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Effects of local and spatial conditions on the quality of harvested rainwater in the Mekong Delta, Vietnam

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A B S T R A C T

The objective of this study was to assess the quality of harvested rainwater in the Mekong Delta (MD), Vietnam for local (roof types, storage system and duration) and spatial (proximity of industry, main roads, coastline) conditions. 78 harvested rainwater samples were collected in the MD and analyzed for pH, turbidity, TDS, COD, nutrients (NH_4, NO_3, NO_2, o-PO_4), trace metals and coliforms. The results show that thatch roofs lead to an increase of pollutants like COD (max 23.2 mgl^{-1}) and turbidity (max 10.1 mgl^{-1}) whereas galvanized roofs lead to an increase of Zn (max 2.2 mgl^{-1}). The other local and spatial parameters had no or only minor influence on the quality of household harvested rainwater. However, lead (Pb) (max. 16.9 μgl^{-1}) and total coliforms (max. 102 500 CFU100 ml^{-1}) were recorded at high concentrations, probably due to a variety of household-specific conditions such as rainwater storage, collection and handling practices.

1. Introduction

There are many types of water resources used for drinking purposes in the rural areas of the Mekong Delta (MD), Vietnam as well as other similar regions in South-East Asia. However, potential sources such as groundwater and surface water are used less extensively due to poor physical conditions of some parameters such as smell, taste and color which lead to a reluctance to consume these water sources for drinking (Herbst et al., 2009). Moreover, piped-water access in rural areas of the MD is still limited to date with only 8–12% coverage (SNV, 2010). Rainwater is advocated as a reliable drinking water source by residents and governmental institutions since it does not have the disadvantages mentioned above for other sources (Özdemir et al., 2011) and is economically feasible. There is, therefore, an opportunity to further encourage the use of rainwater as a drinking water source in the MD. For example, in Soc Trang province a governmental program was developed to enlarge the rainwater storage capacity in water supply stations (Vietbiz24, 2010). Snelgrove and Patrick (2009) suggest measures to increase the volume of harvested rainwater, and to improve the durability and affordability of storage tanks in Vietnam in order to increase the usage of rainwater as a drinking water source. Similar recommendations were made for other countries such as Bangladesh where rainwater is proposed to be a potential alternative source for drinking, cooking and dish-washing purposes in arsenic contaminated areas (Islam et al., 2010). In Australian cities, rainwater is also proposed to be a feasible alternative water source (Zhang et al., 2009). Recent studies, however, show concerns with respect to physico-chemical and especially microbial contamination of household harvested rainwater (HHR). Meera and Mansoor Ahammed (2006) concluded that HHR can be heavily contaminated with pathogenic micro-organisms world-wide. A study in Australia showed the presence of a large variety of pathogens including *E. coli*, enterococci, *C. perfringens*, and *Bacteroides* spp. (Ahmed et al., 2008) while Fewtrell and Kay (2007) indicated the presence of a large variety of pathogenic micro-organisms in HHR in many other countries as well. Heavy metal pollution of HHR is another concern, although reported concentrations are mostly well below international water quality standards (Mendez et al., 2011). However, In New Zealand Pb and Cu concentrations exceeded drinking water guidelines at some locations (Simmons et al., 2001).

Most studies regarding contamination of rainwater focus on the influence of roof types. However, there are significant differences between similar studies in different regions. For example, Mendez et al. (2011) concluded that green roofs are responsible for highest concentrations of microbial pollution, DOC and As in HHR. Although Yaziz et al. (1989) found similar results, their study also

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showed that Pb concentrations were consistently high regardless of roof type. Most studies found microbial indicator bacteria in HHR; however, Lee et al. (2012) only found low to undetectable concentrations of *E. coli* in rainwater harvested from galvanized steel and clay tiles in South-Korea. Other studies emphasized the effects of spatial specific conditions on the quality of harvested rainwater. A study in the USA concluded that the presence of Zn and Cu were most probably caused by industrial emissions given the high concentrations of these substances in rainwater samples that were collected without roof contact (Chang et al., 2004). Mantovan et al. (1995) found variations in rainwater quality caused by population densities and industrial areas while Thomas and Greene (1993) reported Pb concentrations two-folds higher than WHO drinking water guideline values near an industrial zone. Despite the large differences between studies, roof types and spatial conditions such as the presence of agglomerations seem to influence harvested rainwater quality. Aside from these parameters, behavioral factors such as handling and hygienic perceptions are expected to influence the quality of HHR through the lack of hand-washing after, for example, using sanitation facilities (Herbst et al., 2009).

To date, there are only a few investigations on the quality of HHR in the MD as well as other similar regions in South-East Asia. Instead, most drinking water quality investigations in this region focus on ground water due to the well-known presence of pollutants (Buschmann et al., 2008). Research on rainwater quality mainly focuses on the perception of drinking water sources (Herbst et al., 2009) and knowledge about HHR practices and attitudes by residents (Özdemir et al., 2011). The objectives of this study were (also see supplementary material): i) to investigate the quality of household harvested rainwater in the Mekong Delta for general parameters, nutrients, heavy metals and microbial indicator bacteria and compare observed concentrations with (inter)national guidelines with respect to drinking water; ii) to identify the role of local (roof type, storage system, storage duration) and spatial (proximity to industry, main roads, coastline) specific conditions on the quality of household harvested rainwater in the region, iii) to assess the potential influence of household specific conditions on the quality of household stored rainwater and iv) to provide recommendations aimed at improving the quality of harvested rainwater as a safe drinking water resource. The outcome of this study will be useful for policy makers in Vietnam as well as other similar regions in South East Asia to draw conclusions about the use and required treatment of rainwater as a potential drinking water source for the rural areas and for the use at water supply stations in urban areas.

2. Materials and methods

2.1. Study sites

This study was carried out in three provinces of the MD, i.e. Can Tho, Hau Giang and Soc Trang (Fig. 1). Characteristic land-use types in Can Tho and Hau Giang provinces consisted mainly of rice fields (40%), orchards (13%) and fresh water aquaculture (0.5%) combined with open to dense urbanized and industrial agglomerations (German Aerospace Center, 2011), whereas in the Soc Trang province, shrimp farming was the main observed land-use system. Most people in rural areas live along the numerous canals and rivers. The climate in this tropical region is influenced by the southwest monsoon which creates dry and wet seasons. The wet season is generally from May to October with an annual average rainfall of 1660 mm defined by 23 years of measurements (Delta Alliance, 2011). During the dry season rainfall events are scarce or completely absent. A survey of 542 household (HH) interviews in the study sites (own unpublished data) revealed that almost 60% of the HHs are using rainwater as a drinking water source; however, the use differed considerably within the region. Some villages preferred groundwater or even surface water to rainwater, while other villages only used rainwater as their source of drinking water. Households that collect rainwater usually use metal gutters to collect rainwater from roofs. The gutters transport the collected rainwater to storage basins (typically clay jars or concrete tanks) from which it is used with or without treatment.

2.2. Sampling and analytical methods

Samples of household-harvested rainwater were collected in 2012 from July to October. A total of 72 locations were selected at 5 km intervals to achieve good spatial representation. Measurement locations were pre-defined ahead of sampling and localized by GPS in the field (Garmin ETrex, Olathe, KS, USA). After arrival at the pre-defined location, households were screened for drinking water sources. The first household identified using rainwater for consumption near the pre-defined location was selected for analysis regardless of roof type and spatial conditions in order to get insight into actual variation of household and spatial specific conditions. The exact location of sample collection was recorded. Ten samples were collected in Soc Trang province whereas 62 samples were collected in Can Tho and Hau Giang provinces. In addition, a small case study of 6 neighboring households was undertaken in the rural areas of Hau Giang Province to investigate the potential influences of household specific conditions such as behavioral aspects. In this area, most households

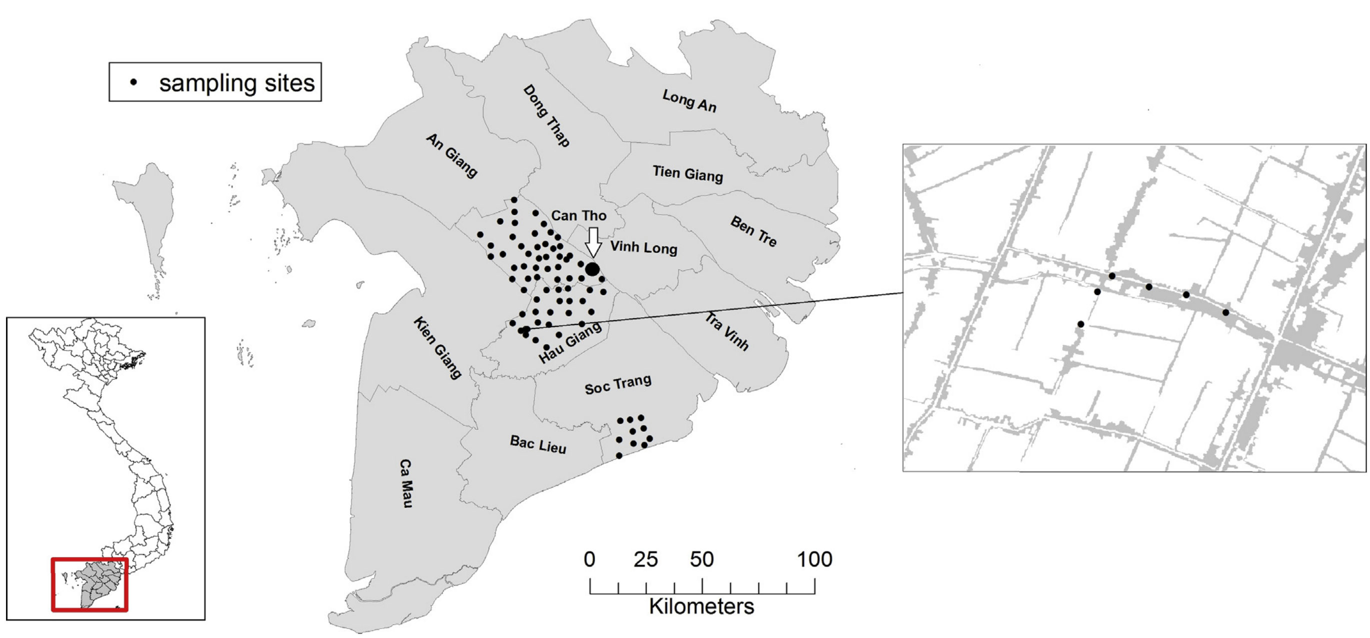

Fig. 1. Visualization of sampling locations in Can Tho, Hau Giang and Soc Trang provinces. The small scale study site is highlighted (southern location in Hau Giang) and shown by a detailed map. Main industrial zone in Can Tho City is shown as a larger black dot.