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Review

Knowledge, attitudes, intentions, and behavior related to green infrastructure for flood management: A systematic literature review

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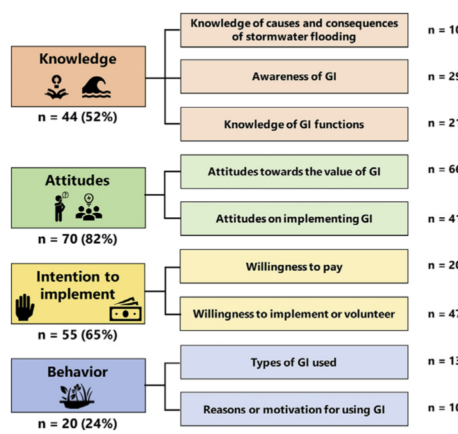
HIGHLIGHTS

- A systematic review found 85 studies on human dimensions of green infrastructure.
- Knowledge and awareness of green infrastructure was low.
- Attitudes about green infrastructure were inconsistently measured.
- Willingness to pay or implement green infrastructure varied across sites.
- Attention to human dimensions will improve green infrastructure design and uptake.

GRAPHICAL ABSTRACT



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ABSTRACT

Green infrastructure (GI), which mimics natural hydrological systems, is a promising solution for flood management at the intersection of urban built infrastructure and natural systems. However, it has not yet achieved widespread uptake, due in part to insufficient understanding of human dimensions of the broader socio-ecological-technical system. We therefore conducted a multidisciplinary systematic literature review to synthesize research on people's existing knowledge about flood risk and GI, and how that shapes their attitudes and motivation to adopt new solutions. We systematically screened 21,207 studies on GI for flood management; 85 met our inclusion criteria. We qualitatively analyzed these studies to extract results on knowledge, attitudes, intentions, and behavior relating to GI for flood management. Overall, knowledge of GI was low across the 44 studies in which

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it was evaluated. Seventy studies assessed attitudes about GI, including the functional, aesthetic, health and safety, recreational, conservation, financial, and cultural value of GI, albeit their measurement was inconsistent. Willingness to implement or pay for GI varied considerably across 55 studies in which it was measured. Twenty studies measured and documented behavior relating to GI use, and these found low rates of adoption. Few studies systematically assessed the role of demographic, socio-economic, or geographic characteristics that could influence individuals' knowledge, attitudes, intentions or behavior, and thereby the success of GI programs. We recommend that researchers should more systematically capture data on human dimensions of GI (i.e. knowledge, attitudes, intentions, and behavior) across diverse settings to improve program design and uptake, especially among vulnerable populations. Greater attention to the social component of the socio-ecological-technical system will help ensure that GI programs are equitable, inclusive, and sustainable.

Contents

1. Introduction

The development of densely packed cities over the past century has required engineering methods to manage stormwater runoff from impervious surfaces (McGrane, 2016). While such methods were adequate for their original purpose, rapid urbanization, persistent degradation of natural land cover, and climate change-related increases in the amount and intensity of rainfall have all made stormwater management an urgent 21st century urban challenge (Ahmed et al., 2018; Gill et al., 2007; Miller and Hutchins, 2017; Schreider et al., 2000). Flooding is an increasing problem, particularly routine, chronic flooding of city streets and basements (Douglas et al., 2010; Hallegatte and Corfee-Morlot, 2011; Jha et al., 2012). While often less visible than catastrophic flooding, such chronic flooding can nevertheless have dire consequences—especially for vulnerable populations—from affecting individuals' and households' finances, health, and water security, to damaging physical infrastructure of cities and incurring widespread disruption of transportation systems and other urban networks (Ahern et al., 2005; Center for Neighborhood Technology, 2014; CRED, 2015; Jepson et al., 2017; Saulnier et al., 2017).

In the past decade, urban planners, engineers, and environmental advocates have emphasized the need for a paradigm shift in sustainable stormwater management practices, including measures such as green infrastructure that can be especially helpful to manage low-grade, chronic flooding (Dhakal and Chevalier, 2016; Eggermont et al., 2015; Taylor and Fletcher, 2007). Green infrastructure (GI) is widely and broadly understood as a set of strategies in built environments that serve a variety of ecosystem needs such as controlling temperature, improving air quality, increasing drought resilience, and managing flooding (Block et al., 2012; Bowler et al., 2010; Kloos and Renaud, 2016; Pugh et al., 2012). GI is therefore increasingly gaining prominence as a core sustainable urban systems strategy. Here, we focus on GI designed to help mitigate flooding, i.e. systems that mimic natural hydrological systems to manage stormwater runoff, such as using “vegetation, soils, and other elements and practices” (U.S. EPA, 2017).

However, despite the growing presence of GI, it has not yet achieved widespread uptake as a core flood management strategy. One plausible reason is that although there is already ample evidence supporting the technical efficacy of GI (e.g. Ahiablame and Shakya, 2016; Eckart et al., 2017; Jaffe, 2010; Liao et al., 2013; Semadeni Davies et al., 2008; Zölch et al., 2017), much less is understood about the broader socio-ecological-technical system in which GI could be adopted (Schifman et al., 2017). As such, there have been a number of calls for more social science research on GI and flood management (Brink et al., 2016; Le Gentil and Mongruel, 2015; Vogel et al., 2015; Walker et al., 2012; Wang et al., 2014). For example, a literature review of flood risk perceptions found that “the majority of studies are of exploratory nature and have not applied any of the theoretical frameworks that are available in social science research” (Kellens et al., 2013).

The social sciences offer various theories and frameworks for understanding the factors that influence behavior change and technology adoption. Specifically, understanding people's existing knowledge about flood risk and GI, and how that knowledge shapes their attitudes and motivations to adopt new solutions would enhance designs and reduce barriers to GI implementation (Chou, 2016). Such barriers are likely to be context-specific and are particularly important to uncover in populations that are more vulnerable to the consequences of flooding to avoid issues of environmental inequity (Drake et al., 2013).

Various behavior change theories such as planned behavior (Ajzen and Fishbein, 1980), the health belief model (Glanz et al., 2015), and diffusion of innovations (Rogers, 2005) suggest that prior *knowledge* shapes one's *attitudes* towards an object or outcome, which can predict *intentions* and motivation for *behavior* change, i.e. installation or use of GI (Fig. 1). “Knowledge” refers to both knowledge about the presence and magnitude of an issue, as well as knowledge about potential solutions. Knowledge, in turn, can shape one's attitudes—such as perceived benefits, perceived harms, perceived susceptibility to a problem, and preference for solutions. Knowledge and attitudes in turn have the potential to shape one's intentions, e.g. willingness to make changes, and subsequently one's actual behavior to adopt that object or outcome. Findings across these domains are ultimately dependent on demographic, socio-economic, and geographic characteristics, which makes it important to understand the role of such characteristics across different contexts (Fig. 1).

Thus far, single-site case studies have explored the human dimensions of GI, but there has been no comprehensive synthesis of research across many sites. Our goal for this systematic literature review of peer-reviewed and gray literature was to address this research gap. Our first objective was to synthesize evidence on (a) knowledge, (b) attitudes, (c) intentions, and (d) behavior about GI for flood management. Our second objective was to describe demographic, socio-economic, or geographic characteristics tied to individuals' knowledge, attitudes, intentions or behavior. In so doing, we aim to lay out a relevant agenda for practitioners and researchers to better incorporate social considerations into ecological and engineering designs to achieve GI that is equitable, inclusive, and sustainable (Eakin et al., 2017; Perales-Momparler et al., 2015; Thorne et al., 2018).

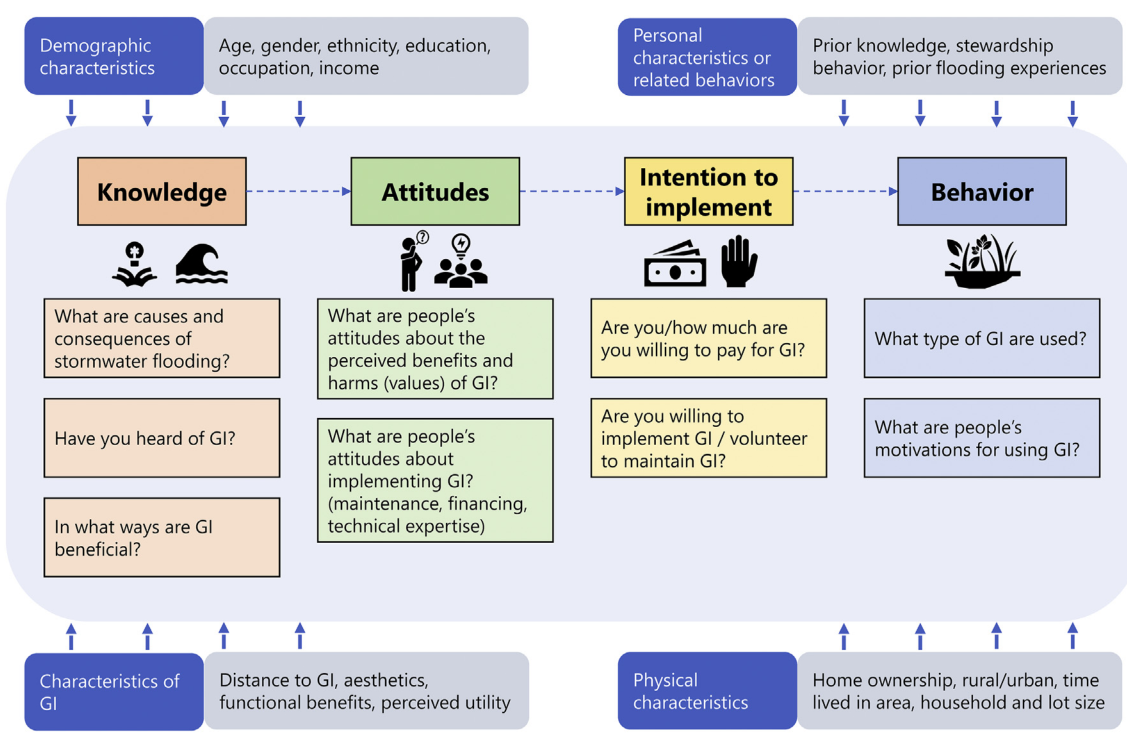

Fig. 1. Conceptual framework linking the domains of knowledge, attitudes, intentions, and/or behavior* relating to green infrastructure (GI) for flood management, along with characteristics that can influence these outcomes (at perimeter). Data analysis was guided by illustrative questions (in boxes at center). *Behavior change is often more complex than the linear representation suggests; this figure is a simplified heuristic of knowledge, attitudes, intentions, and behavior adapted from Ajzen and Fishbein, 1980; Glanz et al., 2015; Rogers, 2005.

2. Methods

2.1. Operationalization of concepts

Our broad definition of GI for flood management includes straightforward "green" concepts meant to address various types of flooding, such as varied natural land cover that provides flood protection and water quality benefits, as well as pervious pavement and stormwater detention systems (Chenoweth et al., 2018; Mell, 2013; U.S. EPA, 2017; Young et al., 2014). We also consider the various synonyms for GI such as natural or nature-based infrastructure, Low Impact Development (LID), Sustainable Drainage Systems (SuDS), water sensitive urban design (WSUD), blue-green infrastructure (BGI), and Best Management Practices (BMPs) for stormwater runoff (Bartesaghi Koc et al., 2017; Fletcher et al., 2015; Liao et al., 2013; McKissock et al., 1999; Mell, 2013; Wright, 2011; Young et al., 2014).

We included various types of GI in this review, from rain gardens, green roofs, pervious pavement, and bioswales to greenstreets, green alleys, subsurface detention systems, and riparian buffers, to reconstructed wetlands or natural spaces such as parks, urban forests, and nature preserves. Installation of these GI can occur at different scales, which can be defined differently depending on the discipline (Felipe-Lucia et al., 2014; Tayouga and Gagne, 2016). Here, we use the McLeroy et al. (1988) conceptualization of the socio-ecological framework, through which we classified the scale of GI in terms of the largest relevant scale of implementation. For example, rain barrel use in homes was at the "household scale," whereas street-level rain gardens and bioswales were categorized as a "neighborhood" scale of implementation. Studies of parks or trees were categorized at the "city" scale, and waterway protection at the "watershed" scale.

For our first objective, we harmonized concepts from commonly used behavior change frameworks into the distinct domains of knowledge, attitudes, intentions, and behavior for heuristic purposes (Fig. 1). "Knowledge" included both awareness (familiarity), as well as knowledge, defined as "information leading to understanding, or for taking informed action" (Glanz et al., 2015). Responses to questions such as "Have you heard of green roofs?" and "What is the connection between a rain garden and stormwater retention?" became the data that we extracted for this domain. We defined attitudes as values that people attach to an object or an outcome (Glanz et al., 2015). Data on this domain came from responses to questions about perceived values of GI, which we categorized as functional, aesthetic, health and safety, recreational, conservation, financial, cultural, and general values. We also analyzed attitudes on GI implementation, such as concerns about maintenance, financing, and community trust in institutions. We defined intentions as one's stated willingness to pay for, implement, support, or volunteer to build or maintain specific GI based on hypothetical situations. Data came from econometric choice experiments and contingent valuation studies, as well as direct survey questions. Finally, we evaluated studies that assessed actual behavior, documenting the types of GI that were installed or used, as well as people's reasons or motivations for using them.

For our second objective, we also extracted data from each study on characteristics such as age, income, ethnicity, home ownership, distance to GI, and stewardship behavior that could further help explain knowledge, attitudes, intentions, and behavior of those surveyed (Fig. 1). For example, we wanted to investigate whether respondents' gender was correlated with knowledge about the functions of GI; whether their age correlated with their attitudes on the aesthetics of GI; or whether income or education was correlated with their willingness to pay for GI or their actual demonstrated behavior in using GI.

2.2. Search strategy

The search strategy used here is similar to that of a prior review on the health and social well-being impacts of GI (Venkataramanan et al., 2019). We systematically searched the following databases between January and March 2018 for scientific and gray literature (reports, dissertations, white papers): PubMed, Web of Science, Scopus, Embase, EBSCO Host, Proquest Dissertations and Theses, and Global Reference on the Environment, Energy, and Natural Resources (GREENR) Database (PROSPERO protocol registration number: CRD42018094256). We placed no restrictions on language, time period of the work, or document type. We also searched the first 300 results in Google Scholar (Haddaway et al., 2015), websites of key GI-related organizations, and citations in studies identified in our literature review (Supplementary Table 1).

Through expert consultation and review of GI typologies (Bartesaghi Koc et al., 2017; Young et al., 2014), we developed a list of the most commonly used terms for GI, and combined them with search terms for surface, rain, and stormwater runoff, waterlogging, and flooding. Database-specific search strategies can be found in Supplementary Table 1.

2.3. Screening process and eligibility criteria

Any study that explicitly mentioned GI designed to manage stormwater or flooding was initially retained. Studies that focused exclusively on non-flooding impacts (e.g. urban heat island effect) were excluded because we wanted to document the evidence relating specifically to flood management. During the full text screen, we only included studies that used primary data to understand knowledge, attitudes, intentions, or behavior, such as through surveys, interviews, focus group discussions, or stakeholder workshops, regardless of study design. We therefore excluded reviews, commentaries, editorials, blog posts, publicity material, and news and magazine articles per standard systematic review guidelines (Higgins and Green, 2011). We also excluded studies that only analyzed the technical efficacy of GI and case studies without primary data, as these types of studies do not provide results pertaining to social aspects of GI design, acceptance, or use.

2.4. Quality appraisal

To systematically assess the quality of studies and each study's strength of evidence, we used a 14-point quality assessment framework that can be used to assess: quality of reporting (six questions), minimizing risk of bias (five questions), and appropriateness of conclusions (three questions) (Venkataramanan et al., 2019). Each of the 14 items can be scored as 0 (not present), 0.5 (moderate), or 1 (appropriate). Studies with sums of 10–14 were considered high in quality, 5–10 were medium in quality, and less than 5 were of low quality (see Supplementary Table 2 for detailed scoring guidelines). The research team scored each study, and 10% were reviewed closely by the first author for quality control.

2.5. Data extraction and analysis

We extracted data consistently from each study using a qualitative coding framework developed *a priori* in a qualitative data analysis program, Atlas.ti 8 (Supplementary Table 3). The framework consisted of codes or "tags" for descriptive characteristics (e.g. study year, study design, sample size); scale of implementation (household, neighborhood, city, watershed); data sources (general public, community leaders, government workers, private developers, and other experts); implementation arrangements (funding sources, implementation responsibility, and ownership scenarios); and GI types. All included studies were coded, i.e. tags were attached to phrases using Atlas.ti 8, in two cycles.

First, we coded studies using our framework (Supplementary Table 3) and summarized key elements of each study to discuss as a group. This discussion process enabled the first author to conduct a second cycle of coding for specific aspects of knowledge, attitudes, intentions, and behavior investigated in each study. To gather data for our second objective, characteristics of study respondents, such as age, education, home ownership status, were also coded; these could have been measured quantitatively (as statistical controls) or qualitatively (assessing differences based on people's varied experiences). Data were then transferred from Atlas.ti 8 via "code-document" and "code-co-occurrence" tables to Microsoft Excel to tabulate frequencies.

3. Results

3.1. Search results and quality appraisal

From a total of 21,207 records screened, we reviewed the full texts of 4601 studies (Fig. 2). Ultimately, we found 85 studies that documented knowledge, attitudes, intentions, and/or behavior relating to GI for flood management (see Supplementary Table 4 for a full summary of included studies.) Most of these studies were published in scientific or practitioner-focused journals. Although we reviewed hundreds of documents from the gray literature, only one conference proceeding met the inclusion criteria of collecting primary data, along with 19 theses and dissertations.

Of the 85 included studies, most were rated as high quality (78%); the remaining were rated as medium quality (Supplementary Fig. 1). The weakest component of study quality was the category of "minimizing risk of bias"; for example, only 24 (28%) studies partly or fully met the criteria for data collection rigor (pilot-testing tools etc.). Furthermore, although studies scored highly on interpreting findings and offering conclusions that remained within the bounds of the study design, only half of the studies discussed the limitations of their research design and analysis.

3.2. Characteristics of included studies

Most studies (87%) were published after 2010 (Supplementary Fig. 2). Sixty-three studies (74%) reported data collection time periods, which all occurred between 1982 and 2016. Fifty studies (59%) collected quantitative data using surveys, 26 studies (31%) used qualitative interviews or focus group discussions, and the remaining used a combination (Table 1).

In total, this review compiles data from roughly 30,600 respondents; the number is approximate as some smaller studies did not state exact sample sizes. The size of these studies ranged widely, with a median sample size of 16 for qualitative studies (range: 4–108), 229 for quantitative studies (range: 17–5194), and 444 for mixed-methods studies (range: 33–735). More than three-fourths of the 85 studies gathered data from the general public, and one-third from government workers (Table 1).

Fifty studies (59%) were of GI in the United States (Fig. 3). Nearly one-third of the US-based studies were from the East, 14% from the Western US and the Pacific, and 19% from the Midwest. We also found five studies of GI in China or Taiwan, five studies each in the United Kingdom, Canada, and Australia, two studies in France, and one study each in 13 other countries.

A variety of GI were described, the most common being bioretention rain gardens and bioswales (44%), rain barrels or tanks (24%), and urban trees (24%). Protection and restoration of natural areas was discussed in ten (12%) studies. Most studies were described by the authors as occurring in urban or sub-urban settings (Table 1). Eight studies were described as occurring in multiple settings such as rural and natural (Badola and Hussain, 2005; Rulleau et al., 2017); urban and rural (Dean et al., 2016; Kaplowitz and Lupi, 2012; Rooney et al., 2015; Wagner, 2008); and urban, rural, and natural combined (Loos and Rogers, 2016; Winz et al., 2011) (Table 1).

Finally, we categorized these GI projects—either real or hypothetical—by the characteristics of implementation that were provided in the studies. Nearly half of the studies occurred at the city scale (41%), and nearly one-fourth explored household and neighborhood-scale GI (Table 1).

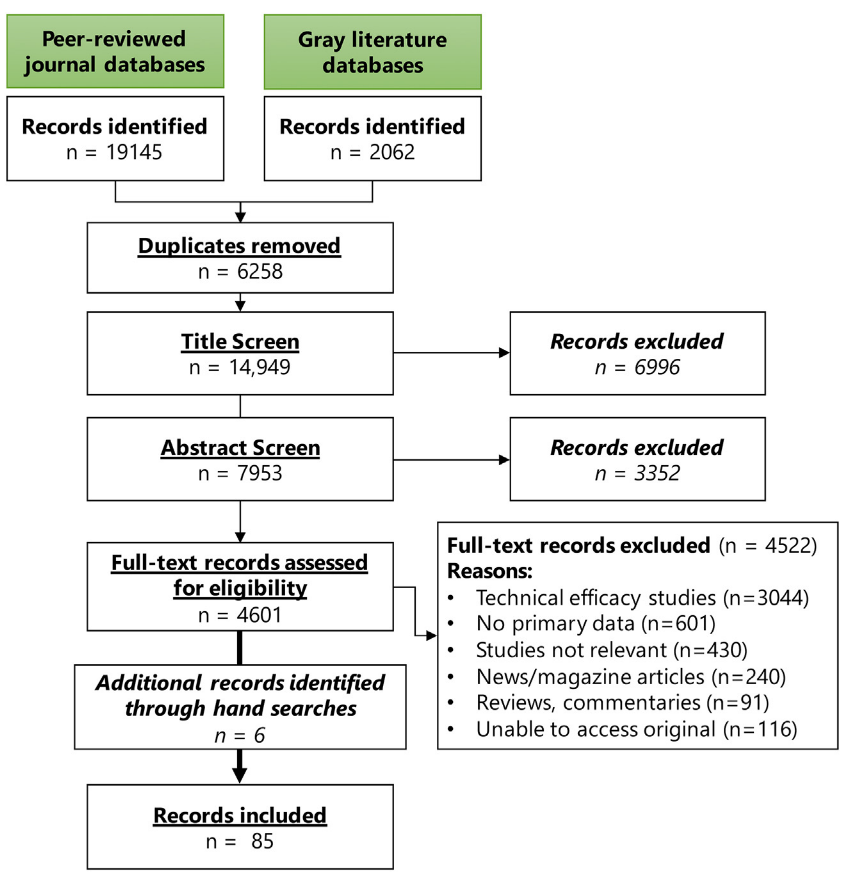

Fig. 2. Screening and selection process of green infrastructure (GI) studies for flood management reporting knowledge, attitudes, intentions, and/or behavior.

Table 1
Characteristics of studies about knowledge, attitudes, intentions, and/or behavior relating to green infrastructure (GI) for flood management (n=85).

Variables	No. of studies (%)
Study design	
Quantitative, cross-sectional, longitudinal, or pre/post	50 (59%)
Qualitative	26 (31%)
Mixed methods (quantitative and qualitative)	9 (11%)
Sources of data[a]	
General public	66 (78%)
Government workers	28 (33%)
Other experts (e.g. academics)	24 (28%)
Private developers	13 (15%)
Community leaders	6 (7%)
Green infrastructure types[a]	
Bioretention rain gardens, bioswales	36 (42%)
Rain barrels, tanks	20 (24%)
Urban trees	20 (24%)
Stormwater retention ponds/basins, culverts, canals	17 (20%)
Permeable pavement	16 (19%)
Green roofs, green walls	15 (18%)
Waterway protection and buffers	15 (18%)
Urban parks	13 (15%)
Protection and restoration of natural areas	10 (12%)
Green alleys, green streets	9 (11%)
Natural land cover/green infrastructure, undifferentiated	8 (9%)
Setting	
Urban/sub-urban	77 (91%)
Urban and rural	4 (5%)
Rural and natural	2 (2%)
Urban, rural, and natural combined	2 (2%)
Scale of GI implementation	
Watershed scale	9 (11%)
City, county, municipality scale	35(41%)
Neighborhood scale	23 (27%)
Household scale	18 (21%)

[a] These do not sum to 100% since some studies included multiple data sources and/or GI types.

Fifty studies (59%) involved projects with multiple permutations of funding sources, implementation responsibilities, and ownership scenarios. Two-thirds of GI projects (67%) in this review were publicly funded, owned, and implemented, but half of them included non-profit, private, or individual homeowners as partners; 35 studies (41%) were solely publicly funded and did not involve partnerships. Twelve percent of projects studied had individual/household funding, ownership, and implementation of the GI; where this overlapped with other implementation or ownership models, it typically involved a cost-sharing or subsidy arrangement with the government. Communal (neighborhood associations or homeowner's associations) and non-profit models were the least-mentioned GI implementation or ownership strategy, appearing in 14 studies (16%).

3.3. Knowledge of GI for flood management

Forty-four studies assessed knowledge or awareness about GI for flood management. Data reported included knowledge about the causes or consequences of flooding ($n = 10$), knowledge about the functions of GI for flood management ($n = 21$), and awareness of different types of GI ($n = 29$) (Fig. 4). Twenty-five studies (57%) primarily used quantitative methods, 12 (27%) primarily used qualitative methods, and seven (16%) used a combination of the two methods.

3.3.1. Knowledge on the causes and consequences of flooding, and on GI functions

Most studies that measured knowledge of the causes and consequences of flooding reported that people accurately identified causes such as "incomplete drainage" (78%) and "extreme weather" (67%) (Wang et al., 2017), as well as increasing impervious surfaces in neighborhoods (Carlson et al., 2015). Those surveyed on their knowledge about the functional benefits of different GI across 21 studies similarly had a moderate to strong understanding of the role that GI can play in mitigating flooding, including in studies of stormwater ponds (72%) (McKissock et al., 1999), rainwater harvesting (64%) (Fletcher et al., 2011), green streets (63%) (Church, 2015), urban forests (87%) (Davies et al., 2017), trees (55%) (Byrne et al., 2015), and rain gardens (63–78%) (Bakacs et al., 2013; Hoban and Kennedy, 2012).

3.3.2. Awareness of GI

However, general awareness of different types of GI, ecosystem services, and stormwater BMPs was low across the 29 studies that assessed these concepts. For example, only 33% of respondents in Dundee, Scotland and 40% of respondents in Fort Worth, Texas, USA were familiar with GI (Abrahams, 2010; Jose et al., 2015). Awareness of more specific terms also varied, such as bioretention facilities (34%) (Kim and An, 2017), rain gardens (46%) (Newburn and Alberini, 2016), and bioswales (54%) (Miller, 2017). Six studies specifically documented differences in perceived definitions, reporting confusion about what counts as "green infrastructure" (Abrahams, 2010; Church, 2015; Matsler, 2017; Vandiver, 2010; Wagner, 2008; Williams, 2012). For example, in Portland, Oregon, USA, some residents felt that "remediation [through bioswales] is not

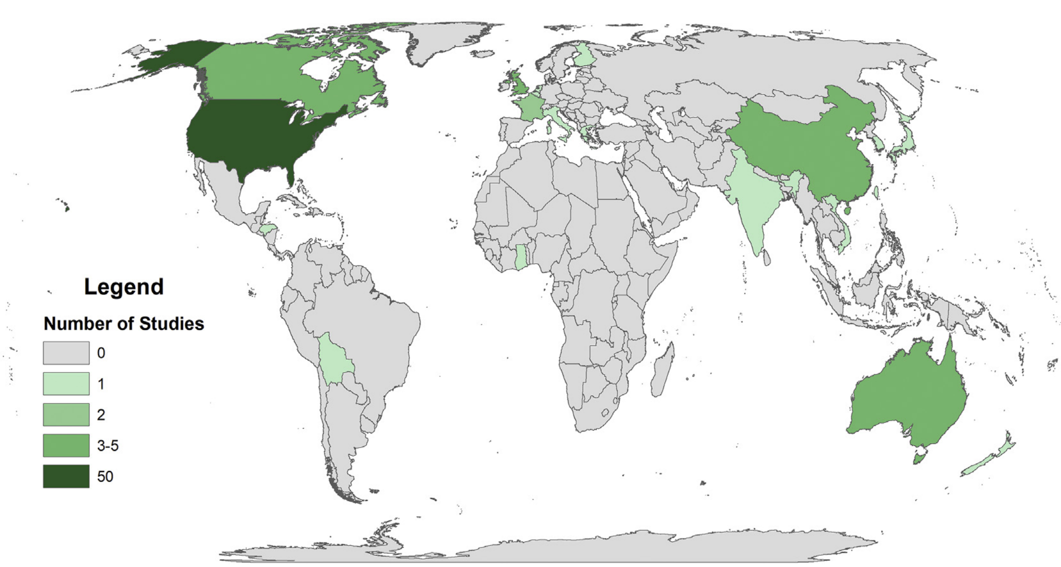

Fig. 3. Geographical distribution of 85 studies on green infrastructure (GI) for flood management.

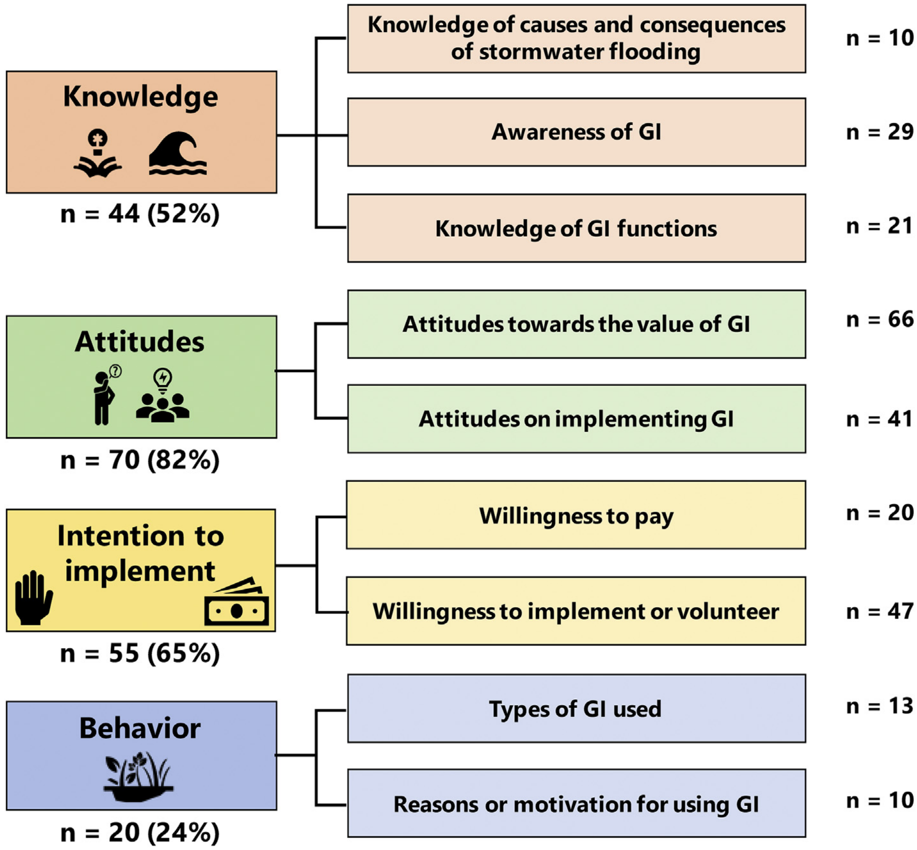

Fig. 4. Knowledge, attitudes, intentions, and/or behavior relating to green infrastructure (GI) for flood management have been investigated in 85 studies. Within these four domains, a variety of themes have been assessed, but not systematically.

nature," but that rain gardens that increase wildlife habitat in urban areas can be considered as "nature" (Church, 2015). Even where familiarity with specific GI terms, such as a green streets and bioswales, was high, this did not equate with accurate knowledge of the concepts' functionality (Church, 2015; Everett et al., 2018).

Stormwater practitioners also perceived public awareness to be low (Matsler, 2017). For example, in Minneapolis, Minnesota, USA a practitioner told researchers that "People are just not aware that the rainwater that goes off their yard and down the storm sewer system is the number one cause of pollution in urban waters" (Hammitt, 2010). On the other hand, practitioners in a study from Cleveland, Ohio, USA and Milwaukee, Wisconsin, USA saw GI as a useful tool for public outreach and connection (Keeley et al., 2013).

3.3.3. Characteristics of those surveyed about GI knowledge

Most surveys of GI knowledge did not disaggregate data by participant characteristics. Six studies documented characteristics by age, gender, home ownership, race, and ethnicity (Table 2). For example, Peng (2010) reported that homeowners in Syracuse were more likely to have knowledge of permeable pavement than renters, older people had greater knowledge of trees, more educated people had higher levels of environmental knowledge, and White-Caucasian residents had higher GI-related knowledge scores than other racial groups.

3.4. Attitudes about GI for flood management

Seventy studies measured attitudes about GI. These attitudes were from the perspective of the general public, community leaders and non-profits, government workers, private developers, and other experts. We grouped these attitudes into the themes of perceived benefits or harms (values) relating to GI and implementation of GI (Fig. 4).

Table 2
Covariates of knowledge, attitudes, intentions, and/or behavior captured across studies on green infrastructure (GI) for flood management (n=85).

Domain:	Knowledge	Attitudes	Intention to implement	Behavior
Number measuring covariates:	6 of 43 studies	35 of 70 studies	33 of 55 studies	8 of 20 studies
Demographic characteristics				
Age	2	8	9	3
Gender	1	9	5	4
Ethnicity	1	5	1	1
Education	1	8	11	2
Occupation	-	1	4	-
Income	-	7	11	3
Physical characteristics				
Home ownership	-	4	2	3
Rural/urban	-	1	-	-
Time lived in area	-	2	3	-
Household size	-	2	1	-
Lot size	-	-	1	1
Personal characteristics or related behaviors				
Prior knowledge of GI	1	5	8	4
Stewardship behavior	1	3	4	-
Experiences with flooding or GI	3	8	7	-
Receipt of information about GI	1	4	1	1
Religious participation	-	-	1	-
Water consumption	-	-	1	-
Characteristics of GI				
Distance to GI	-	1	1	1
Aesthetics	-	-	1	-
Functional benefits of GI	-	-	1	-
Perceived utility of GI	-	-	1	-

3.4.1. Attitudes towards the value of GI

People were surveyed or interviewed about their attitudes towards GI in 77% of all studies. They were most frequently asked about the functional value of GI for water management (flood protection, water quality improvements), aesthetic value (visually pleasing landscape), and health and safety value (air quality, physical safety around natural areas) (Fig. 5). Less frequently elicited values were appreciation for recreational opportunities (spending time in parks, fishing), conservation of biodiversity, and financial (property value). Respondents mostly discussed positive attributes, such as reduction in air and noise pollution (Derkzen et al., 2017; Kati and Jari, 2016; Kocisky, 2016; Miller, 2017).

However, our analysis also revealed attitudes about disservices or potential harms, such as concerns over the functional efficacy of GI at mitigating stormwater runoff. For example, in studies from Taiwan, Finland, and the USA, respondents expressed worry that GI would not be sufficient to mitigate flooding (Chou, 2016; Church, 2015; Kati and Jari, 2016; Meng et al., 2017), and in two studies from Canada and the USA, some even worried that GI would lead to more flooding (Cote and Wolfe, 2014; Turner et al., 2016). Concerns about other potential impacts included an increase in mosquitoes, unkempt aesthetics of their landscape, and physical safety issues, e.g. that a brownfield conversion to GI would put children at risk of contamination from unknown chemicals in Toronto, Canada (De Sousa, 2003). In Australia, Canada, and the USA, homeowners were also worried that GI would lower home value (Brown et al., 2016; Cote and Wolfe, 2014; Turner et al., 2016).

3.4.2. Attitudes on implementing GI

Forty-one studies documented attitudes about the implementation of GI (Fig. 4). Sixty-one percent of these studies documented community leaders' or the general public's perceptions, 49% surveyed government or private developers, and 41% surveyed other experts.

The most salient theme was concern about the maintenance of GI, such as the challenge of maintaining plants and landscapes to remain aesthetically pleasing as well as functional. Residents interviewed in Portland felt that that bioswales were "overgrown, messy and ugly," and wished they could intervene to maintain them. One respondent described how "Down the street from us there is a swale and … they dug it out and a sign appeared almost immediately saying 'this is a protected space, do not clip, dig, remove any of these plantings', […] So, we're not encouraged to do something unique with our swale," suggesting that they would like to place a positive value on the swale but were not encouraged to do so (Everett et al., 2015). However, others interviewed in this study did not want to play a role in maintaining their GI. Indeed, across nine studies that asked about maintenance responsibility, most residents wanted the city or municipality to take care of GI (e.g. Crimian, 2013; Hoban and Kennedy, 2012).

Other related themes concerned funding constraints, lack of technical expertise, and the importance of government leadership. Practitioners interviewed in several studies noted that there is an overall lack of awareness and expertise among engineers about GI for stormwater management, thereby affecting the ability to design it relative to gray infrastructure (Cousins, 2017; Hammitt, 2010; Keeley et al., 2013; Martin et al., 2007; O'Donnell et al., 2017; Winz et al., 2011). Collaboration between government departments and clarification of responsibilities was crucial (Carlson et al., 2015; Cousins, 2017; Keeley et al., 2013), as was support from local authorities to implement GI (Hammitt, 2010; O'Donnell et al., 2017; Winz et al., 2011).

A few studies from Australia and the USA noted the importance of community attitudes about support for GI and trust in institutions (Brown et al., 2016; Simons, 2017; Thorne et al., 2018). Conversely, perceived value or uniqueness could also be important in obtaining community support, as was the case in a creek restoration project in Charleston, South Carolina, USA (Crimian, 2013).

3.4.3. Characteristics of those surveyed about attitudes relating to GI

Half of the 70 studies that measured attitudes disaggregated data by participant characteristics (Table 2). The most frequently mentioned variables were socio-demographic, such as age, gender, education, and household income. Age was often positively and significantly correlated with positive attitudes towards GI, e.g. older people tended to have more concern about urban flooding and wanting to solve it using GI (Wang et al., 2017), tended to participate more in stream restoration activities (Asakawa et al., 2004), and had a stronger preference for natural areas than younger people (Williams, 2012). Three out of eight studies reported that higher education was positively correlated with higher value for GI (Miller, 2017), preferences for certain types of GI (Derkzen et al., 2017), and more safety requirements (Williams, 2012); the remaining did not identify significant associations.

A few studies measured time lived in the area, home ownership, and cost of GI as potential covariates of attitudes about GI. Prior knowledge of GI, experiences with GI, and stewardship behavior were also measured. For example, prior knowledge was correlated with positive attitudes or values (Kim and An, 2017; Lo et al., 2017; Peng, 2010; Wang et al., 2017). In Cleveland, those without GI were more likely to feel that its maintenance requirements did not justify its overall value (Turner et al., 2016).

3.5. Intention to implement GI

Intentions were measured in 55 studies (65%) through measures of willingness to pay, willingness to volunteer, or a general willingness to implement, install or use GI.

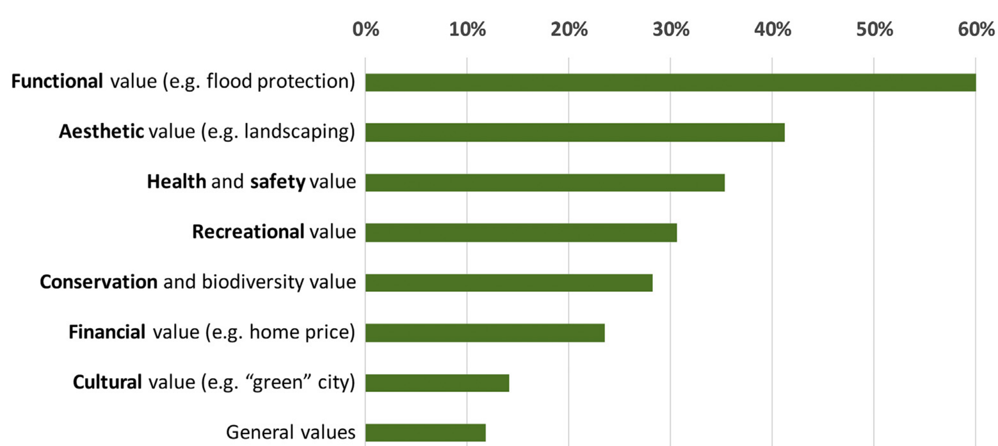

Fig. 5. Types of perceived values identified by frequency across the 70 studies that measured attitudes relating to green infrastructure (GI) for flood management.

3.5.1. Willingness to pay (WTP)

One-fourth of the 85 studies investigated WTP for GI (Fig. 4). Of these, six were choice experiments (Brent et al., 2017; Drake et al., 2013; Kenney et al., 2012; Londoño Cadavid and Ando, 2013; Penn et al., 2014; Rulleau et al., 2017) and four were contingent valuation studies, which use econometric methods to indirectly measure WTP (Chen et al., 2014; Chui and Ngai, 2016; Dumenu, 2013; Reynaud et al., 2017). The remaining used simple descriptive questions in surveys such as "How much would you be willing to pay to install [GI]?"

Of the descriptive studies, a large proportion of respondents said they were not willing to pay any amount for GI (Cote and Wolfe, 2014; Derkzen et al., 2017; Newburn and Alberini, 2016; Persaud et al., 2016; Wang et al., 2017). One exception was a study from Dundee, Scotland that found 50% of respondents would pay more for a house located near natural land cover (Jose et al., 2015). In a tree planting study from Chicago, Illinois, USA people reportedly wanted detailed plans on how their money would be spent first, and had a general distrust of city use of resident money (Kocisky, 2016).

WTP varied across the choice experiments. In Melbourne and Sydney, Australia, mean WTP was as high as US$200/household/year for some GI (Brent et al., 2017), and in Alsace, France it was as low as $US11/household/year (Rulleau et al., 2017). A study on stream bank restoration from Baltimore, Maryland, USA reported mean WTP ranging from US$17 to US$75/household/year, depending on the type of streambank GI (Kenney et al., 2012), while households that had experienced basement flooding in Champaign-Urbana, Illinois, USA were willing to pay US$35/household/year (Londoño Cadavid and Ando, 2013).

The four contingent valuation studies also reported different WTP. On the higher end, a study from Flanders, Belgium reported mean WTP as an acceptable increase in water bills of US$55/year for a recurrent 20 year payment (Chen et al., 2017). The other three studies were on the lower end, from US$11.3/year for public spaces in Hong Kong, China (Chui and Ngai, 2016), to US$22.5/year to protect an urban forest in Kumasi, Ghana (Dumenu, 2013) to US$28–30/year for a recreational water park in Lombardy, Italy designed explicitly as GI (Reynaud et al., 2017).

3.5.2. Willingness to implement

We extracted information on willingness to implement or volunteer from 47 studies. There was overall a high willingness to implement different types of GI, e.g. 96% for sponge city construction in Shandong Province, China (Wang et al., 2017); 93% for permeable driveways in Kitchener, Canada (Cote and Wolfe, 2014); 89% for GI in residential buildings in Hong Kong, China (Chui and Ngai, 2016); and 69% for different types of GI in Ocotillo Anexo, Honduras (Milou, 2008). In one study from Michigan, USA, most respondents were even in favor of fines for not implementing GI (65%) and enforcement to implement GI (50%) over mechanisms such as regulation, zoning, information, voluntary programs, and subsidies (Kaplowitz and Lupi, 2012).

A few studies uncovered lower willingness to implement GI (Kati and Jari, 2016; Monaghan et al., 2016; Newburn and Alberini, 2016; Persaud et al., 2016; Varras et al., 2016). For example, Newburn and Alberini (2016) found that only 17% of respondents in Howard County, Maryland were willing to install a rain garden at their own expense, 43% were not willing even if offered a rebate, and 40% would do so with a rebate. Respondents felt uninformed and wanted more technical advice before making a decision (Newburn and Alberini, 2016).

3.5.3. Characteristics of those surveyed about the intention to implement GI

Thirty-three of the 55 studies that measured intentions also measured at least one characteristic of the people surveyed (Table 2). The most frequently mentioned variables were education, income, age, prior knowledge of the benefits of GI, and prior experiences with GI. Characteristics most often reported as having a positive, statistically significant relationship were higher income (Chui and Ngai, 2016; Cote and Wolfe, 2014; Derkzen et al., 2017; Dumenu, 2013; Kenney et al., 2012; Reynaud et al., 2017) and higher education (Brown et al., 2016; Chui and Ngai, 2016). Kenney et al. (2012) and Reynaud et al. (2017) both reported that living closer to public GI was correlated with higher WTP for GI in Baltimore and Lombardy, respectively. Some studies reported that older people were more likely to be willing to implement GI (Chen et al., 2017; Kocisky, 2016), whereas other studies found that younger people were more likely to do so (Carlet, 2015; Chui and Ngai, 2016; Reynaud et al., 2017).

3.6. Behavior relating GI use

3.6.1. Types of GI used and motivations

Twenty studies used primary data to understand behavior relating to GI for flood management, which we defined as installing or using GI, such as green roofs, rain gardens, rain barrels, permeable pavement, and use of public parks (Fig. 4). GI installation varied from 6% for green roofs in Chicago, Illinois (Hendricks and Calkins, 2006), 23% for rain gardens in Cincinnati, Ohio (Mayer et al., 2012), 24% for rain gardens, bioretention cells, or rain barrels in Cleveland, Ohio (Turner et al., 2016), 53% for re-directing downspouts to a garden in New Jersey and Virginia (Bakacs et al., 2013), and up to 74% for rain barrels in Indiana (Gao et al., 2016).

Most of these studies observed results of projects that encouraged the installation or use of GI. Four studies also reported on incentivized behavior, using reverse auctions, where householders were asked to place bids of the minimum amount they were willing to accept to have GI installed on their property, i.e. a subsidy payment to offset the opportunity cost of having the GI installed for free. A zero-dollar bid was understood to mean that the resident did not request any subsidy payment and would have accepted the rain garden for free. Out of 350 eligible properties in Cincinnati, 55% of respondents bid $0 for rain barrels (mean of $36.44) and 49% bid $0 for rain gardens (mean of $70.12), with the highest accepted bid being $250. A total of 83 (24%) rain gardens and 176 (50%) rain barrels were installed (Green et al., 2012; Mayer et al., 2012). Authors concluded that the incentive of the rain garden or rain barrel itself was sufficient for many residents but was more effective when combined with a bid amount. They also recommended an "education and survey campaign" to better understand residents' awareness and willingness to implement GI (Mayer et al., 2012). Results were less promising in the other reverse auction study in Victoria, Australia, where 41% of 740 households invited into the auction submitted expressions of interest and of those, only 14% submitted full bids to install rain gardens (Brown et al., 2016; Fletcher et al., 2011).

A study from Cincinnati reported a social capital effect, i.e. that people living within five homes of someone with GI were more likely have GI installed on their property (Green et al., 2012). Other reasons or motivations for using GI such as rain barrels were for water conservation, improving water quality, and gardening (e.g. Bakacs et al., 2013; Gao et al., 2016; Green et al., 2012). Installing GI for managing stormwater runoff or flooding only appeared in two studies (Carlson et al., 2015; Martin et al., 2007). Installation and maintenance costs were often reported as the main barriers (Carlson et al., 2015; Gao et al., 2016). As one respondent in a study from Victoria, Australia noted: "We like all that stuff and I mean we try to be pretty green but at the end of the day the economics for us is the bottom line" (Brown et al., 2016).

3.6.2. Characteristics of those surveyed about GI use

Eight of 20 studies on behavior characterized those who were surveyed based on variables such as age, gender, income, home ownership, and prior knowledge of the benefits of GI (Table 2). Age was only analyzed in two studies on use of natural areas, where younger and older age groups were reported to use parks more than middle-aged respondents (Wright Wendel, 2011). Gender was not significant in predicting behavior except in one study, where women were more likely to install rain barrels (Gao et al., 2016). Higher income was associated with a modest 1% increase in participation in GI programs, as was being white (Lim, 2017). Home ownership was also a clear predictor of GI behavior in two studies (Gao et al., 2016; Lim, 2017). Finally, prior knowledge was found to significantly increase the likelihood of installing rain barrels (Gao et al., 2016) and practicing certain stormwater management practices (Brehm et al., 2013).

4. Discussion

Through a systematic literature review, we analyzed 85 studies on knowledge, attitudes, intentions, and behavior relating to GI for flood management. To our first objective, we found that overall knowledge and awareness of GI was low; a wide range of attitudes on GI were measured; willingness to implement or pay for GI varied considerably; and only a few studies measured and documented behavior relating to GI. To our second objective, we summarized all measured demographic, socioeconomic, or geographic characteristics that could be tied to individuals' knowledge, attitudes, intentions or behavior across the studies. We found that few studies systematically assessed the role of characteristics such as age, income, home ownership, race, distance to GI, and stewardship behavior that could explain results and shape evidence-based programs. Taken together, these findings offer a baseline understanding of knowledge, attitudes, intentions and behavior relating to GI. They also highlight key research gaps that can help inform equitable, inclusive, and sustainable uptake and impact of GI for flood management.

4.1. More systematic data collection is needed in each of the four domains

4.1.1. Knowledge

Awareness of the different types of GI was low across the 29 studies; this may be partially explained by the fact that there are a multitude of terms used for GI and there is also no consistent definition of GI. In other words, it is hard to gauge people's awareness about a nebulous concept. However, rather than trying to develop narrower definitions, it may be more beneficial to ascertain broader public knowledge about nature-based solutions and their multiple functions and co-benefits to design appropriate information or awareness-generation campaigns. Data must be collected systematically, however, and ideally with disaggregated information. For example, only six studies attempted to disaggregate knowledge or awareness-based findings based on characteristics such as home ownership, education, and income level; such data would yield valuable information on how to target awareness campaigns designed to influence attitudes towards GI.

4.1.2. Attitudes

The many values associated with GI present a starting point to be considered in future work (Fig. 5). It is important to note that the frequency described in Fig. 5 is not an indicator of what was most or least valued because the same values were not consistently presented as options to participants across studies, and these values may vary based on context. For example, some communities might value native planting as a form of cultural capital, while others may view it as unpleasant and unkempt. While functional or aesthetic values were measured most often in these studies, concepts such as attitudes about conservation, experiences with flooding, and the cultural value of nature emerged as less frequent but important measures to gauge attitudes about GI. Furthermore, while there is a burgeoning literature on the relationship between nature and health (Houghton and Castillo-Salgado, 2017; Kabisch et al., 2017; Lachowycz and Jones, 2011; Twohig-Bennett and Jones, 2018; Tzoulas et al., 2007), it is notable that our review did not identify any studies that assessed people's attitudes about the health value of GI for flood management. This supports findings from a previous review of health and well-being impacts of GI for flood management, and indicates a need to examine GI as a potential intervention to improve community and public health (Venkataramanan et al., 2019). Future research, disaggregated by participant characteristics, should explore a broader set of values beginning with—but not limited to—the list we have compiled (Fig. 5), so that findings can be generalized to wider populations (Scholte et al., 2015).

4.1.3. Intentions and behavior

The differences in willingness to implement or pay for GI across 10 econometric and 45 descriptive studies may relate to poor understanding of GI and its benefits, as well as lack of trust in institutions. This was not particularly surprising given the relatively low awareness and knowledge about GI, which likely shapes people's attitudes, and can subsequently influence intentionality and behavior. Although almost all studies were from high-income countries, the wide range in WTP may also be due to country-specific or regional differences in income and/or expectations of state contributions to services.

Although 35 studies did measure at least one demographic characteristic of the samples they surveyed (e.g. age and education), few studies explored the role that characteristics such as prior knowledge and other attitudes towards GI and conservation played in shaping WTP or implementation of GI. As with knowledge and attitude-based studies, disaggregating data on intentions would vastly improve our understanding of GI and shape evidence-based implementation. For example, a meta-analysis of contingent valuation studies on open urban space found “important regional differences in preferences” and concluded that “the potential for transferring estimated values between regions is likely to be limited” (Brander and Koetse, 2011).

It is important to consider, however, that willingness to pay or implement are hypothetical measures of a person's stated preference. As a result, some consider these to be less reliable indicators of people's actual behavior or “revealed preference” (Matsler, 2017). Others consider these techniques as valuable to estimate environmental changes that cannot be observed in real data, provided they use rigorous stated preference methods such as contingent valuation and choice experiments (Londoño Cadavid and Ando, 2013). Only four contingent valuation studies and six choice experiments were found through this review, indicating an opportunity for further systematic research to fill gaps in the behavior change framework we propose.

4.2. A more holistic, context-specific, behavior change framework is needed for GI

To be able to gather data more systematically across these four domains and disaggregate them by participant characteristics, we suggest that social science research on GI must be vastly expanded into different settings and with under-represented communities. Not only did we identify a widespread geographic bias in GI projects in the literature (Fig. 3), but also an enormous gap in representation of different communities. Several studies reported higher income as a key factor in greater GI use (Brehm et al., 2013; Newburn and Alberini, 2016), but few studies were able to incorporate representative sampling of different demographics (e.g. at the city scale). Residents in wealthier, privileged communities often have the resources to cope with flooding and the ability to recover more easily than their counterparts. On the other hand, low-income or historically under-served communities in the same cities may be located in areas where there is a higher flood risk and where gray infrastructure tends to be more degraded (Dunn, 2010; Miller, 2014). They typically lack the resources or political power to demand improvements from the state. As such, access and equity remain important and underexplored areas with regard to GI (Brink et al., 2016; Heckert and Rosan, 2016).

The context-specific nature of GI also necessitates the need to document more examples and data on knowledge, attitudes, intentions, and behavior from a variety of contexts and scales to be able to broadly apply lessons learned to GI design, implementation, and incentive programs (Baptiste et al., 2015; Drake et al., 2013; Thurston et al., 2010). Such an approach will help a) highlight multiple perspectives; b) identify missing links between knowledge, attitudes, intentions and behavior; and c) tailor GI communication and advocacy strategies.

4.2.1. Importance of highlighting multiple perspectives

First, the importance of multiple perspectives was rarely mentioned in studies in our review; only a few specifically compared experiences of different communities within their study sites. For example, Crimian (2013) found that community responses to creek restoration projects varied depending on the community context; the higher income and predominantly white community on the north side of the creek saw access as a means of improvement that would instill more ownership in community members, whereas the southern residents (predominantly low income and racially diverse) felt that their primary concerns with the creek were economic development, safety through recognition of community members, and neglected community investment from public agencies. This variation in perceived benefits of natural land cover by socioeconomic status and community assets has also been echoed in other studies (Bradley et al., 2018; Williams, 2012), and can impact the success of GI programs.

4.2.2. Importance of identifying missing links between knowledge, attitudes, intentions and behavior

Second, through direct engagement with communities, implementers and researchers can better piece together the links between knowledge, attitudes, intentions, and behavior for specific GI projects. This approach can help ensure that GI projects are informed by available evidence, and that results are sustained by increasing community trust and ownership (two attitude-related challenges identified in our review). Clarkwest (2012) observed that community engagement in the stormwater management design process instilled a sense of ownership not only in the project design but also in the maintenance of drainage systems.

For example, to address the concern of maintenance responsibility, it would be important to understand whether a community does not partake due to knowledge gaps, lack of a sense of ownership, or other resource constraints. While knowledge gaps may again be addressed through targeted campaigns, community-centered approaches can help other challenges. One such approach of community engagement is asset-based community development, which involves identifying and engaging local community assets (people, institutions, etc.) in an intentional and community-driven manner (Kretzmann et al., 2005). Such approaches allow implementers and researchers to work together to understand the breadth of resources available in the community that can be leveraged to identify solutions jointly. In the case of GI projects, for example, contracts could target local engineers or organizations in the community, including responsibility for routine maintenance. Rather than introducing GI to a community, the perspective would shift to co-creating GI in the community, increasing a sense of ownership and willingness to implement and maintain the GI (Dolowitz et al., 2012; Simons, 2017). In this manner, inclusive and representative engagement used to gather systematic data in partnership with communities can lead to truly sustainable GI programs (Green et al., 2012; Loos and Rogers, 2016).

4.2.3. Using evidence to tailoring GI communication and advocacy strategies

Lastly, borrowing the concept of "issue framing" from the policy implementation literature, context-specific factors on knowledge, attitudes, intentions, and behavior must be taken into consideration when formulating external cues such as GI promotion messaging and policy initiatives (Kingdon, 2003). For example, participatory research can be conducted with communities to better understand why they prefer manicured landscapes over native plants, or why they are concerned about the maintenance responsibility for GI. Gathering such information on knowledge and attitudes in the initial stages of a GI project can help tailor education and communication campaigns on the services that native plants provide for flood management. If the challenge is that people are not aware of the benefits of native plants, targeted awareness campaigns (through community meetings, fliers, etc.) can help disseminate appropriate information to shape attitudes and intentions. If, despite knowing about the benefits of native plants, people prefer to have manicured landscapes at the risk of flooding, it may be beneficial to first target communities or neighborhoods that are more willing, and leverage social networks and social capital to modify attitudes in more resistant communities (Green et al., 2012). Therefore, systematic social science research on GI can build an evidence base and improve program outcomes.

4.3. Limitations

There are several limitations inherent to literature reviews. Given the many definitions of GI, it is possible that we have not captured every relevant study. It is also possible that we encountered some publication bias as we did not identify many non-English studies or those from a broader geographic range, but other reviews have also found that most empirical studies have been conducted in the United States (Wang et al., 2014). By incorporating different study designs, we summarized findings from survey-based (close-ended questions with specific options) and interview-based (open-ended) research; while this results in a more comprehensive assessment of the literature, frequencies of knowledge scores, types of attitudes, and willingness to pay measures mentioned in this review should be viewed as illustrative and not as meta-analytic data.

5. Conclusion

Guaranteeing the technical efficacy of the GI system alone will not be sufficient for its widespread uptake; it is imperative to prioritize the social dimensions of the social-ecological-technical system as well (Eakin et al., 2017; Thorne et al., 2018). Results from this systematic review indicate that there is a wide range in knowledge, attitudes, intentions, and behavior relating to GI (Fig. 4), which likely vary depending on a variety of individual and community characteristics (e.g. Table 2). Research guided by a conceptual framework that links knowledge, attitudes, intentions and behavior and its covariates (e.g. Fig. 1) can help achieve widespread adoption of GI for flood management that is equitable, inclusive, and sustainable.

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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 data

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