Rainwater harvesting in rural Trinidad; a cross sectional, observational study
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ABSTRACT
Rainwater harvesting is a well-established practice in many parts of the world. In the right environment it can provide a convenient, inexpensive and sustainable source of potable water. This study explored rainwater collecting system use within rural Trinidadian communities. Data regarding participants’ demographic details, water practices, health- and water-related beliefs were collected from six separate regions late in 2009 using a purpose designed questionnaire. The findings, obtained from the 1,523 study participants resident in 292 households were analysed. Almost half (130) of the participating households utilised rainwater as their main supply although some found it necessary to switch to alternative sources during dry periods. The majority of participants (478) who harvested rainwater were very satisfied with the quality of their water and relatively few (212) were concerned that it may pose a risk to their health. Rainwater harvesting systems are well established in Trinidad and are well accepted by those who use them. Further research is needed to establish why more households do not adopt this technology as alternative sources remain inconsistent and inadequate in many respects. These findings will assist individuals and government agencies in making informed decisions when planning and managing water sources on the island.

Key words | cross-sectional survey, drinking water, rainwater harvesting, risk perception

BACKGROUND
In many parts of the world, access to safe drinking water is still limited. A recent report by the World Health Organization (WHO) and the United Nations Children’s Fund (UNICEF) estimated that around 900 million people worldwide do not have access to improved sources of drinking water and the Millennium Development Goal target to significantly reduce this number by 2015, is unlikely to be met (WHO/UNICEF 2011). With the global population predicted to rise by almost $5 \times 10^9$ people by 2050 (United Nations 2008) and with current water resources already under pressure, alternative but safe sources of water need to be secured.

Centralised water supplies and delivery via pipes is often the most convenient, reliable and safest source of potable water. However, substantial infrastructure is required to support this technology and it is costly to install and maintain. Water sources may be under marked pressure from multiple users leading to intermittent supply. Inhabitants of less developed or sparsely populated areas of the world may have to rely on water from unimproved sources that are potentially less safe, from wells and rivers for example. Rainwater harvesting, the collection and storage of rain from the roofs of dwellings or outbuildings, holds many potential advantages over other sources. Materials are present or readily available and once systems are in place, holds many potential advantages over other sources. Materials are present or readily available and once systems are in place, there are few additional costs for the individual or wider community. Thus families do not rely on government or community reserves that may be subject to interruption or exhaustion. Rainwater harvesting systems range from the basic to the sophisticated (Figure 1).
Rainwater harvesting is considered by the WHO to be an improved water supply (WHO 2000). In general, rainwater collection from domestic roofs are relatively straightforward systems requiring a mechanism for collecting water as it runs off roofs and something for storing the water. However, there are still several issues that need to be addressed when considering rainwater harvesting as a major source of drinking water. Such issues include the year round availability of sufficiently heavy rains and whether such supplies are sufficient during dry seasons, and whether rainwater collection is sufficient for all household needs including drinking, food, consumption, hygiene and irrigation. Perhaps the two most important issues are the potential risk of contamination and secondly whether the stored water can act as a source for breeding mosquitoes. Contamination of water supply may be bacterial and or chemical and come from birds and animals on the roof or from chemicals applied to the roof or remaining in storage containers. Outbreaks of diseases have been linked to contaminated harvested rainwater (Koplan et al. 1978; Franklin et al. 2009). The issue for breeding mosquitoes is that these insects may spread diseases such as malaria, yellow fever, or dengue fever. Indeed defective rainwater harvesting systems have been implicated in the spread of dengue fever (Heukelbach et al. 2001; Mariappan et al. 2008). In many Caribbean countries such as Trinidad and Tobago the risk from dengue fever is seen as an especially important problem. Consequently there is the remaining issue about whether or not owners of rainwater harvesting systems have the knowledge and skills to manage these systems adequately in order to prevent risks to human health.

The Caribbean state of Trinidad and Tobago is both culturally and economically diverse. The majority of the 1.5 million inhabitants reside in Trinidad, the larger of the two islands and most of these residents dwell in urban areas, with just 26% living in rural locations (UNDP 2002). The climate is warm and humid throughout the year and the islands experience regular rainfall except between the months of January and May. This period is typically described as the dry season, a time that receives just 20% of the annual rainfall (Schneiderman & Reddock 2004). Trinidad, the larger of the two islands and the focus of this research, predominantly utilises ground and surface water for domestic use through a network of wells, reservoirs and rivers (WRA 2001). It was estimated in 2002 that the island had a per capita water availability of 2,500 m$^3$ and as such was not considered water-scarce by international standards (MPUE 2002). And yet there was then and still are residents who fail to receive regular or improved water supplies. Many of those without access to an improved supply are provided with trucked in water.

At the beginning of the 21st century it was estimated that around 86% of Trinidadian residents had access to improved water sources (WHO 2000). This figure demonstrates a decline rather than a rise in adequate water supply as between 93 and 98% of people had access to improved water sources from the 1970s to the turn of the century (Gleick 2002). Of those that do receive piped water to their homes or nearby standpipes just 14% report having a continuous supply, the remainder receiving intermittent water between two to three (2–3) days per week, whilst others may be receiving water at levels less than those reported (Schneiderman & Reddock 2004). Figures produced by the Trinidad and Tobago Water and Sewage
Authority (WASA 2002) reveal that 36% of water produced by WASA on the island is used by domestic consumers, 14% supplies industry and 1% supplies agricultural users whilst 50% remains unaccounted for, presumed to be lost through leaks, overflow, evaporation and illegal connections. Given these figures, it appears that Trinidad and Tobago may have adequate reserves and access to sufficient surface supply to meet the demands of residents and others particularly in contrast to other countries.

However, many thousands of Trinidadian residents fail to receive good quality potable water delivered to or near to their homes and a small but significant proportion of the population utilise rainwater for domestic use (Schneiderman & Reddock 2004). The Caribbean island is perhaps an ideal environment in which to harvest rainwater, the tropical climate ensuring sufficient precipitation all year round, even during the ‘dry season’. This inexpensive and independent resource would seem an attractive alternative for island inhabitants and it is unclear why more households don’t employ such systems. It is the aim of this study to explore the rainwater harvesting systems in use amongst Trinidadian communities in order better understand the technology and allow households and government agencies alike to make informed decisions during water resource planning and management.

METHODS

The basic study design was a cross sectional survey of households conducted in communities which were known to practise rainwater harvesting for at least part of the year.

Recruitment

Prior to formal data collection, communities were organised with the help of key informants to gain entrance, to inform of the project aims and goals and to determine preliminary information regarding water sourcing and health status among residents. Project leaders also worked with policy leaders to gain approval for entrance to communities, to procure information regarding census of communities in target and to delineate official practices and targets regarding water supply practices currently engaged and anticipated. A subset of the community was treated to items from the questionnaire to determine clarity of items and relevance of items to daily household practices of water harvesting, storage, management and utility practices. Formal data were collected for this cross-sectional observational study from December 2009 to February 2010. Ethical approval for the study was received from the Republic of Trinidad and Tobago Research Ethics Committee within the Ministry of Health.

Communities on the island of Trinidad were identified based on current practices of water delivery status and households were recruited from 9 villages grouped into 6 study regions (Figure 2). Regions 1 and 2 were located on the mountainous north eastern coast, 3 and 4 were inland and central to the eastern side of the island, and 5 and 6 were located on the coast in the south-west. A sampling frame was devised which sought to select communities most likely to use a broad range of water sources and included communities from a variety of distinct geographical areas. Each region contained one or more rural communities with a total of 45 households or more. Every third household was visited within each region by the research team until sufficient numbers had been recruited.

Data collection

Data were collected for this cross-sectional observational study from December 2009 to February 2010. Data were collected from 292 households using a questionnaire adapted from that used by Few et al. (2009). The researchers, operating in pairs, invited household members to participate in the study following explanation of the nature of the project and obtaining informed consent. One adult (>16 years old) from each household was asked to report on demographic information, house and key possessions, water usage and sanitation practices together with water related thought and beliefs. In addition the researcher graded house quality as very good, good, poor or dilapidated, though it was left to the individual researcher to decide how to make these judgements. Each household member, 1,523 in total, was asked to provide information regarding their hygiene practices and health. Where this was not possible due to extremes of age for instance, the information was gained from an adult within the household with adequate
knowledge. A copy of the questionnaire can be obtained from the corresponding author.

Data analysis

The findings were entered into an Access database and the data-set interrogated at both household and individual level using SPSS v.18 statistical software. Comparisons were drawn based primarily on the main household water source and a number of key variables. Adjustments were made where appropriate for the possible effects of clustering.

RESULTS

Demographic and economic variables of households

A total of 292 households participated in the study. In these 292 households there lived 1,523 people, an average of 5.2 people per house. Around a third (518) of the participants were children under 12 years of age and there were similar numbers of male (741) and female (778) respondents. Almost half (709) of participants described themselves as being of East Indian ethnicity, 419 (27%) of African ethnicity and the majority (358) of the remainder described themselves as mixed ethnicity. Most families (211) had lived in the same community for more than 25 years with only 31 (11%) having moved communities within the last 10 years.

Around 90% (262) of the sample households had a total family income over the past 12 months of 100,000 Trinidad and Tobago dollars (TT$) or less, equivalent to approximately UK£10,000 sterling or US$15,700. Approximately 30% (86) of households earned 25,000 TT$ or less during this period whilst only 2 households had earnings greater than 200,000 TT$. Interestingly, almost half (133) of the houses were judged by researchers to be of a good quality and 73 (25%) were deemed to be very good quality. Nearly all (273) houses had a television, most (258) had a fridge but only just over a third of households (109) had a motor vehicle and 69 (24%) had a laptop computer.

Water use and practices

The data collection phase of the study took place during December and January of 2009 and 2010 respectively, months which usually mark the end of the rainy season.
Table 1 reports the drinking water practices of sample households during the rainy and dry seasons. The sample households generally used one of five different sources of water, with almost half of them using rainwater harvesting systems during the rainy season and just under a third consuming water that was piped directly into their homes. Water source utilisation is similar in the dry season in a number of respects with the exception of those using rainwater harvesting systems. Just over a quarter (35) of households that use rainwater as their main source of drinking water during the rainy season, change to alternative sources, predominantly to truck-borne water, during the dry season.

Households that stated their main source of water was piped were asked to estimate the number of hours per week they received water. Only a third (31) of families reported they received a continuous supply of water whilst just under a quarter (21) claimed they failed to receive running water for more than 48 hours per week.

When the main source of drinking water is viewed in terms of the income of the family (Figure 3) a distinct pattern can be seen. Those houses that have the lowest wages use the widest range of water sources. Unlike other economic subgroups, these households are divided relatively equally in terms of their main sources of drinking water, the higher earning households tending to use only rainwater harvesting systems or piped water. As people become more wealthy they are more likely to have in-home connections and less likely to have in-yard connections or rely on public standpipes. By contrast wealth does not affect the preference for rain water in most income groups. When water source is compared to observed housing quality a less distinct pattern emerges with a range of sources being used by households in all categories. This may reflect the subjective nature of the researchers’ opinion.

Rainwater harvesting as a main water source was explored in terms of the household’s geographical location. Households in the centrally located regions 3 and 4, both had relatively high numbers of rainwater harvesting systems, 44 (88%) and 27 (54%) respectively. Situated on the northern mountainous coast the inhabitants of region 2 also utilised rainwater readily with 28 households (57%) using this as their main supply. However, just 10 families (20%) in the neighbouring region 1 used this method. Regions 5 and 6, located in the south of the island, had very low numbers of households with harvesting systems, one (2%) and nine (19%) respectively.

A total of 219 households reported they collect rainwater for domestic use although it can be seen from other data that this is not the main source for many of them. All such households reported that they stored the collected water outside in containers which were either made of plastic or steel and were either open or covered. Most households (162) stored water in covered plastic containers and less likely to have in-yard connections or rely on public standpipes. By contrast wealth does not affect the preference for rain water in most income groups. When water source is compared to observed housing quality a less distinct pattern emerges with a range of sources being used by households in all categories. This may reflect the subjective nature of the researchers’ opinion.

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with just 45 families using open steel or open plastic containers and 37 using steel containers that were either open or covered. When looking at storage systems in terms of wealth it is again clear that the greatest variety of methods is used in the lowest income groups. Of the 17 rainwater collecting households that earn over 100,000 TT$ per year, only 1 family did not use covered plastic containers in contrast to 25 out of 65 households in the lowest income group, that did not use this type of system. An example of the covered plastic containers typically used can be seen in Figure 1.

Just under a third (90) of all households recruited to the study regularly treated their water, most often using bleach or chlorine tablets although a few also boiled, filtered or added alum to their water to improve the quality. When discussed in terms of treatment according to source (Table 2), water collected from rainwater harvesting systems is one of the most commonly treated water sources. Almost half of households (63) that collect rainwater for drinking treat the water in some way whereas only 10 (12%) of those who have water piped to their dwelling treat their water.

Beliefs

Those who consumed rainwater were generally more satisfied with the quality of their water than those who consumed water piped to their homes. The study found that 478 participants (70%) who harvested rainwater were extremely satisfied with the quality of the water compared to 251 (52%) who received their main supply from water piped to their homes. The taste of water appeared to be an important factor with 622 rainwater (91%) collectors preferring the source for this reason in contrast to just 208 tap drinkers (43%) who valued their source for this quality. When questioned about potential health risks and water supply, 675 participants (44%) stated that they did believe there were health risks associated with rainwater harvested drinking water and 1,039 (71%) believed there were health risks associated with truck-borne water supplies. It is apparent from further analysis of the data that most who considered rainwater unhealthy consumed alternative sources of water. Over half (270) of those with piped water to their homes felt there were health risks associated with rainwater. In contrast 212 individuals (31%) whose main water source was from rainwater harvesting systems felt their own health was at risk. Interestingly, the one household that consumed river water also felt that rainwater presented health risks.

**DISCUSSION**

It was estimated at the turn of the century that around 14% of Trinidadian residents consumed water from unimproved sources (WHO 2000). Almost 10 years on there is evidence that many families are still without adequate water supply, our findings indicating that in rural communities only around 85% of inhabitants during the dry season and 94% during the rainy season consume water from improved sources. Of those receiving piped water 31% were found to receive a continuous supply, an improvement on the findings of previous research but still an unacceptably low percentage. This preliminary study suggests that in this tropical environment water provisions are inconsistent or at times absent.

At the time of data collection, around half of the participants were using rainwater harvesting systems for domestic purposes. This finding is similar to that of a survey conducted some years ago by Virjee (2004) though as the communities were chosen because of their likely high use of rainwater harvesting we cannot determine whether there has or has not been a change. The widespread use of this method suggests it is a viable and perhaps acceptable means of water procurement in this Caribbean state and may reflect the inadequacy of alternative sources. Virjee and Gaskin (2010) report that residents, in response to intermittent piped water that varies in pressure and quality, adapt to their situation with alternative solutions. It is plausible
that collection of rainwater is one form of the coping behaviours so described, a method which relies purely on natural resources and the individual household, and is independent of government agencies that residents have grown to view with scepticism (Schneiderman & Reddock 2004). Viewing this technology as a ‘way of coping’, however, may have negative connotations that imply it is a temporary solution and the water produced is in some way inferior to other sources. Indeed it is the case that in some areas there appears to be a preference for rainwater over piped water and rainwater collection has persisted despite adequate piped water.

The distinct seasonal variation in the size of the rainwater harvesting population is important in terms of water resource planning and management. The households that use alternative sources during the dry season, around one quarter of those that collect rainwater, represent large numbers on a national scale, a factor that needs careful consideration when planning for the future. Whilst water from rainwater collecting systems is inexpensive, energy efficient, relatively convenient and according to current evidence, safe, the same cannot necessarily be said for some of the alternative sources utilised during the dry season. It was noted that a fair proportion of those that switched water sources changed to using truck-borne water as their main source. This resource, considered by the WHO (2004) as an unimproved supply due to its high cost to the individual or state, holds few of the advantages of rainwater harvesting and attempts should be made to limit its use in the future. With three quarters of the rainwater harvesting population able to use one source as their main supply all year round, further research is necessary to ascertain why some households are able to collect and store more water than others.

We found that rainwater was utilised by households of varying degrees of wealth. A large proportion of households of all income levels chose to use rainwater as their main source of domestic water which suggests this may be seen as a viable economic option for rural Caribbean households. When using storage container type as a measure of system quality, there is little difference between the economic groups, the majority in each using covered plastic containers.

A number of distinct geographical features interact with weather systems to produce recognised rainfall patterns on the island. The north-east of the island receives the most rain with a mean annual rainfall of 3,800 millimetres (mm), a consequence of the north-easterly prevailing winds meeting the mountainous Northern Range. Parts of the low lying western and southern regions receive much less rain, some as little as 1,200 mm per year (Shrivastava 2003). The patterns that emerge when water sources are examined by region, are not straightforward. To discover that the communities that harvested rain the most were situated centrally, was surprising and we must conclude that the decision to collect rainwater is not based solely on the amount of rainfall. One region, for instance is situated on the northern mountainous coast but just 20% of the study households in this region collected rainwater. This could be for a number of reasons; 43% of those with piped water received a continuous supply, much higher than the study (31%) or national average (14%) (Schneiderman & Reddock 2004) although these levels are still far from desirable. There is no defined amount of rainfall needed for successful rainwater harvesting although experts suggest that this practice may be unsuitable in regions receiving less than 400 mm per year (Lye 1992). It is reasonable to expect that households located in areas receiving more moderate amounts of rain need to employ particularly effective catchment and storage strategies to buffer ‘drier times’ and they must ensure that the water they do collect is used efficiently.

Around half of all households that collected rainwater treated it in some way prior to use. Expert opinion on whether untreated rainwater is associated with adverse health outcomes is divided. Some recommend point-of-use treatment for rainwater based on microbiological evidence (Lye 1992) whilst others suggest this may not be necessary. This source has been linked with six separate outbreaks of illness since the late 1970s (Heyworth et al. 2006) and considering the small number of recipients per system, many other instances of contamination may have gone unreported. Researchers have concluded that the water collecting surface, usually a roof, is frequently the site of contamination, most often small mammal and bird faeces harbouring the causative organisms. In a study conducted by Heyworth et al. (2006) in southern Australia, it was noted the majority of those who consumed rainwater failed to treat it and in addition, it was felt their collecting systems were in general, poorly maintained. Irrespective of this the illness rates of this group were lower than those consuming piped water.
One aim of this study was to determine the opinions and beliefs of residents regarding the collection and consumption of rainwater. Those practising rainwater collection techniques were generally satisfied with the quality of their water and relatively few were concerned that it might pose a risk to health, suggesting that for many of the current users, this may be acceptable as a long term and permanent source. It seems, however, that those not currently using this resource are more sceptical, the majority considering consumption of rainwater a health risk and as such this group of users may be less willing to accept rainwater harvesting as a future option. Recording people’s views using dichotomous questionnaires may be a quick and convenient way of collecting data of this nature, however, it provides little insight into the basis of these opinions and may fail to capture the aspects and issues that are especially important to the participants. Further research exploring some of these issues in more depth, with the use of focus groups or interviews is necessary for us to gain a greater understanding of this aspect of water use and practices.

There have, of course, been questions raised in the literature concerning the safety of rainwater harvesting. Most concern has been focussed on the risk of enteric infections (Lye 1992). However, in a recent systematic review of the literature we found little evidence that harvested rainwater posed a greater risk of illness than other improved water sources (Dean & Hunter 2012). Furthermore we found that harvested rainwater was associated with reduced risk of illness compared to unimproved sources. Another potential hazard with rainwater harvesting and storage concerns the risk of dengue fever as such stored water can act as mosquito breeding sites (Nathan & Knudsen 1991). However, this risk would apply to all stored water including water that had to be stored because of intermittent mains water supplies or reliance on tanker deliveries. The key issue here is to ensure that whenever water is stored it is stored in a way that prevents mosquitoes breeding.

CONCLUSIONS

As far as we are aware, this is the first comprehensive investigation of domestic rainwater harvesting systems within Caribbean communities. Our study found that this simple, convenient and inexpensive technique has been adopted by many households across the island of Trinidad, alternative sources such as mains water often proving unreliable because of dated and poorly maintained water infrastructure. For some though, particularly those located in the low-lying south-west of the island, this method of water collection may at times present supply issues with low rainfall during the drier months forcing the use of other, perhaps unimproved sources. Those who currently use rain collection techniques generally find the water acceptable in terms of its quality and do not consider it a risk to their health. In contrast, those using alternative sources are more sceptical about the consumption of rainwater, an area that needs further investigation if these concerns are to be adequately addressed.

Rainwater harvesting may, in the right climate, provide a sustainable source of water at very low individual, state and environmental cost. The findings of this study will assist in the promotion of rainwater harvesting in the future and allow individuals and government agencies alike to make informed decisions when planning and managing their water source. Where harvested rainwater becomes common, public health agencies should be prepared to help give populations sufficient knowledge to manage this resource in a way that protects public health.

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