisciplinary projects, is presented.

2. Case study context: peri-urban communities, Lebanon

After the permanent closure of the Naameh Landfill in May 2016, one of the biggest and most heavily relied on landfills serving the capital Beirut and Mount Lebanon, and in the absence of an official national SWM plan (Mattar et al., 2018), municipalities had to hastily assume responsibility over SWM without the adequate technical and financial resources. This has resulted in haphazard waste disposal, decentralization and intensification of environmental and health damages, and the loss of local opportunities for reduction and sorting at source. As a result of the SWM crisis, the Nature Conservation Center at the American University of Beirut (AUB-NCC), leveraging the experience of AUB experts to tackle the most pressing local environmental challenges, produced and disseminated a Guide to municipal SWM (Massoud and Merhebi, 2016).

Consequently, six municipalities, located around the Naameh Landfill (Fig. 1), approached AUB-NCC, seeking expert support in assessing the multifaceted impacts of the landfill's closure and improving their respective, then-current, SWM plans. The communities, home to nearly 33,070 residents and covering an area of 142.70 km^2, made claims of disease spreads and expressed concern that their water and air were being contaminated.

3. Implementation approach

The methodology followed a well-cited process that started with (1) building a team of researchers and non-academic partners and collaboratively framing the problem, (2) co-creating solution-oriented knowledge, and (3) integrating and applying the co-created knowledge (Lang et al., 2012).

3.1. Phase A: Collaborative research team building and problem framing

The transdisciplinary team included six municipalities and local communities as well as an interdisciplinary group of AUB professors (community engagement, air quality and modeling, water quality, medical health, statistical analysis, SWM, behavioral science, and public outreach and communication). The research team consulted local stakeholders through scoping meetings and recommended that citizen committees (composed of five to ten members) are established in each of the villages to act as an intermediary body of exchange between their respective municipalities and communities (Talhouk et al., 2019). Following, a comprehensive needs assessment revealed common and village-specific technical, financial, institutional, and socio-economic constraints to improved SWM.

3.2. Phase B: Co-creation of solution-oriented and transferable knowledge through collaborative research

The joint design of data collection processes and analysis of preliminary research findings extended from July 2017 to March 2019. Activities conducted under this Phase are summarized in Table 1. Team building was held, including a participatory mapping exercise to identify all natural, sustainable, and social community dimensions (Talhouk et al., 2019). Air and water quality sampling was conducted and health data was collected (N = 2720). Only bio aerosols, volatile organic compounds (VOCs), methane (CH_4), and hydrogen sulfides (H_2S) were measured to assess air quality. As for water quality, the main water sources and their type of use were mapped in coordination with local authorities. To assess the overall water quality at the sources, the Weighted Arithmetic Water Quality Index (WQI) has been adopted from Tyagi et al. (2013) on conductivity, pH, chlorides, nitrates (NO_3), Phosphorous (Total), Barium, Chromium, Selenium, Zinc, Total and Fecal Coliforms. This method assigns values to the water quality relative to the degree of purity in relation to a standard – in this case, LIBNOR (1999a, 1999b). The Weighted Arithmetic WQI has been widely used by different authors (e.g., Chauhan and Singh, 2010; Chowdhury et al., 2012; Olowe et al. 2016; Rao et al., 2010). In this classification a WQI value rating more than 100 is not suitable for drinking according to the referenced standard. In the health study, 562 participants self-reported experienced symptoms and diseases in the respiratory, nervous, gastro-intestinal, cardiovascular, and dermatology and rheumatology systems, and provided information on behalf of their families, leading to a total of 2720 responses. The choice of participants was indexed based on an air pollution model that identifies the most affected areas in terms of exposure to air pollutants from two landfills based on local topology and historical wind data. All air pollution sampling sites were chosen far away from any direct source (main roads and others) and overlooking the Naameh Landfill. Computer simulations were carried out using The Air Pollution Model (TAPM) (Hurley, 1999) to study the communities' exposure to NOx concentrations originating from the operation of the two landfills (Appendix 1). This index, coupled with information provided by municipal employees on the distribution of the inhabitants in the villages, was relied upon to determine the number of surveys to administer in each village (Appendix 2).

An on-the-ground waste quantification and characterization using a weight scale and sorting compliance exercise (from 95 collection points) in four communities was conducted. The objective of this exercise was to help the target municipalities better manage their SW. Results were reported with geolocations using Survey 123 from Environmental Systems Research Institute (ESRI). Citizens were engaged in the collection of waste information in

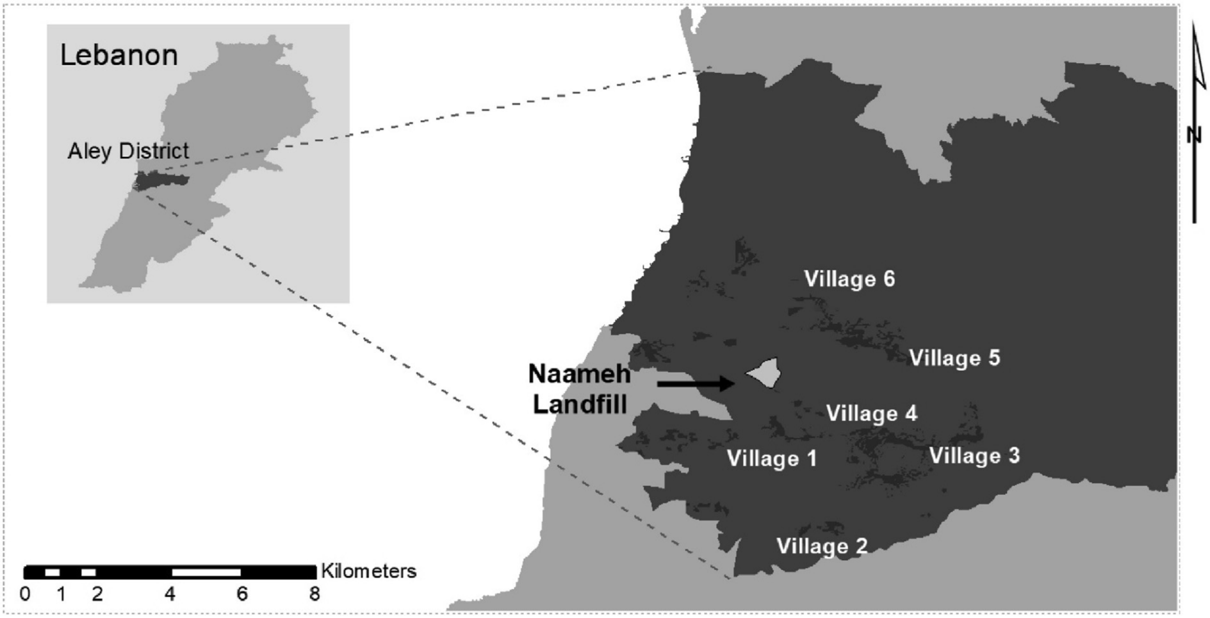

Fig. 1. Map showing the location of the Naameh landfill and the surrounding villages where the study took place.

the proximity of the collection points. No measurements were conducted in the remaining two communities, where SWM was dealt with by a private company. SW was not characterized at the Naameh Landfill as the community could not be granted access to the landfill site, which was completely managed by a private company.

The quantitative waste assessment was coupled with a behavioral assessment, whereby interviews (N = 60) and survey questionnaires (N = 562) helped in understanding then-current consumption and waste generation practices and community readiness to engage in general and waste-specific pro-environmental practices (sorting, reduction, and composting). The sample size of the qualitative study has been chosen to capture the variety and diversity of experience, perspectives, and information when it comes to studying mindfulness in consumption as the same cultural background is expected across the population of each community. The sampling design was based on a study conducted by Guest et al. (2006) which showed that for high level of homogeneity among the population, a sample of six interviews may be sufficient to reach saturation and enable the development of meaningful themes and useful interpretations. The qualitative study used the ethnography framework (Elliott and Jankel-Elliott, 2003) and snowballing sampling techniques (Biernacki and Waldorf, 1981) to explore the entire food decision process (from planning to disposal) based on Schanes et al. (2018) household food-related practices and routines model. As for the quantative study, the same participants selected for the health study were surveyed for the quantitative behavioral assessment. Most of this study was designed under the framework of the Theory of Planned Behavior (Ajzen, 1991) using a combination of scales proven to have high internal consistency (e.g., Ghani et al., 2013; Wan et al., 2017), in addition to validated and commonly used scales in environmental psychology to measure environmental identity and concern (Clayton, 2003; Dunlap et al., 2000). Citizen committee members were very cooperative in the recruitment of participants and the organization of household visits during Phase B (Chammas and Yehya, 2019).

3.3. Phase C: Re-integrating and applying the co-created knowledge

From October 2017 to February 2019, tailored tangible deliverables were generated for the community as listed in Table 1. All results were translated into Arabic (the mother tongue of the community) and community events were held in locations easily accessible to all stakeholders. Findings from the behavioral and environmental assessment were disseminated in closed meetings and workshops, which served as a platform for discussion among citizen groups, the local authority, and the academic experts.

4. Results

4.1. Participatory mapping

Fig. 2 summarizes the main assets identified in the area as a result of the participatory mapping process. This process drove local authorities and their constituencies to learn about their place-based assets.

4.2. Environmental (air, water, and health) sampling

The air quality sampling results revealed low values of airborne bacteria, fungi, methane, and H_2S explained through the fact that, at the time of measurement, a landfill gas collection system had been installed and one year had passed since permanent landfill closure. Bioaerosols' results are in line with findings from Roodbari et al. (2013), who identified the lowest levels of airborne bacteria and fungi around an old landfill as compared to other SWM facilities (waste container bins and transfer stations) in Iran. Similarly for methane, the lowest emissions were reported from the oldest and smallest landfills and the highest emissions from the bigger landfills in Mønster et al. (2015). Besides, studies have shown that landfill age affects H2S generation (Kim et al., 2006; Yang et al., 2015), low share of H_2S in the biogas is thus expected in old landfill facilities, as measured by Porowska (2016).

Also, no major evidence of water contamination from SW open dumping was found. Water resources were microbiologically contaminated by discharge of untreated sewage. The seven tested spring sites had levels of fecal and total coliforms above the Maximum Contaminant Levels set by the World Health Organization. The presence of E. coli in five out of the seven samples indicates that sewage infiltration from septic tanks or sewage lines was the major source of bacteriological contamination. As indicated

Table 1
A summary of the activities, outputs, and outcomes generated under the TDR study.

Activity	Output	Result	Outcome
Participatory mapping	Mapping exercise	Six aerial maps highlighting environmental and community assets	Strengthened bonds between community members Identification of assets to better conserve them Improved short and long term SWM plans Communication material (workshop presentations and infographics illustrating research findings)
Environmental sampling	Air quality sampling (11 bio-aerosols and VOCs, CH_4, and H_2S samples) Air pollution model to identify most affected areas in terms of exposure to air pollutants	**Bioaerosols (CFU/m^3):** Total Bacteria Count 21.6; 10.6–37.1; 9.7 Fungi 404.4; 270.9–534.0; 83.9 **VOCs:** higher values in the background location (Village 3) than closer to the landfill **CH_4 (ppm):** 0.12; 0.0–4.00; 0.42 **H_2S (ppm):** 0.02; 0.0–0.71; 0.05	
	Water quality sampling (general parameters, microbiological, metals, and organic compounds tested for in 13 wells and seven springs)	**WQI** **Springs upper basin** 3854; 572–8121; 2827 N sources WQI < 100 = 0 **Wells upper basin** 2287; 896–4751; 2138 N sources WQI < 100 = 0 **Wells lower basin** 1697; 1.9–5067; 2215 N sources WQI < 100 = 2	
	Health (self-reporting of experienced symptoms and diseases in the respiratory, nervous, gastro-intestinal, cardiovascular, and dermatology and rheumatology systems collected for 2270 participants)	Higher self-reported frequencies of ill-health symptoms and diseases closer to the landfill	
Waste quantification and characterization and sorting compliance	Measurements from 95 collection points	**Waste Generated (kg person/day)** 1.15; 0.14–8.8; 1.12 **Sorting Compliance (% sorted waste in weight)** Village 3 = 68% Village 4 = 48% Villages 1,2,5,6 = No sorting at source	
Community environmental attitude and behavior assessment	60 interviews on mindful consumption and waste generation practices 562 survey responses collected on community readiness to engage in general and waste-specific pro-environmental practices	Community's perception about waste production differs from the real accounting of generated waste	

Findings in the 'Result' column are represented as follows: average (unit); minimum and maximum (same unit); standard deviation.

in Table 1, all tested sources except two wells in the coastal area have a WQI value rating more than 100. When analyzing the preliminary findings with municipality officials, the team was informed that three out of the six municipalities were taking action to construct a sewer network and treatment plant, which is expected to mitigate the impact on the area's water resources. While levels of total and fecal coliforms have not been studied yet, Khadra and Stuyfzand (2014) defined the hydro-geochemical facies in the area. The researchers indicated that one area located north-west of the landfill is likely to be affected by leachate percolation in the aquifer due to elevated concentrations of chlorides, Boron, Lead, and Zinc measured from one well. In fact, Zinc and high values of conductivity and chlorides are present in four of the tested wells in the coastal area, but the results are not conclusive. Zinc could either be the result of landfill leachate infiltration or well corrosion from two of the four wells at least. Moreover, high levels of conductivity and chlorides are likely to be related to saltwater intrusion, well documented in the area (Khadra et al., 2017; Masciopinto, 2013).

As for the health study, residents living closest to the landfill reported more cases of severe asthma, skin allergies, extreme fatigue, and weakness in hands and feet (an increase of 38.3%, 8.5%, 8.3%, and 4.2%, respectively) compared to those farthest from the dumpsite. The finding for skin allergies falls within the range reported for allergies in ocupational workers in Thakur et al. (2018), India.

4.3. Waste quantification and characterization and sorting compliance

The average SW generation was found to be 1.15 kg/person/day, 43% higher than the national average for rural areas (0.8 kg/person/day) reported in the Lebanon Country Report on SWM (SWEEPNET, 2014). Fig. 3 shows the average waste composition and citizen compliance to the sorting plans. It is noted that a higher compliance is contingent on a municipal monitoring scheme.

4.4. Community environmental attitude and behavior assessment

The behavioral assessment indicates that the community's perception about waste production differed from the real accounting of the generated waste (Section 4.3). The qualitative study indicated a similar overarching pattern where the participants were waste averse and reported having good intentions not to be wasteful, motivated by ethical and budget concerns rather than environmental sustainability (unpublished data). This finding has been also reported in earlier studies (e.g., Neff et al., 2015; Pearson et al., 2017).

In the quantitative behavioral study, more than half of the participants reported that commitment to environmental protection was a self-driven inspiration. They strongly identify with nature (Average: 4.24; SD: 0.62 over a scale of 5) and have a genuine concern for the environment (Average: 3.4; SD: 0.6 over a scale of 5) (Fig. 4a). Concerning the three waste-specific pro-environmental

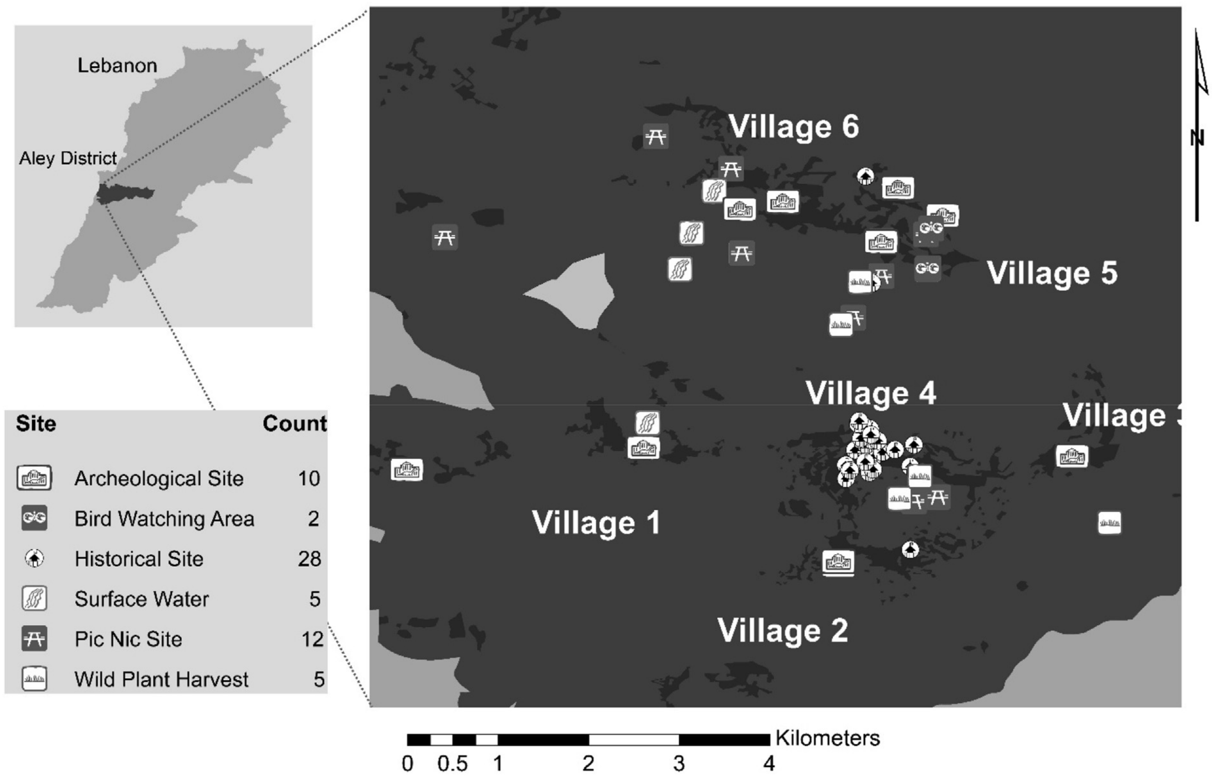

Fig. 2. Main ecological assets identified in the studied area by the local citizens as a result of the participatory mapping process.

behaviors, participants self-reported a solid knowledge of the benefits of and an awareness of the mechanics of sorting at source. Moreover, infrastructural aspects (i.e., availability of sorting bins, clear fate of recyclables and waste rejects, and presence of municipal follow-up and incentives) coincided with stronger engagement in, and higher moral obligation towards waste separation. As for waste reduction, the results reported that participants strongly engage in this behavior. Regarding composting, the communities view situational factors (time, space, availability of equipment, knowledge, and hygiene) as obstacles. However, more than 75% of the participants reported willingness to receive information about appropriate household composting techniques. There is a high correlation between favorable situational factors and recycling behavior (pearson correlation factor = 0.75), favorable situational factors for recycling and moral obligation (pearson correlation factor = 0.63), recycling moral obligation and behavior (pearson correlation factor = 0.51), reduction attitude and behavior (pearson correlation factor = 0.59), recycling and reduction behavior (pearson correlation factor = 0.51), and a moderate correlation between recycling knowledge and moral obligation (0.47) (Fig. 4b). Situational factors such as storage convenience, collection times, and satisfaction with local facilities also encouraged public's involvement and consequently, the participations rate in waste separation in Ghani et al.'s (2013) and Stoeva and Alriksson's (2017) studies.

5. Lessons learned and key factors for effective knowledge co-creation

This section presents the TIES approach and discusses nine strategic steps to achieving a contextualized transdisciplinary knowledge co-creation.

1. Inherent common interest:

TIES is founded on an inherent and common interest between the community and the researchers, namely to address a locally pressing environmental problem. Key factors include the communities' pre-existing and self-reported strong environmental identity and drive to address the given environmental problem.

2. Flexible interdisciplinary research team:

TIES emphasizes openness among researchers to external support after the initial problem description and team building. As TDR started, it became obvious that a modelling expert, to devise a methodology capable of addressing differences between communities and exposure groups, was needed. Comparison of the findings with those of other studies confirms that it is not always initially evident what knowledge from which discipline will be useful; and so, openness, exchange, and integration of inputs from new potential actors is fundamental (Mauser et al., 2013).

The findings also highlight the importance of accounting for the intention-behavior gap in TDR. Featuring socio-behavioral sciences was key for two reasons. On the one hand, the first priority within an environmental management hierarchy (i.e., prevention) calls for the need to shift from a structural to a nonstructural approach (Elleuch et al., 2018). This required a comprehensive assessment of the personal and situational factors that either facilitate or constrain sustained adoption of environment-friendly community practices. On the other hand, the quantitative behavioral study used a self-reporting instrument that tends to introduce social desirability (over-reporting "good" or under-reporting "bad" behavior), therefore, it was not possible to validate the reported answers (Asare, 2015). As such, conducting a quantitative assessment of waste generation was key to compare and contrast

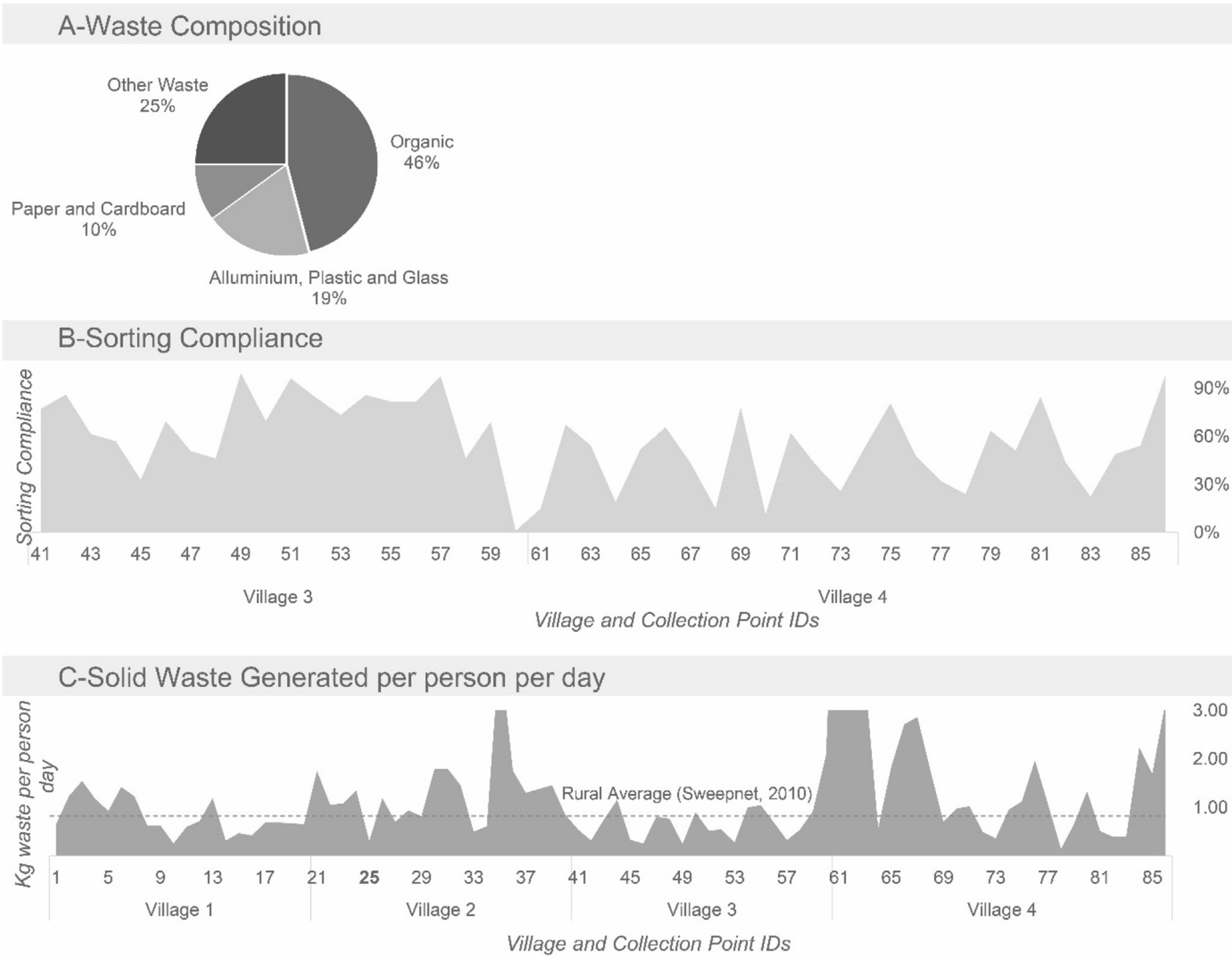

Fig. 3. Waste characterization and sorting compliance results in the studied area: (a) pie chart for the waste composition, (b) sorting compliance for Villages 3 and 4 based on individual collection point IDs, and (c) SW generated per person per day in Villages 1 to 4 based on individual collection point IDs.

perceived and actual behavior. Insights from the qualitative study revealed the influence of rural Lebanese cultural practices on the participants' daily routines. This case provides a clear example of how the cross-fertilization of expertise in natural and social sciences gave a more accurate outlook of the intention-behavior gap than a disciplinary perspective.

3. Representative citizen committee:

The representation of relevant community groups in citizen committees is key to successful knowledge co-creation. Diversity in age, gender, educational background, and occupation was advocated for in group formation, to ensure broader participation and inclusion of marginalized groups. Furthermore, the team insisted that each committee includes environmentalists, members from National Scout and local Civil Society Organizations (CSOs) as they usually have experience in participating in local initiatives as well as municipality members, who have political mandate and decision-making authority in their communities. In accordance with the present results, previous studies demonstrated that co-design and co-production run more smoothly when community leaders are socially engaged, action-oriented, co-operative, and willing to try unconventional things (Moser, 2016; Yokota et al., 2018). Maintaining an autonomous and unrestricted membership and taking steps toward community representation ensured sufficient team legitimacy and continued participation, which are common obstacles in TDR (Scholz et al., 2009; Wiek et al., 2012).

4. Contextually informed outreach coordinator:

The study calls to attention the appointment of a contextually-informed outreach person in order to maintain mutually beneficial relationships between the researchers and the participating communities. The outreach coordinator proved invaluable in acting as a bridge between researchers and the community and promoting better integration of local and scientific knowledge as also found in Yokota et al. (2018).

5. An iterative research process to account for the shifting socio-political context during implementation:

Although the scoping meetings helped define the environmental problem at hand, an iterative needs assessment approach enabled the team to gather constructive input from the citizen committees and understand the communities' socio-political context. Previous studies have also called for the need to account for the socio-political priorities during TDR's design and implementation (Lang et al., 2012; Stauffacher, 2010; Scholz and Binder, 2011).

The team was able to set an amendable research timeline that adhered to community dynamics and local resident schedules. This

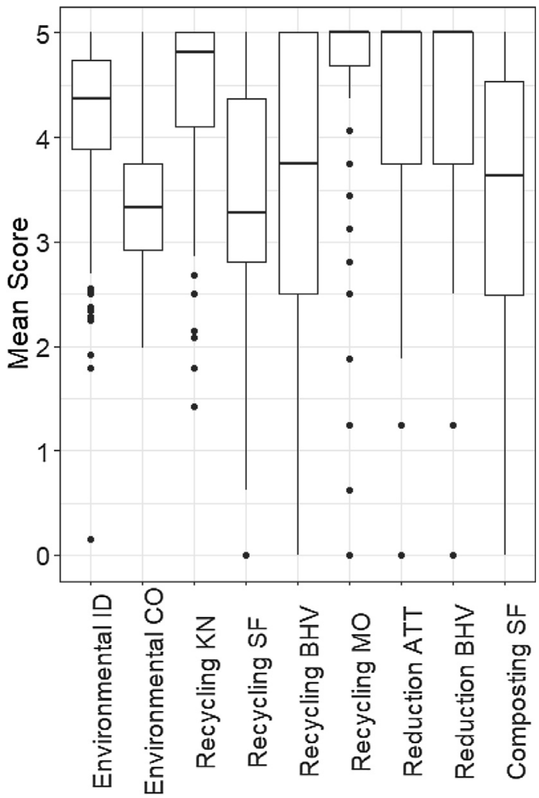

Fig. 4a. Respondents' scores of the different variables used in the quantitative behavioral assessment (ID: Identity; CO: Concern; KN: Knowledge; SF: Situational Factors; BHV: Behavior; MO: Moral Obligation; ATT: Attitude).

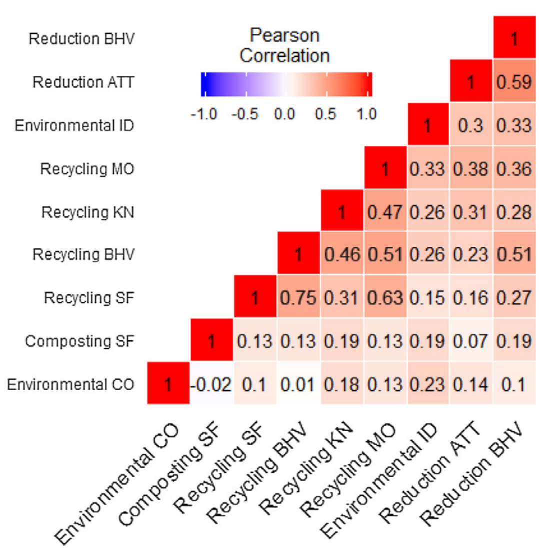

Fig. 4b. Correlation matrix showing the correlation coefficients between the different variables used in the quantitative behavioral assessment.

flexibility was effective in ensuring a jointly controlled research protocol between science and practice and in positively influencing stakeholders' sense of ownership (Naqshbandi et al., 2011; Zscheischler et al., 2017). Yet, the team had to deal with several contretemps during implementation, which made it challenging to maintain the trajectory of activities and deliverables previously agreed upon with the funder. For example, one of the study's objectives was to increase sorting compliance through awareness campaigns. However, the needs assessment showed that, two of the municipalities, which were adopting a model of SWM decentralization at the time when the scoping was conducted, were constrained to subcontract a private company for waste collection and follow short-term impromptu plans. During implementation and due to stringent funding guidelines, it was not possible to account for the fact that they lost jurisdiction over SWM. The quantitative behavioral study also showed that the problem was not about these communities' insufficient knowledge but rather the absence of appropriate infrastructure to support sorting at source. Funding agencies typically require that deliverables be specified in the proposal submission phase, however, the findings confirm those of Baalbaki et al. (2019), who pointed out that research projects cannot be expected to determine which outputs will occur from the beginning, thus putting "the conventional methodology that is usually bound to timeline and clear deliverables into question" (p. 13). Flexibility may be built in by allowing a leeway period during the early part of the project where deliverables and timelines are revised in agreement with the participation of all stakeholders including funders to ensure a more balanced problem ownership.

6. Common expectations of the research process:

Developing a shared understanding of the research process and expectations between and among the researchers and the community to avoid facing methodological challenges (as described by Colquhoun et al., 2013; Wiek et al., 2010) is clearly supported by the current findings. Mutual expectations around the scope of the team's interventions were developed based on the type of actions that were allowable under the awarded fund. Besides, assessing communities' perception and behavior required research ethics review and approval, which delayed data collection. The team insured, during interim workshops and through the co-development of the study's action plan, that all stakeholders understand the strong emphasis placed on scientific rigor and quality.

7. Practical boundary objects:

TIES supports prior evidence that methods usually employed by technically minded experts to design SWM in engineering terms prior to public involvement poorly account for appropriateness to the local context (Henry et al., 2006; Morrissey and Browne, 2004). The study's deliverables became "boundary objects" (as defined by Lang et al., 2012) with which community members could understand the technical, sociocultural, political, economic, and legal multifacetedness of SWM. Unlike Lang et al. (2012), the context-specific 'technical' recommendations that came up were not viewed as drawbacks. A critical part of developing a functional and integrated SWM process is accounting for the context of the SWM system being addressed, which, according to Marshall and Farahbakhsh (2013), many developing countries have failed to consider. To amplify societal and scientific impacts, it is suggested to contiguously co-design spin-off activities in the same communities. This was made possible in the study as the team secured additional funding to integrate the stakeholders' needs for household composting tools and a school awareness program, both of which were beyond the scope of the main study.

8. Effective communication:

TIES promotes integration across the academic/non-academic boundary by building relationships and integrating the team's knowledge and values with those of the communities. In the project, the communities' hospitality created a safe haven where the views of researchers and the community were both welcomed and conversed over. After receiving a communication training, researchers followed a similar approach when meeting with community members. Their conversations began on a personal note, eventually leading to the real gist of the whole meet-up. During the qualitative study, researchers talked over a cup of coffee and the occasional meal, and shared housekeeping tasks with participants while conducting their interviews. The snowballing sampling technique data collectors resorted to enabled participants to be actively involved in data collection and suggest additional informants from their acquaintances. This approach is consistent with the literature (Yokota et al., 2018; Zscheischler et al., 2017).

TIES' approach to knowledge dissemination stresses the need for effective communication to promote mutual understanding and avoid misinterpretations. As described in Section 3.3, fit for purpose workshops were designed and conducted in accessible language and locations. Meeting days and times were set in a way to avoid conflict with other important community activities. These are coping strategies suggested by Stokols et al. (2010) to avoid setting barriers for participation in TDR. The coordinator built and maintained regular communication and strong relationships with community members through recurrent, in-person courtesy visits and meetings rather than only phone calls or e-mail exchanges, which brought about more effective communication. This result supports evidence from previous observations (e.g. Goven et al., 2015; Naqshbandi et al., 2011; Stokols, 2006). Consistent with Snowden (2002), this approach enabled the communities to say more than what they could express in writing, thus enhancing the integration of local and scientific knowledge. Through team building activities, the partners sustained participation and promoted better integration. In line with Walter et al. (2007), the benefits alleviated tensions in some villages and gathered community members regardless of whether they had suboptimal relationships with their respective municipalities and were initially reluctant to partake in municipal initiatives.

9. Ex-post assessment:

Consistent with Lang et al. (2012) and Späth's (2008) recommendation, TIES points towards the importance of designing and conducting an ex-post assessment to keep track of the project's scientific and societal impacts. The study's approach helped the communities distinguish evidence-based knowledge from biased or misleading information, worked with the local communities to help them become more effective communicators and policy contributors, and strengthened public confidence in relying on scientific evidence in advocacy.

The study relieved the anxiety associated with SW malpractices with regards to air and water contamination. Moreover, the health results confirmed the fear of the communities as they indicated an increase in a multitude of symptoms and diseases in areas closest to the landfill. The comprehensive assessment of the factors, which shape SWM practices, provided each of the communities with tailored first-hand information to plan for improved short and long-term SWM. However, it was still difficult to ensure that the recommendations produced by the process were implemented. The literature offers two explanations for this challenge: (1) it is difficult to assess impact right after a project's completion due to the multiple layers TDR links together and the relatively long and uncertain time scales to accomplish a certain degree of impact (Walter et al., 2007; Roux et al., 2010), and (2) the absence of impact should not be interpreted as 'uselessness' but must be understood in terms of conditions and context (Godin and Doré, 2005; Polk, 2015). This finding further supports the existence of a complex web of contextual circumstances that are detrimental to achieving impact, and can only, to a limited extent, be compensated for in TDR (Belcher et al., 2016; Hansson and Polk, 2018).

6. Discussion

6.1. A conceptual framework based on lessons learned (TIES)

Building on the challenges and lessons learned, the study presents TIES, a framework that addresses a local sustainability issue agreed upon by both communities and researchers (Fig. 5). Both the research team and the representative citizen committee were flexible around inclusion to adapt to newfound knowledge emerging from an iterative and collaborative process to defining context, setting research objectives, and designing methodologies. In addition to enabling a contextual project design, the iterative process, informing and being informed by the research team and citizen committee, creates a set of common expectations. The implementation of activities produces boundary objects that link scientific knowledge production and communication to the social context while creating positive social dynamics. The continual team building, exchange, translation of knowledge, and informal communication between the research team and the community serve to build trust and alleviate pre-existing tensions between community members and their local governments.

6.2. Implications and recommendations for further research

6.2.1. Managerial implications

TIES has the capacity to provide significant value across diverse areas, including research managers and researchers involved in the design, execution, management, and evaluation of waste-related TDR projects, public authorities and community members, funding agencies, and the education sector.

TIES can be used as a roadmap for research and research managers as they move through the full lifecycle of TDR. It is also helpful for designing process evaluation activities to track scientific progress as well as progress towards integration of different forms of knowledge and mutual learning throughout the project.

TIES offers practical implications for public authorities and community members to improve their municipal environmental management practices. In fact, the modern environmental management literature stresses the need for community participation in setting environmental priorities, designing, and executing interventions (Athayde et al., 2016). The participatory environmental management approach ensured by TIES creates ownership, acceptance for, and use of jointly identified management strategies (Düspohl et al., 2012). In terms of SWM for example, TDR outcomes provide suggestions to public authorities on how to encourage waste prevention behavior, which is part of broader municipal waste management strategies (Corsini et al., 2018). Particularly in this study, public authorities could use insights from the qualitative study to design culturally-anchored campaigns with tailored messaging built on the community's constructions of food waste. In terms of wastewater management, findings from a participatory water assessment could encourage public authorities to mitigate water pollution. Locally, this translates to controlling the release of untreated wastewater discharge and pushing governmental institutions to continuously monitor the Naameh landfill and regularly test selected wells.

The lessons learned compiled into TIES provide implications for funding agencies with regards to their grant design and management policies. TIES demonstrates the benefits of putting considerable amounts of time and effort prior to receiving the award, which is generally not covered by the funding (Hall et al., 2012; Luthe, 2017). Moreover, introducing grant guidelines and review criteria that promote iteration in community and expert exchange instead of pre-determined and rigid activities creates outcomes that are more attuned to the needs of all stakeholders. By encouraging

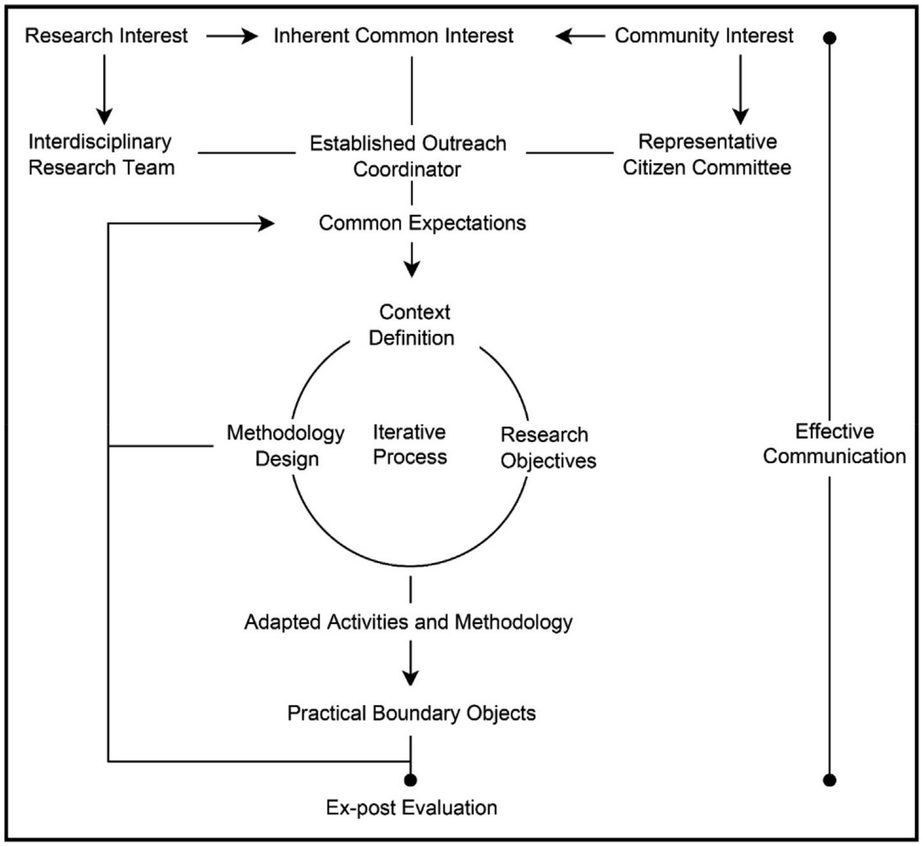

Fig. 5. Conceptual framework: key factors to facilitate an effective and efficient TDR process based on nine lessons learned deduced from this study.

iteration and providing resources to take these foundational steps in the research process, funding agencies can reap even more constructive results from their investments.

The study also provides management suggestions for the education sector. Many researchers have advocated for the incorporation of transdisciplinary modules in universities' curricula to lay the foundation for an improved understanding of the concept (Gillis et al., 2017; Schmidt and Pröpper, 2017; Schwaninger, 2019). This can be done by capitalizing on generic skills required for TDR and highlighted in TIES, including teamwork, communication, and critical thinking. Educators could use TIES to inform the design of curricula and programs responding to local community needs while involving various disciplines.

6.2.2. Research contribution

The study provides new empirical observations on full-circle TDR practices emerging from the global South and the dynamics between researchers and extra-scientific actors around local environmental management issues. Seeing that the social acceptance of SWM has been rarely reported until now (de Souza Melaré et al., 2017; Nie et al., 2018), TIES contributes to the SWM literature by providing an improved process for how the community can be included in the design, implementation, management, and evaluation of SWM initiatives.

The non-phased, process oriented nature of TIES, linking the lessons learned in a logical order addresses commonly-held limitations in previously proposed TDR frameworks. TIES has been inspired from several commonly accepted frameworks designed by previous researchers (e.g., Luthe, 2017; Mauser et al., 2013; Tejada et al., 2019; Yokota et al., 2018) which closely parallel the one proposed by Lang et al. (2012) and is built on contextually-informed lessons learned also documented in empirical and theoretical literature from the social, cognitive, behavioral, management, and organization sciences. However, in these three- or four-phase models, the distinction between the different phases is not clearcut, as they overlap and iterate in practice (Ruiz et al., 2017; Thompson et al., 2017; Wang et al., 2019). Moreover, in each of these phases, several authors recommend design principles or coping strategies of how to carry out TDR; yet, the logical link between them is not clearly established (Bracken et al., 2015; Hall et al., 2012; Lang et al., 2012). By addressing these limitations, TIES brings forward a suitable reference frame for full-circle knowledge co-creation. This responds to the call in the literature for a generic, collaboratively developed framework process that integrates community-level socio-cultural realities and needs with scientific knowledge in line with national development priorities (Thomas et al., 2018).

Standardization and extensive use of TIES would enable the comparative analysis of TDR in different studies and contexts, which was previously stifled by a lack of common language across different studies (Lotz-Sisitka et al., 2016). This deeper evaluation would provide insights into the effects of the overall framework conditions on the success of integration and the specific interplay of different factors affecting TDR (how variations in key characteristics of such research initiatives may influence the process in different contexts), as also recently recommended by Tejada et al. (2019). It is hypothesized that such variations may lead to differences in outcomes. This would inform the design of best practices for different types of TDR collaborations given their context-specific features.

6.2.3. Recommendations for further research

Opportunities exist for research using a mixed method approach to further empirically test TIES on multiple environmental management challenges in different socio-cultural contexts and identify opportunities for improving applicability and scalability. Additional evidence for effective practices for knowledge co-creation could be provided from further studies in the global South.

In the present study, researchers, municipalities, communities, and local CSOs dominated the process while other stakeholders including ministries and SWM private companies were not represented. A potentially fruitful direction for future research would be to apply TIES in projects including national authorities and private sector actors.

7. Conclusion

This research responds to the call in the literature for more emphasis on understanding how TDR plays out in specific socio-political and environmental contexts of SWM in the global South, and suggests a non-phased, process-oriented, conceptual framework including nine contextually informed guidelines for knowledge co-creation tackling limitations of commonly used TDR frameworks.

The TDR approach started with building a team comprised of researchers and non-academic partners collaboratively framing the problem, continued with co-creating solution-oriented knowledge, and ended by integrating and applying the co-created knowledge. In addition to the challenges that are largely internal to the transdisciplinary process (such as differences in the values and expectations about the research process), the research pointed towards the influence of TIES' internal and external dynamics and shed light on contextual obstacles that hindered effective collaboration in some instances. These include challenges associated with the funding agency's stringent rules and regulations and tracking scientific and social impacts due to shifting socio-political circumstances.

Building on the study's contextually-informed challenges and lessons learned, a reference frame (TIES) for managers and academics was brought forwad to design, implement, manage, and evaluate TDR in environmental management. TIES would be particularly beneficial to SW managers due to the sector's heavy reliance on multiple fields of knowledge and the need for sustained community inclusion in planning and implementation.

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.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasman.2020.03.043.

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