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RESEARCH ARTICLE

Managing the risks of stormwater through rainwater harvesting systems and rain gardens: A global perspective

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Abstract

This study investigates the sustainable role of rainwater harvesting (RWH) systems and rain gardens (RG) in stormwater management based on worldwide perspectives by using both quantitative and qualitative data. The research relied on a questionnaire-based survey. Domain experts on water management from 38 different countries with different levels of annual precipitation rates and income (GDP per capita), contributed to the survey. Statistical analysis, including reliability analysis, normality test, and, Kruskal–Wallis test were performed for the quantitative data. The qualitative part of the survey was analysed through content analysis software, QDA Miner Late v3.0. The study showed that rainwater harvesting technologies and rain gardens are not adequately valued for mitigating stormwater risks, although proper implementation of RWH technologies and optimum use of RG promise several contributions, such as better water infiltration into the soil, decreased groundwater contamination, increased vegetation, proper level of soil moisture and hindered surface runoff. It was also observed that countries' annual precipitation rates and income levels directly impact higher awareness and current sustainable implementations. However, the perception of the flood as a crucial danger was determined as highest in countries with moderate annual precipitation rates. The importance of public engagement through policy-makers and local authorities was highlighted by promoting Nature-based solutions, pilot projects, incentives, and altering design criteria on newly constructed buildings to boost the use of RWH technologies and RG as a cheaper, accessible, and sustainable solution for stormwater management.

1. Introduction

The main goal of stormwater (SW) management is controlling the surface runoff to reduce water pollution and restore ecosystem integrity [1]. Such systems play important role on avoiding or mitigating storm water impacts, decreasing infrastructure demand, filtering pollutants on site, reducing urban heat island effect and temperature, increasing humidity and infiltration, improving soil properties, raising groundwater recharge, decreasing runoff and air pollution, providing alternative resource for drinking water and many other facilities [2, 3, 4]. Among rainwater management systems, rain harvesting systems (RWH) and rain gardens (RG) offer promising solutions for sustainable flood retention measures and the reuse of rainwater.

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RHW simply involves the process of collecting and storing rainwater for later use [5, 6]. These systems offer a source of supplemental water supply to meet increasing urban demand, especially for the areas suffering from inadequate water supplies, lack of water resources, and for particular circumstances, including under semi-arid conditions and on small islands [7, 8, 9]. Rainwater harvesting is also crucial on harnessing the production potential within dryland systems [10].

RGs or bioretention systems, which function as an effective device for on-site runoff volume reduction and stormwater quality enhancement and use natural processes of the hydrological cycle such as infiltration and evapotranspiration, are the best storm water management practices [11, 12]. Such gardens are of great importance in reducing rainwater volume and flow, preventing asset's destruction, removing pollutants from urban runoff, supplementing water supplies for various purposes, including drinking, sanitation and irrigation, providing an aesthetic contribution to urban areas and enriching groundwater recharge [13, 14, 15]. Rain gardens are valued in many countries with different projects and campaigns. One of the prominent campaigns is 'The 10,000 Raingardens for Scotland campaign', which was launched in 2014 to promote and encourage the use of rain gardens as a sustainable and natural way to manage water, particularly in urban areas [16]. Washington State University and Stewardship Partners [17] (2023) are leading a ground-breaking campaign to install 12,000 RGs in the Seattle/Puget Sound Region, in order to soak up 160 million gallons of polluted runoff to protect waterways and help to stop the stormwater crisis. More than 6,000 rain gardens were built within the campaign up to now. Melbourne Water [18] in Australia work with councils and the community to build public RGs in streets, parks and schools.

Although growing concerns over the impacts of climate change and socio-environmental issues are forcing countries and cities to rethink conventional urban water management practices, the change towards more sustainable practices has been remarkably slow [19]. In this line, this study aims to discuss the sustainable and alternative role of RWH and RG in stormwater management and determine strategies to promote these implementations.

2. Literature Review

There are several studies, which highlight the importance of RWH and RGs. According to the survey of Domènech et al. [4] on determining the performance of rainwater harvesting systems, the importance of operation and maintenance, technical design and construction, awareness, market for spare parts, and the ability of vulnerable households to maintain the system was highlighted, in addition to observation of good quality water in general. Studies mainly focused on the potential benefits and optimum ways to obtain better efficiency and different aspects. Ali et al. [20] emphasized the importance of bioretention technology for controlling SW quality. Biswal et al. [21] addressed the effect of bioretention on the management of high runoff volumes and the reduction of nitrogen pollutants through various mechanisms. Liang et al. [22] highlighted the importance of the photocatalytic effect method using Nano-titanium dioxide for removing various pollutants from runoff water. Zhang et al. [23] pointed out restrictive issues in urban development due to a lack of expertise regarding the technical capacity of rain garden facilities. Osheen and Singh [24] recommended a shallow excavated flat profile as the most suitable profile for a rain garden's optimal hydrologic performance, as a result of their laboratory experiments on three rain gardens with different slope profiles. Mwamila et al. [25] addressed the possibility of improving the performance of the RWH system through monitoring water levels and adhering to demand guidelines, regarding RGs or bioretention systems.

3. Research Design and Methodology

This is exploratory research aimed at assessing current stormwater management systems and the sustainable and alternative role of RWH and RG for stormwater management. The research questions are as follows:

1) How is the current situation of stormwater management,

2) How is the awareness level towards RWH and RG,

3)What are future prospects regarding RWH and RG,

4) How is cost assessment of the current stormwater management systems and RWH &RG,

5) What are the ways to enhance systems for removal, collection, and reuse of RW and potential sustainable practices,

6) What are the ways to improve and spread RG and RWH systems?

To answer these questions, first, a literature review was conducted. Then, a questionnaire was designed and administered to domain experts to understand current stormwater management systems and the future role of RWH and RG by considering awareness level, cost assessment, and improvement ways. A detailed flowchart of the study is shown in Fig. 1.

3.1. Questionnaire design

The questionnaire had two parts. The first part had 26 questions on a 5-point Likert Scale (1=Very Low, 2=Low, 3=Moderate, 4=High, 5=Very High) where respondents were expected to answer questions which were categorized into 4 clusters: 1) Current Situation (CS), 2) Awareness Level (AL), 3) Future Prospects (FP), 4) Cost Assessment (CA). The second part had 2 open-ended questions about improvement Strategies (IS). The quantitative and qualitative parts of the study were analyzed through statistical methods and content analysis, respectively. The target population was water management experts working in different fields, such as academia, water resources institutions, private companies, consultancy firms, etc. from all over the world.

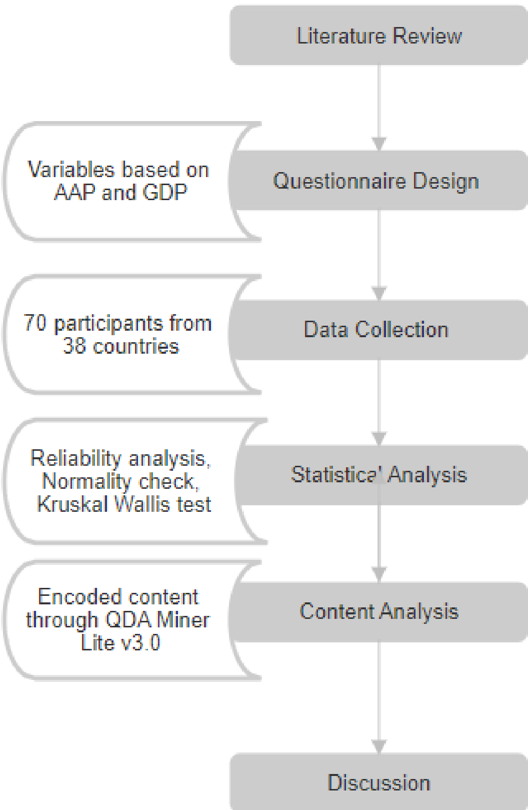

Fig. 1. Flowchart of the study

A random sampling method was adopted in choosing respondents [26] to ensure an equal possibility of being selected for both parts of the survey. A total of 70 international respondents from 38 different countries took part in the survey. The respondents' countries were divided into different categories, as seen in Table 1 according to variables explained as follows:

1. variable) Countries of respondents were categorized into three groups as countries with high, moderate or low average annual precipitation (AAP) (mm in depth),

2. variable) Countries of respondents were categorized into three groups as countries with high, moderate or low gross domestic product per capita (GDP per capita) (current US$),

3. variable) In order to determine how the level of AAP and GDP per capita affect countries with similar levels separately, the countries were categorized as indicated in Table 1,

4. variable) Type of regions where respondents live were categorized into three groups as rural, urban-mostly separate buildings or urban- mostly mass housing. The average AAP and GDP per capita of countries were taken from the World Bank data [27, 28].

Table 1. Countries of participants based on AAP and GDP

Characteristics	Category		N	(%)
Average Annual Precipitation (mm in depth) (AAP)	Low (AAP<500)		16	22.86%
	Moderate (10000 ≥ AAP ≥500)		30	42.86%
	High (AAP >1000)		24	34.29%
		Total	70	100.00%
Gross Domestic Product per capita (current US$) (GDP per capita)	Low (GDP per capita <15k)		21	30.00%
	Moderate (30k ≥ GDP per capita ≥15k)		22	31.43%
	High (GDP per capita >30k)		27	38.57%
		Total	70	100.00%
AAP (mm in depth) and GDP per capita (current US$)				
Countries	AAP	GDP per capita		
Afghanistan, Azerbaijan, Russia, Syria	Low	Low	5	7.14%
Saudi Arabia, Kuwait	Low	Moderate	5	7.14%
Qatar, United Arab Emirates	Low	High	6	8.57%
Bulgaria, Lebonon,Serbia, Tajikistan, Turkey	Moderate	Low	9	12.86%
Czech Republic, Hungary, Lithuania, Poland, Portugal, Spain	Moderate	Moderate	10	14.29%
Belgium, Canada, Germany, Italy, Netherlands, USA	Moderate	High	11	15.71%
Bosnia Herzegovina, Brazil, Croatia, India, Nigeria, Paraguay	High	Low	7	10.00%
Slovenia, Uruguay	High	Moderate	7	10.00%
Iceland, Norway, Scotland, Switzerland, UK	High	High	10	14.29%
		Total	70	100.00%

3.2. Statistical tests and content analysis

Statistical analysis was performed for responses of the first part attributed to categories CS, AL, FP and CA, which included 26 questions based on the Likert-scale to determine meaningful relationships between different parameters. First, a reliability analysis was conducted to determine internal consistency by evaluating Cronbach's alpha values. While an alpha value of 0.7 is considered acceptable, values of 0.8 (good) and 0.9 (excellent) are preferred [29]. The study yielded an alpha values of 0.85 which confirm the internal consistency. Then, a normality check was performed through the Kolmogorov–Smirnov normality test, which gave p values less than 0.05, meaning that the data were not normally distributed [30]. Therefore, a non-parametric test Kruskal-Wallis test was utilized [31], which is a strong and reliable method for data that is not normally distributed. Mean values were found and significant relationships were determined by calculating Assig. (p) values.

Content analysis was carried out to determine the highlights of the second part, which involved two open-ended questions attributed to the category of improvement strategies (IS): 1) Ways to enhance systems for removal, collection, and reuse of RW and potential sustainable practices, 2) Ways to improve and spread RG and RWH systems. Content analysis can be identified as a methodological framework within which various approaches of textual and non-textual analyses can be performed [32]. The data was analyzed and coded through QDA Miner Lite v3.0 software.

4. Research Findings

Only significant relationships (Assig. Sig. $p<0.005$) were taken into consideration based on the Kruskal Wallis test analysis. According to Table 2, which shows questions, categories, mean values of participants' responses and Kruskal Wallis test results, and Fig. 2 and Fig. 3, which display different relationships based on AAP and GDP as well as results of content analysis, the following findings were explained in Section 3.1-3.5.

4.1. Current situation

Although, the mean value of sustainable practices for SW removal (μ=3.06) and problems with SW removal (μ=2.84) were seen as moderate, implementation levels of RG and RWH were low with μ values 2.27 and 2.63 respectively. In parallel, availability of systems in individual buildings that collect and reuse rainwater (μ=2.029) and level of incentives on RG and RWH (μ=2.100) are inadequate worldwide. As seen on Table 2 as well as Fig. 2 and Fig. 3, there is a significant relationship between GDP/AAP level and projects for facilitating removal and reuse of SW (p=0.01). Among the countries with same AAP levels, countries with higher GDP have more projects. Similarly, the countries with higher AAP, implement more projects among countries with same GDP levels. There is also a significant relationship between GDP level and implementation level of RG. Countries with higher GDP have higher implementation level among countries with same AAP levels. Mean values for 'Sufficiency of workforce and staff for SW removal' are increasing with rising GDP level among countries with same AAP level (medium or high).

4.2. Awareness level

Global awareness toward flood issue, RWH, RG, reuse of rainwater is not low. The importance of the reuse of rainwater for sustainability and ecological systems (μ=3.771) has the highest mean value in this category. As seen on Fig. 3, the mean values for 'Flood as an important global problem' and 'Potential level for better use of rainwater' is lowest among countries with low AAP level. Income level also positively influences the level of knowledge about RG, incentives on RG and RWH implementations. In high-income countries, the workforce and staff for rainwater removal are considered more sufficient than countries with moderate and low GDP per capita. AAP also positively affects the implementation level of RG and new SW removal projects in countries with low GDP per capita.

Table 2. Countries, categories, mean values, Kruskal Wallis test results

	Countries	Afghanistan, Azerbaijan, Russia, Syria		Saudi Arabia, Kuwait		Qatar, United Emirates		Bulgaria, Lebonon, Serbia, Tajikistan, Turkey		Czech Republic, Hungary, Lithuania, Poland, Portugal, Spain		Belgium, Canada, Germany, Italy, Netherlands, USA		Bosnia Herzegovina, Brazil, Croatia, India, Nigeria, Paraguay		Slovenia, Uruguay		Iceland, Norway, Scotland, Switzerland, UK				Kruskal Wallis
	N	5		5		6		9		10		11		7		7		10		70		Asymp. sig.
	AAP (mm in depth)	Low		Low		Low		Medium		Medium		Medium		High		High		High		Total		p-value
	GDP per capita (current US$)	Low		Medium		High		Low		Medium		High		Low		Medium		High				
Current Situation (CS)		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	
CS1	Problems with removal of SW	2,80	0,84	2,80	0,84	2,83	0,41	2,56	0,88	3,00	0,67	2,73	1,42	3,43	0,98	2,71	0,95	3,00	1,25	2,87	0,98	0.851
CS2	Projects for removal and reuse of SW	1,00	0,00	2,20	1,30	3,00	1,41	1,78	0,83	3,20	0,79	3,55	1,04	2,14	0,69	2,71	1,50	3,10	1,20	2,66	1,24	0.001*
CS3	Implementation level of RG	1,60	0,89	2,00	1,41	2,33	1,37	1,44	0,53	2,40	0,97	2,91	1,38	1,43	0,53	2,86	1,35	2,80	1,23	2,27	1,20	0.035*
CS4	Implementation level of RWH	2,00	1,22	2,40	1,95	2,50	1,64	1,78	0,83	3,00	0,94	3,36	1,29	2,57	0,98	2,71	1,38	2,70	1,25	2,63	1,28	0.221
CS5	Experience with flood	3,20	1,10	3,40	1,52	1,67	1,21	2,67	1,00	3,00	1,05	2,73	1,56	3,00	1,29	3,14	0,69	2,90	1,52	2,84	1,26	0.493
CS6	Rainwater utilization systems for new buildings	3,20	1,79	2,40	1,52	2,83	1,47	1,78	1,30	2,90	0,99	3,18	0,75	2,14	1,46	2,43	0,98	2,80	1,14	2,64	1,24	0.164
CS7	Availability of sustainable RW systems	2,40	1,14	3,00	1,22	2,17	0,98	2,33	1,22	3,30	1,06	2,91	0,83	2,29	1,50	2,71	1,25	2,80	1,23	2,70	1,15	0.490

Table 2. Cont'd

CS8	RWH systems in individual buildings	1,40	0,89	2,80	1,64	1,83	1,17	1,44	0,73	1,90	1,45	2,64	1,29	1,86	1,46	2,43	1,62	1,90	1,29	2,03	1,31	0.452
CS9	Local authorities' attention to RG and RWH	1,80	0,84	3,20	2,05	2,83	1,47	2,56	1,13	2,80	1,32	3,09	1,30	2,57	0,98	2,57	1,27	3,30	1,64	2,80	1,34	0.750
CS 10	Incentives on RG and RWH	1,20	0,45	2,60	1,52	2,83	1,33	1,89	0,78	2,00	0,67	2,73	1,19	1,43	0,79	2,00	1,00	2,00	0,82	2,10	1,04	0.073
CS 11	Sufficiency of workforce for SW removal	3,40	1,14	2,40	0,89	3,50	1,38	1,44	0,53	2,10	0,74	3,09	1,04	2,00	0,82	2,86	1,07	2,50	1,27	2,53	1,14	0.004*
CS 12	Sustainable practices for SW removal	3,00	1,58	3,20	0,84	3,17	1,72	2,78	1,39	3,10	0,88	3,64	1,29	1,86	0,90	3,00	1,63	3,40	1,07	3,06	1,28	0.317
Awareness Level (AL)																						
AL1	Knowledge level about RG	2,40	1,14	2,80	1,30	3,33	1,63	2,44	1,24	3,20	1,23	3,73	1,19	3,14	1,57	4,00	1,00	4,10	1,10	3,31	1,32	0.085
AL2	Knowledge level about RWH	2,60	1,34	3,20	1,30	2,83	1,83	2,78	1,56	3,60	1,35	3,91	1,04	3,86	1,46	3,43	1,51	4,20	1,23	3,47	1,41	0.292
AL3	Importance of reuse of rainwater	2,80	1,30	3,60	1,52	3,83	1,17	3,11	1,36	4,30	0,82	4,45	0,82	3,57	1,62	3,86	1,21	3,70	1,49	3,77	1,28	0.235
AL4	Individual idea/attempt for better reuse RW	2,60	1,34	4,00	0,00	2,50	1,38	3,11	1,36	3,40	1,35	3,55	1,13	3,29	1,50	2,86	1,35	3,40	1,26	3,59	3,16	1.270
AL5	Flood as an important global problem	2,20	1,10	2,80	1,48	1,83	0,98	3,44	1,01	3,40	1,07	4,00	1,10	3,57	1,13	3,57	0,79	4,30	1,06	3,40	1,24	0.006*

Table 2. Cont'd

Future Prospects (FP)																						
FP1	Future plans for RG projects	1,40	0,89	3,00	1,00	2,67	1,63	1,78	0,67	2,50	1,43	3,00	1,18	2,14	1,07	2,43	1,51	3,10	1,52	2,50	1,30	0.146
FP2	Future plans for RWH projects	3,00	1,41	2,80	1,30	2,50	1,64	1,78	0,83	2,90	1,29	3,36	1,29	2,14	1,07	2,57	1,40	3,20	1,32	2,73	1,31	0.214
FP3	Potential level for making more active use of RW	2,40	1,67	3,60	0,55	2,83	1,33	3,56	1,01	4,50	0,85	4,73	0,47	3,43	1,62	4,57	0,79	4,00	1,41	3,89	1,27	0.008*
FP4	Level of flood threat	2,80	1,48	3,60	1,34	2,17	1,17	2,89	1,45	3,60	0,84	3,73	0,79	3,43	1,40	3,57	0,79	3,50	1,43	3,31	1,21	0.325
FP5	Water shortage in the future	2,40	1,14	3,80	0,84	3,33	1,63	2,44	1,13	3,60	1,26	2,64	1,21	2,71	1,25	2,43	0,79	2,70	1,49	2,87	1,26	0.278
FP6	Reuse of rainwater in agricultural areas	2,60	1,14	3,40	1,52	3,83	1,17	3,89	1,27	3,40	1,35	3,18	0,87	3,71	1,11	3,43	1,51	2,70	1,34	3,34	1,25	0.452
FP7	Rainwater as an alternative water source	3,00	1,00	3,60		2,83	1,83	3,67	1,12	4,10	0,99	3,73	1,27	3,86	1,21	4,14	0,90	4,10	1,29	3,74	1,24	0.580
Cost Assessment (CA)																						
CA1	Cost of RWH systems considering the benefit-to-harm ratio	1,80	0,84	2,80	0,84	2,17	1,17	2,44	0,88	2,70	0,95	2,55	1,04	2,86	1,46	2,86	1,21	2,10	1,10	2,49	1,06	0.585

Table 2. Cont'd

CA2	Repair maintenance cost for existing rainwater drainage and collection systems	3,00	1,58	2,80	1,30	2,33	1,51	2,67	1,58	3,00	0,82	2,82	0,87	2,00	0,82	3,14	1,07	3,20	1,48	2,80	1,21	0.565

*significant difference for p>0.05; μ= mean; ; σ = standard deviasion

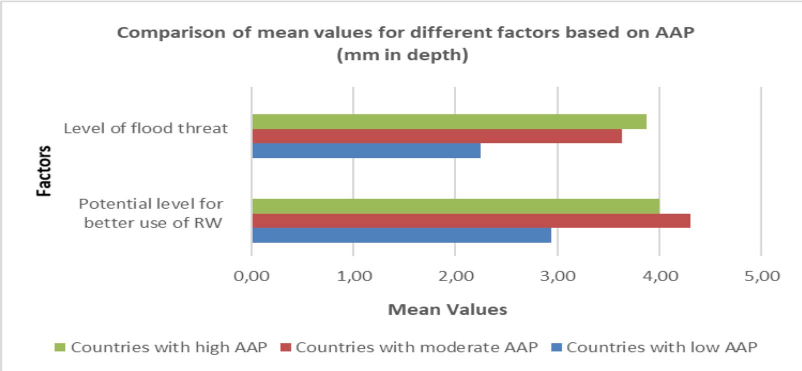

Fig. 2. Statistical analysis for different AAP levels

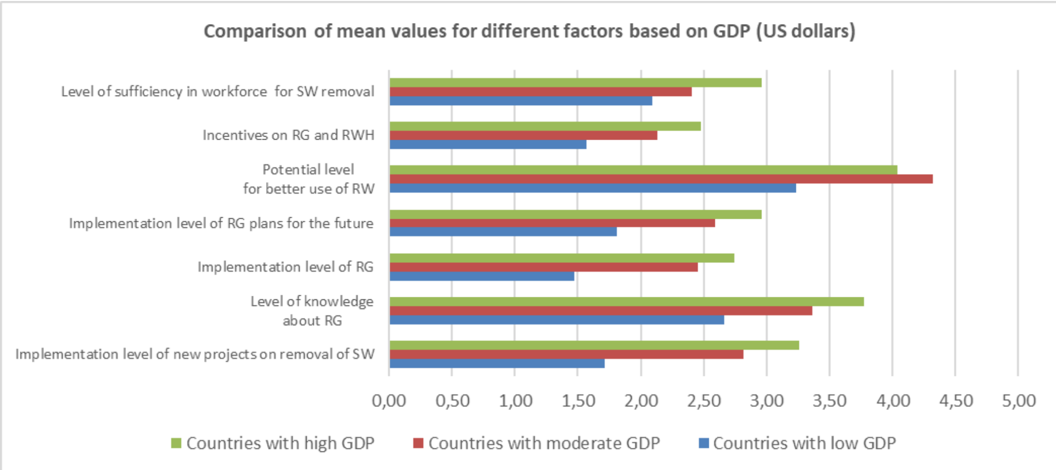

Fig. 3. Statistical analysis for different GDP levels

4.3. Future prospects

Potential level for better use of rainwater placed the 1st rank (μ=3.886). The potential level of making more active use of rainwater is highest in countries with moderate AAP or GDP. Implementation level of RWH (μ=2.729 and RG (μ=2.500) plans for the future is not high worldwide. Future plans for RG is rising up with increasing GDP level. Fig. 2 shows that AAP has direct influence on consideration of flood as a crucial danger. Flood is seen as a more threatening risk in countries with higher AAP. It is also perceived as a more foreboding risk in countries with higher GDP per capita with same AAP levels. Threat level of flood and potential level of more rainwater utilization are highest in countries with moderate AAP. On the other hand, the level of sufficiency in workforce and staff for SW removal is the lowest in such countries.

4.4. Cost assessment

Mean value for repair-maintenance cost for existing rainwater drainage and collection systems (μ=2.800) is higher than the mean value for cost of RWH systems considering the benefit-to-harm ratio (μ=2.486). A meaningful relationship between type of region where respondents live and level of repair-maintenance costs for existing SW removal systems. Table 1 shows that level of such costs is the lowest in urban mass housing projects (μ=2.35) and is the highest in rural regions (μ=3.73).

4.5. Improvement strategies

This part is analysed through content analysis. The responses to these ended questions were coded under three categories (Legislation, Local Authorities and Public Policies) through QDA Miner Lite v3.0 software. Then, the frequency of codes were calculated. The higher percentage of words is the more significant data is. Fig. 4 and Fig. 5 show the categories, codes and percentage of words (PoW), which were expressed by the respondents regarding IS1 and IS2, respectively. Giving importance to Nature-based solutions (PoW=%28) as well as technology based solutions to improve RWH systems (PoW=%13) are leading codes regarding public policies enhance systems for removal, collection and reuse of RW and potential sustainable practices (IS1). Altering design criteria for newly constructed buildings (PoW=%22) attributed to legislation category has been considerably valued by the respondents in order to enhance systems for removal, collection and reuse of RW and potential sustainable practices. Pilot projects (PoW=%7) were considered as the most important part of the local authorities' strategies. Enhancing knowledge and capacity building (PoW=%22) as well as incentives (PoW=%8) were highlighted by the respondents as prominent public policies in order to improve and spread RG and RWH systems (IS2). Among legislative actions, altering design criteria for newly constructed buildings (PoW=%17) placed first rank. The importance of pilot projects (PoW=%8) were emphasized attributed to the category of local authorities.

5. Discussions

The findings of quantitative data clearly showed that although reuse of rainwater has been considerably valued and there is considerable global awareness toward reuse of rainwater as well as RWH and RG, current implementation level and future plans of ecological practices based on RWH and RG projects, are insufficient. Enhancing knowledge and capacity building through public engagement is very important in the transition towards sustainable water management [33]. While RWH promises several benefits for more active use of rainwater, RG has potential to affect the community about the importance of green infrastructure and engineering behind the design [34].

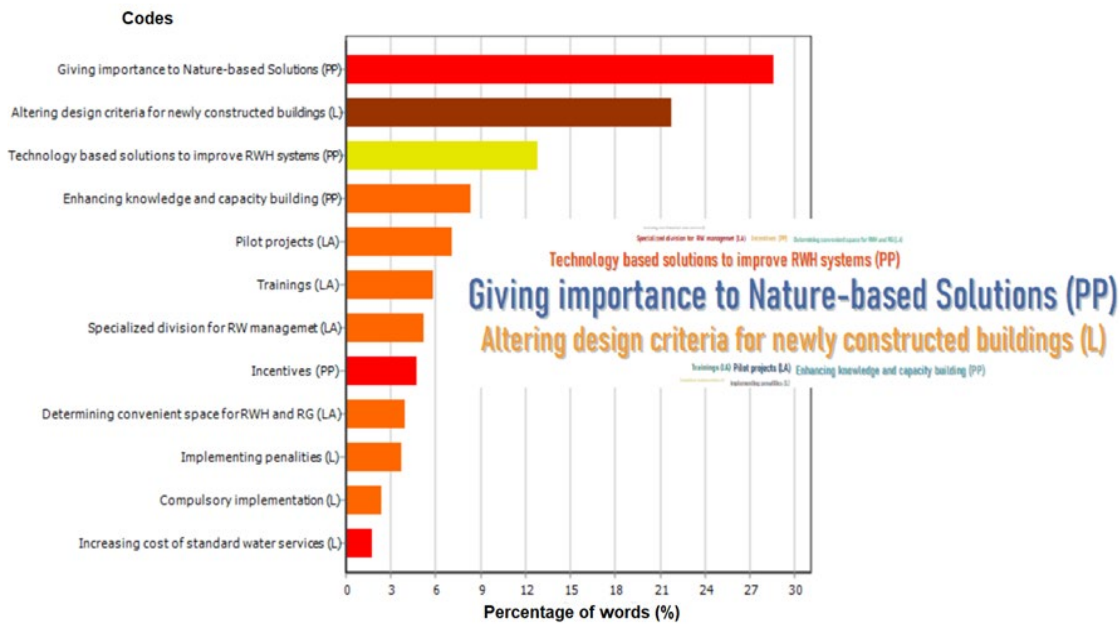

Fig. 4. Content analysis-IS1: Ways to enhance systems for removal,collection and reuse of RW

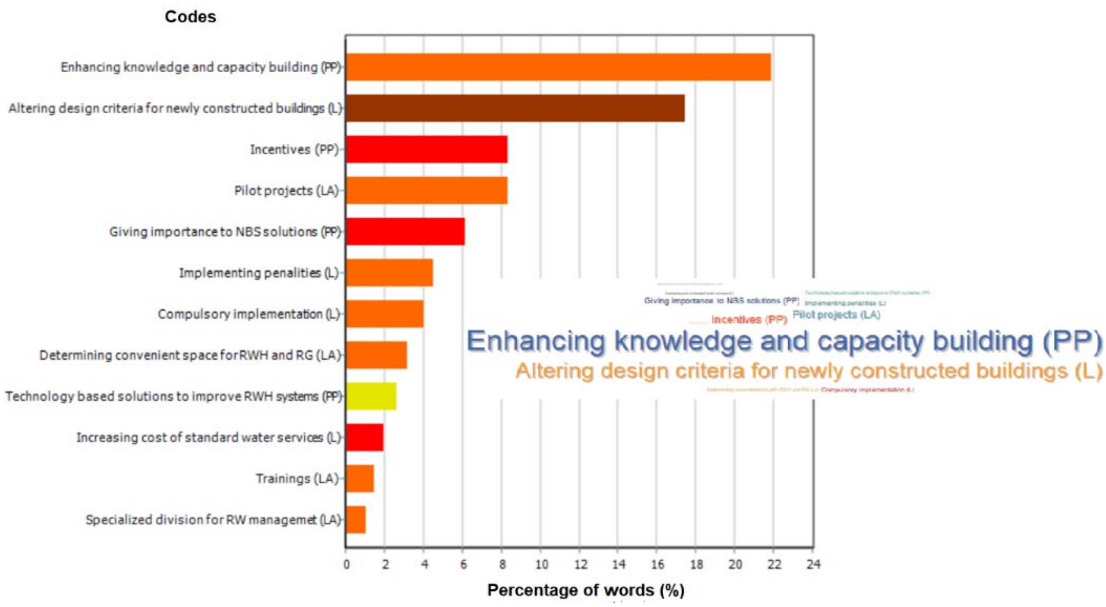

Fig. 5. Content analysis for IS2: Ways to improve and spread RG and RWH systems

Although rain gardens are an established element of water sensitive urban infrastructure, information on people's preferences for such systems is insufficient [35]. Introducing and promoting the real benefits of Nature- based solutions (NBS) and ways for enhancing capacity building at policy making level are of great importance for increasing implementation level of such systems. Therefore, seminars, webinars, conferences, and other supportive events should be widely organized. Incentives and supports also play a crucial role in inspiring people and local authorities toward such implementations. Local authorities' pilot projects are critical to pioneering NBS. Technology based solutions and proper design to improve RWH systems as well as altering design criteria for newly constructed buildings is also essential for ensuring low-cost, environmental friendly, separate SW collection and sewage removal and widespread use of RWH and RG. RWH promises mitigating the adverse effects of climate change and increasing crop production, but reliable, efficient and feasible systems can be ensured through proper design and implementation [36]. Rain gardens have numerous benefits, but the level of their optimality in urban development is unknown due to lack of expertise regarding the technical capacity of such facilities [23]. Similarly, optimal usage is not known for RWH. Therefore, new technical guidelines should be published, and introductory events should be organized. Rainwater harvesting systems are very effective in buildings with a large roof area; thus, the implementation of such systems in mass housing projects, public areas and similar buildings are reasonable. Green roof should also be encouraged. Green roofs, which act as a sponge, hold, filter and release rainwater to the collection systems during the rainfall [37]. This is vital for decreasing runoff SW. In order to optimize costs, rainwater harvesting systems should be planned according to location requirements. RWH and RG decrease surface runoff considerably. Therefore, if widespread use of such systems is achieved, design requirements of stormwater collection systems could be fewer, providing cost benefits. For example, pipelines with fewer diameters would be sufficient. AAP and GDP have direct influence on awareness and applying sustainable practices with sufficient workforce. Tendency to adopt these systems and implementing projects for facilitating SW is increasing with either rising annual precipitation rates among countries with similar income levels or income level among countries with similar annual precipitation rates. Perception of flood as a threating danger may be expected to be the highest in countries with highest AAP rate. But, the study showed that this perception is highest in countries with moderate AAP. This can be explained by the fact that countries which are exposed to heavy rainfalls get used to live with the reality of flood danger and they constructed their infrastructure and took measures against flood risk. Due to precipitation extremes in recent years, countries with moderate AAP may show vulnerabilities to handle heavy rainfalls due to infrastructural deficiencies and lack of enough workforce. Similarly potential reuse capability of rainwater is also more valued in countries with moderate AAP compared to ones with high or low AAP. In countries which receive large volume of rainfall, water scarcity is generally not a problem. Therefore, reuse of rainfall is not a concern of policy makers. On the other hand, reuse of rainwater is not much considered in countries which lack enough rainfall.

Considering cost assessment of current SW management systems, the study indicated that repair-maintenance cost for existing rainwater drainage and collection systems (μ=2.800) is higher than the cost of RWH systems considering the benefit-to-harm ratio (μ=2.486). In the literature, several studies mentioned that RWH systems are cost effective. Tanik [38] and Bashar [39] argued that RWH are cost effective in terms of investment, operation costs and payback periods. In rural regions cost of existing systems may be high due to high costs of logistics and supply problems. Rainwater harvesting (RWH) is generally perceived as a valuable and cost-effective alternative water resource for potable and non-potable uses and also often utilized in a hybrid system supplementing tap water as well as for reducing flood risks [40, 41].

Major changes are necessary for existing stormwater management systems to control floods in urban landscapes, protect natural ecosystems, and mitigate infrastructural destruction of stormwater hazards [42]. Traditional stormwater management may lead to long term environmental concerns, thus, Water Sensitive Urban Design (WSUD) can offer more sustainable solutions [43]. Implementing RWH, systems with optimal design offer climate resilient stormwater management with decreased costs. Rainwater harvesting not only increases water supply, but also reduce stormwater pollutant discharges [44]. The study of Zabidi et al. also showed the pond harvesting systems bring about several benefits in terms of economics, environmental aspects and volume of water harvested [45].

On the other hand, RGs are cheap alternative but available space to adopt them may be problematic in high intensity residential and commercial areas [41]. Therefore, implementing RGs to rural areas, which have higher logistical costs for repair and maintenance cost of SW management, can be a good alternative in addition to RWH systems.

6. Conclusions

This study investigated the sustainable role of RWH and RG on stormwater management based on worldwide perspectives from 38 countries with different income levels and annual precipitation rates by utilizing both quantitative and qualitative data. The paper tried to focus on the current state and future prospects of stormwater management systems by considering cost assessment as well as determining awareness level toward sustainable practices based on RWH and RG. It seems that sustainable water management systems will be on the agenda of the majority of countries to protect the ecology regardless of their average annual precipitation and income level. The findings of the study indicate that proper implementation of RWH and optimum use of RG promise several contributions to stormwater management. Therefore, policymakers should encourage local authorities and make people more engaged with NBS through pilot projects, incentives, and altering design criteria on newly constructed buildings. AAP and GDP levels have a direct impact on higher levels of awareness, and current implementations However, the perception of flood as a crucial danger is highest in countries with moderate AAP levels. This may be sourced by a lack of infrastructure and workforce with hardening conditions of precipitation extremes.

The sample of the study is limited to 70 international respondents. Further research with more respondents could expand the scope of the study and yield better results. This study addressed different countries based on only AAP and GDP levels. Prospective studies that involve more countries with different characteristics, may offer different findings. Despite its drawbacks, the study is of great importance for underlining the threat of flood disaster, reuse of rainfall, and raising awareness toward RWH and RG among different stakeholders. Participants with exceptional experience in water management from 38 different countries contributed to the survey. Therefore, the study provides a representative assessment of worldwide current and future situation in implementing RWH and RG

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Author Contributions

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Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

The authors declared that all participants were fully informed consent for inclusion before they participated in the study, and the study meets national and international guidelines.

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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