

# Design of dual water supply system using rainwater and groundwater at arsenic contaminated area in Vietnam

Duc Canh Nguyen and Moo Young Han

## ABSTRACT

Fresh water, a renewable but limited resource, is scarce in many areas of the developing world. This paper proposes a dual water supply consisting of both rainwater and groundwater to provide sustainable water for an arsenic contaminated area. In this paper, a novel model has been developed based on rainfall variance. A rainwater harvesting (RWH) system can obtain optimal performance by changing the demand for water use according to rainfall. This model was then used to design a RWH system for Cukhe village. Using rainwater for potable purposes on dry days and for all purposes on rainy days is recommended. The cost of RWH systems is also analyzed. In order to achieve 100% reliability for a four-member household, a RWH system should have a roof area of 100 m<sup>2</sup>.

Additionally, a tank size of 2 m<sup>3</sup> is recommended for overall cost efficiency. From the yearly water supply chart, it is recommended that rainwater be supplied for potable purposes only in January–April and October–December, while it should be supplied for all purposes in May–September.

**Key words** | demand change by rainfall, dual water supply, rainfall variance, reliability, RWH system

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## INTRODUCTION

Fresh water, a renewable but limited resource, is scarce in many areas of the developing world. Oftentimes, this scarcity is due to the unplanned withdrawal of water from rivers and groundwater.

In Cukhe village, located in the outskirts of Hanoi, Vietnam, people do not have access to a safe water supply for many reasons, including the government's inability to establish centralized water supplies. In addition, the existing water sources – the river and groundwater – are contaminated with human waste and arsenic (Michael Berg *et al.* 2001). Therefore, the promotion of alternative water supply options to the traditional water sources is an urgent endeavor. We found that a dual water supply consisting of rainwater and groundwater is a suitable method for providing sustainable water to the local residents. This approach is suitable for several reasons. Rainwater harvesting is a sustainable method to obtain good-quality drinking water at low cost and with little energy expenditure in the village (Nguyen *et al.* 2013).

Groundwater, on the other hand, has been found to have a low turbidity but a very high concentration of heavy metals. Hence, it can be supplied for non-potable purposes such as toilet flushing.

Securing sufficient quality and quantity of rainwater is an important issue in ensuring the safety of the water supply. Although rainwater maybe microbiologically contaminated, it will require minimum treatment before using it for potable purposes. Many researchers have investigated and proposed several simple methods for removal of microorganisms in rainwater. Amin & Han (2009) proposed the use of solar collector disinfection as an efficient low-cost method for potential use of rainwater as potable water; Ahammed & Meera (2006) also proposed some simple home water purification devices. Furthermore, boiling is a simple and efficient method.

Rainwater tank capacity is one of the most significant design parameters. Many researchers have attempted to promote significant potable water savings with the use of

rainwater (Handia *et al.* 2003; Ghisi *et al.* 2007; Amin & Han 2009; Muthukumaran *et al.* 2011). There are numerous methods already developed for predicting the performance of rainwater harvesting (RWH) systems. A model for determining the effectiveness of rainwater tanks and storm water runoff using long-term historical rainfall data has been developed by Vaes & Berlamont (2001). A computer model has been developed by Jenkins (2007) for formulating continuous simulations of the amount of rainwater stored in a tank, amount of rainwater used, amount overflowed, and the number of mains topped up for household rainwater tanks. Furthermore, Mun & Han (2012) developed a design and evaluation method for a RWH system to improve its operational efficiency based on sensitivity analysis.

These models are generally employed with a focus on developed countries, where the use of rainwater is usually applied in relation to economics rather than basic human health. Moreover, previous researchers conducting such modeling have not considered rainfall variance, a factor that can improve the performance of a RWH system. In rainy seasons, due to the excess amount of rainwater, it can be supplied for multiple usages. The same cannot be said for water use during dry seasons.

This paper proposes a dual water supply consisting of both rainwater and groundwater to provide a sustainable drinking water supply. A novel modeling concept has been developed, taking rainfall variance into consideration. This method was employed to design the conceptual RWH system at Cukhe village.

## MATERIALS AND METHODS

### Typical housing and current water supply system

Cukhe is a typical village of the Red River Delta region close to Hanoi, the capital city of Vietnam. It lies at 20°56'7"N, 105°47'45"E. It covers a geographic area of 5.76 km<sup>2</sup> and has a population of 4,667. Typical roofs in this region are made from brick, galvanized iron sheeting, and asbestos with an average roof area of 50 m<sup>2</sup>.

There are currently two kinds of water supply systems in Cukhe: groundwater systems and rainwater harvesting systems, both having different structures and forms (Figure 1).

Groundwater is the main water source in Cukhe village. Most of the households own a deep well. Households use electric pumps to take the groundwater and treat it with a simple filter system. A groundwater system includes a spray aeration with perforated pipe, slow sand filter and a storage tank. The filter efficiency for groundwater systems affects the water quality; thus, periodic cleansing and changing of the filter is an important attribute of the overall system. However, the lower socioeconomic class (comprised of many who have suffered from diseases owing to the use of groundwater without the periodic cleansing and changing of filters) does not necessarily trust the potable use of groundwater.

The existing rainwater system is comprised of a rooftop for a collection area and a reservoir tank. Each house has a 1–6 m<sup>3</sup> rainwater reservoir installed. Water collected on the rooftop collection area fills the reservoir via guttering. Rainwater collected during the monsoon season is used even



Figure 1 | Rainwater system (left) and groundwater system (right).

during the dry season; however when the stored amount is insufficient, groundwater is used. There are many differences in the groundwater system design and form for those of different socioeconomic status, but in most cases the use of rainwater is almost the same.

## Strategy for water supply

### Dual system according to water quality

The water quality from various sources of rainwater and groundwater was tested and compared with the World Health Organization (WHO) drinking water guideline (data not shown here; Nguyen *et al.* 2013). Groundwater was shown to have a low turbidity but a very high concentration of heavy metals (arsenic) and nitrite. However, this groundwater can be acceptable to supply for non-potable purposes such as toilet flushing, cleaning or gardening. Meanwhile, the test results for rainwater quality showed that the quality exceeded that stated in the standards listed in the WHO drinking water guideline. As such, rainwater can be supplied for potable purposes such as drinking, cooking and bathing. Many studies have also reported rainwater as a good quality water source which can be used as drinking water without any other treatment if the catchment and rainwater tank are managed well (Coombes *et al.* 2006; Lee *et al.* 2012). Since the rainwater quantity is not enough to be used for all purposes, a dual water supply consisting of both rainwater and groundwater is recommended.

### Design and evaluation method for RWH systems

The design and performance efficiency of a RWH system is based on the daily water balance model which was developed by Mun & Han (2012). The model considers various factors such as tank size, daily rainfall quantities, losses, daily water demand, and overflow (as shown in Figure 2).

The overall process can be mathematically described as follows.

Cumulative water storage equation:

$$V_t = V_{t-1} + Q_t - D_t \quad (1)$$

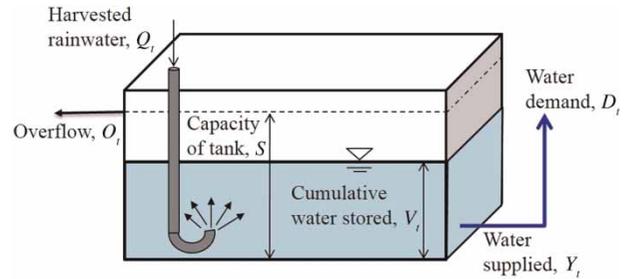


Figure 2 | Schematic diagram of water flow in a rainwater tank.

$$V_t = 0, \text{ for } V_t < 0 \quad (2)$$

$$V_t = S, \text{ for } V_t > S \quad (3)$$

$$Y_t = D_t, \text{ for } V_t \geq 0 \quad (4)$$

$$Y_t = V_{t-1} + Q_t, \text{ for } V_t < 0 \quad (5)$$

where  $V_t$  is the cumulative water stored in the rainwater tank ( $\text{m}^3$ ) after the end of  $t$ th day,  $Q_t$  is the harvested rainwater ( $\text{m}^3$ ) on the  $t$ th day,  $V_{t-1}$  is the storage in the tank ( $\text{m}^3$ ) at the beginning of  $t$ th day, and  $D_t$  is the daily water demand of the household ( $\text{m}^3$ ) of  $t$ th day.  $S$  is the capacity of rainwater tank ( $\text{m}^3$ ).  $Y_t$  is the amount of water supplied from the RWH system on the  $t$ th day.

For the old model (Mun & Han (2012) model), the daily demand  $D_t$  is not dependent on rainfall variance and it is considered as a constant number by time. This study model develops an algorithm to determine the daily demand based on rainfall variance for the best use of the RWH system. In the other words, RWH system should secure the water supply in dry days and utilize the excess amount of rainwater in rainy days. If the cumulative water stored in the rainwater tank after the end of  $t$ th day ( $V_t$ ) is lower than the capacity of rainwater tank ( $S$ ), rainwater supply should be limited to meet the minimum demand ( $D_{\min}$ ) at the  $t$ th day. If  $V_t$  is higher than  $S$ , it means that the amount of rainwater is excessive. Hence, rainwater can be supplied for multiple usages within the maximum demand ( $D_{\max}$ ) on the days before the  $t$ th day. The daily demand can be mathematically described as follows:

$$\text{If } V_t \leq S, D_t = D_{\min} \quad (6)$$



roof area per  $\text{m}^2$  (USD);  $R$  is the expanded roof area ( $\text{m}^2$ ); and  $C_I$  includes both materials/equipment and installation costs (USD).

## Data

For this study, daily rainfall data were collected from Hanoi city for a typical dry year such as 2005. It should be noted that the long-term annual average rainfall for the city is 1,800 mm, whereas in 2005, the total annual rainfall was 1,594 mm. Figure 4 shows the rainfall time series for the year 2005. Although the typical roof area is  $50 \text{ m}^2$ , it is possible to expand the roof area by using a canvas fabric catchment or locally available materials (Nguyen *et al.* 2013). A range of roof areas ranging from 0– $350 \text{ m}^2$  was considered. With regard to the tank sizes, 0– $10 \text{ m}^3$  were considered. To compare the performance of this study model with the old model, three demand scenarios were selected, namely: (a) low demand (for potable purposes only, which is typically about  $4 \times 15 \text{ L}$  per day per household); (b) high demand (which for all purposes is typically  $4 \times 50 \text{ L}$  per day per household); and (c) variable demand as dictated by rainfall (for potable purposes on dry days and for all purposes on rainy days). The low demand and high demand scenarios are calculated by the old model; the variable demand as dictated by rainfall scenario is calculated by this study model.

## RESULTS AND DISCUSSION

Figure 5 shows the variation of reliability varying with tank sizes and roof areas under different demand scenarios:

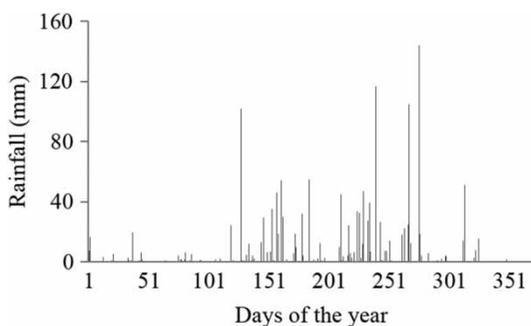
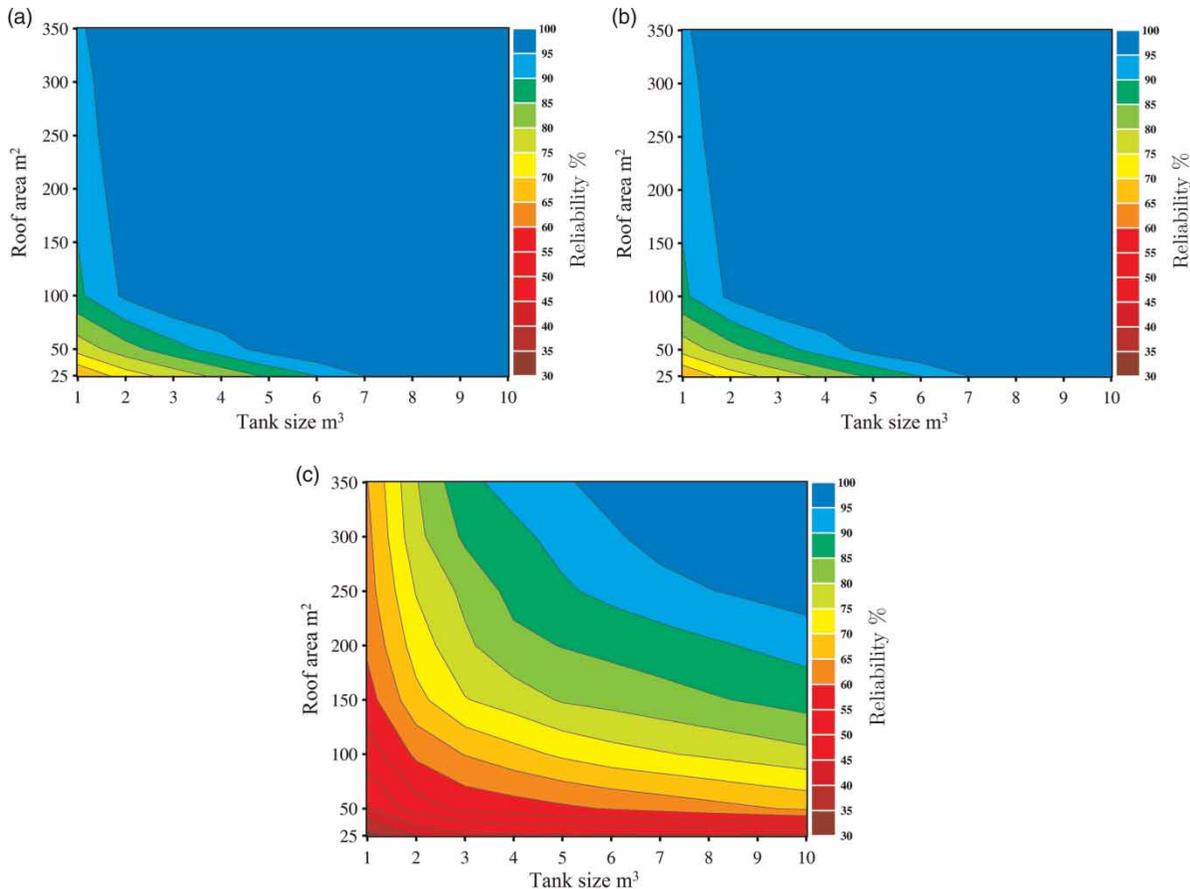


Figure 4 | Daily rainfall data for the year 2005 from Hanoi city.

(a) for low demand scenarios; (b) for varying demand as dictated by rainfall; and (c) for high demand scenarios. From the figure, it is clear that reliability increases with a proportional increase in tank size or roof area. With a tank size and a roof area, the reliability of low demand scenarios is equal to the reliability of the scenario in which demand is variable due to rainfall. These reliabilities can be significantly higher than the reliability of high demand scenarios. For the low demand and variable demand due to rainfall scenarios, 100% reliability can be achieved with a tank size of  $8 \text{ m}^3$  and roof area of  $25 \text{ m}^2$ . The tank size can be decreased to  $2 \text{ m}^3$  when the corresponding roof area is  $150 \text{ m}^2$ . For a high demand scenario, 100% reliability can be achieved with a tank size of  $10 \text{ m}^3$  with a roof area of  $250 \text{ m}^2$ . The tank size can be decreased to  $6 \text{ m}^3$  with a corresponding roof area of  $350 \text{ m}^2$ .

Figure 6 shows the variation of the water savings with varying tank sizes and roof areas under the different demand scenarios: (a) low demand, (b) varying demand as dictated by rainfall, and (c) high demand scenario. It is found that the water savings can be increased with an increase in tank size or roof area. With the appropriately sized tank size and roof area, the water savings for a high demand scenario are equal to those of the scenario in which demand is variable due to rainfall. These savings can be significantly higher than the water savings estimated for the low demand scenario. For the low demand scenario, the maximum water saving of a RWH system is  $22 \text{ m}^3$  for a four-member household per year. This can be achieved with a tank size of  $2 \text{ m}^3$  and roof area of  $100 \text{ m}^2$ . Meanwhile, for the high demand and variable demand due to rainfall scenarios,  $44 \text{ m}^3$  of water can be saved with a tank size of  $2 \text{ m}^3$  and a roof area of  $100 \text{ m}^2$  for a four-member household per year. The maximum water saving of a RWH system is  $73.2 \text{ m}^3$ . The higher the water saving, the lower groundwater exploitation, meaning that the electricity cost for pumping groundwater can be reduced. Moreover, the land subsidence in Hanoi area can be decreased since groundwater extraction is the main cause (Nguyen & Helm 1995).

From these results, it is clear that for the scenario whereby demand is varied as dictated by rainfall, as was calculated by this study model, a RWH system can obtain optimal performance with maximum reliability and water saving.



**Figure 5** | Variation of reliability (%), (a) for low demand scenario (b) for varying demand as dictated by rainfall scenario and (c) for high demand scenario.

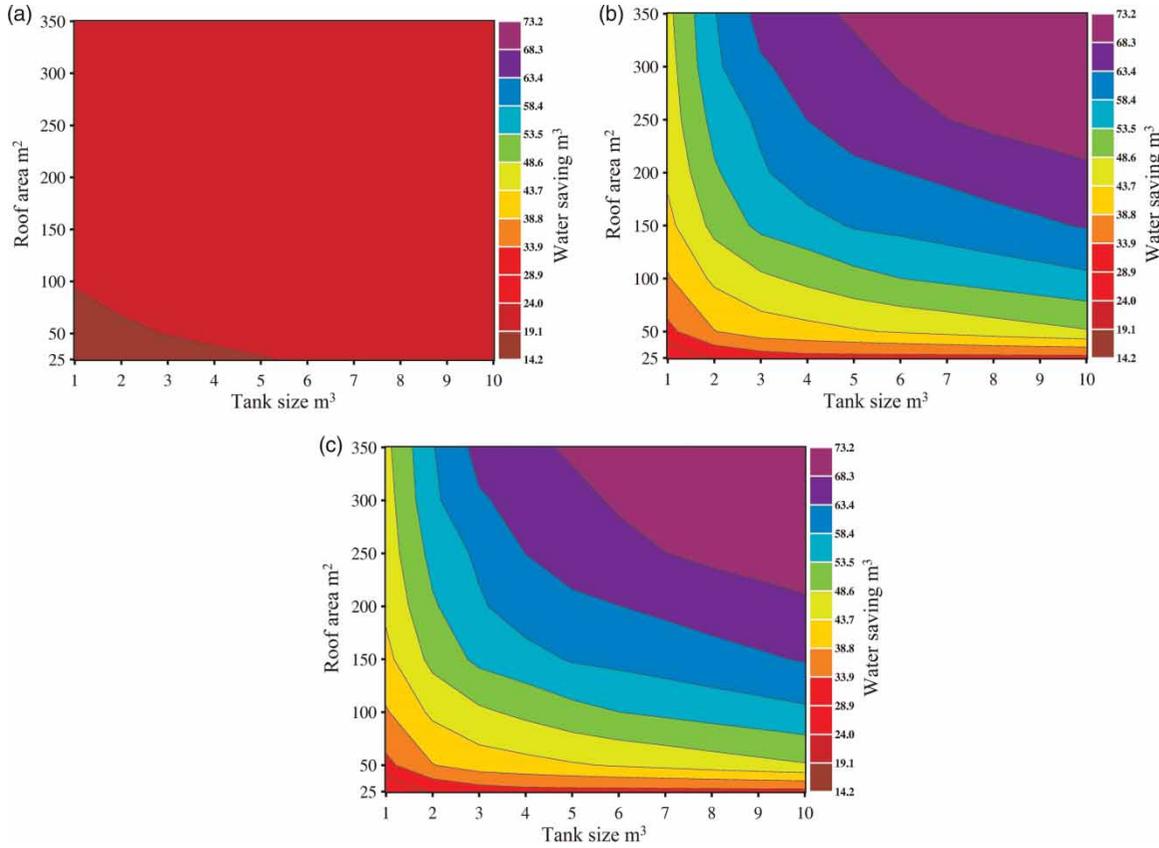
Figure 7 shows variation of cost and reliability with tank size and roof area for the scenario where demand is varied as dictated by rainfall. The cost of the RWH system increases with a proportional increase in tank size or roof area. In order to get 100% reliability, a RWH system with a roof area of 100 m<sup>2</sup> and tank size of 2 m<sup>3</sup> is recommended because it has the lowest cost. The investment cost of the RWH system is 330 USD. Assuming that the RWH system has a life of 30 years and the cost of electricity for pumping groundwater per cubic meter is 0.02 USD/m<sup>3</sup>, the total water supply cost of the dual system is 0.16 USD/m<sup>3</sup>.

Figure 8 shows the water supply chart for a four-member household with a RWH system which has a roof area of 100 m<sup>2</sup> and a tank size of 2 m<sup>3</sup>. The daily demands are calculated for each day in a year by this study model. From these results, it is recommended that rainwater be supplied for potable purposes only in January–April and October–December.

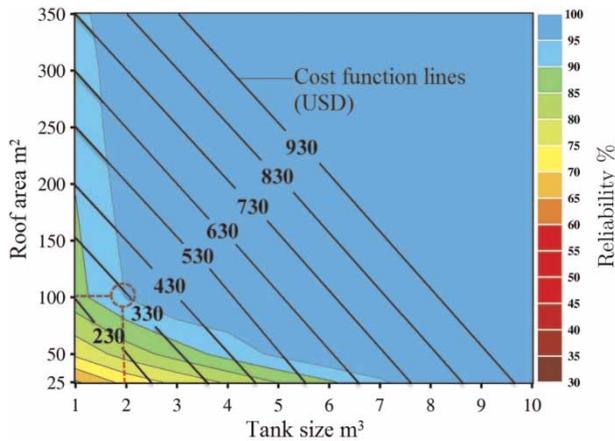
Additionally, the figure shows that rainwater should be supplied for all purposes in May–September. Groundwater is supplied for non-potable purposes as a supplement water supply in January–April and October–December.

## CONCLUSION

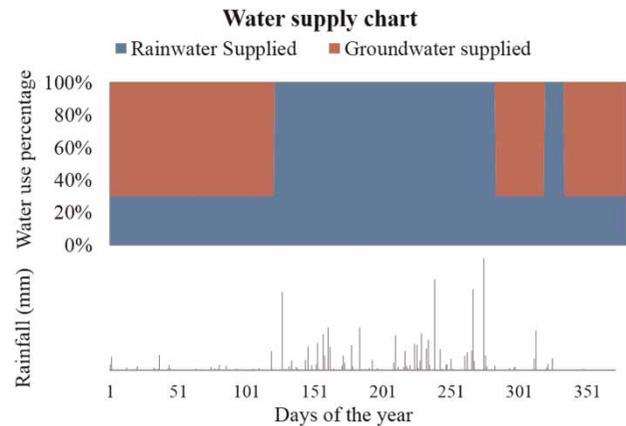
This paper investigates a dual water supply consisting of both rainwater and groundwater for providing sustainable water for Cukhe village – an area where the current water supply has been found to be contaminated. Rainwater quality is typically good. Although rainwater may be microbiologically contaminated, it will require minimum treatment before using it as potable water. Groundwater of the village, on the other hand, was found to have a low turbidity but high concentration of heavy metals (As). As such, it can be supplied for non-potable purposes.



**Figure 6** | Variation of yearly water saving for four-member household ( $m^3$ ): (a) for low demand scenario; (b) for varying demand as dictated by rainfall scenario; and (c) for high demand scenario.



**Figure 7** | Variation of cost and reliability by tank size and roof area for demand which is varied due to rainfall scenario.



**Figure 8** | Water supply chart for four-member household with a RWH system which has a roof area of  $100 m^2$  and a tank size of  $2 m^3$ .

In this paper, a novel simulation chart is developed based on rainfall variance and is then used to analyze the RWH system performance. Also the daily water demands are calculated for each day in the year by the model. A RWH system

can obtain optimal performance when water use from the system is variable as a function of the rainfall pattern. The cost of RWH systems is also analyzed. In order to obtain 100% reliability for a four-member household,

a RWH system with a roof area of 100 m<sup>2</sup> and a tank size of 2 m<sup>3</sup> is recommended in terms of cost efficiency. Also it is recommended that rainwater should be supplied for potable purposes only in January–April and October–December but should be supplied for all purposes in May–September.

The design and evaluation method proposed in this paper will be useful in evaluating and comparing the performance of RWH systems developed for other areas. These methods can also be applied to other regions using site-specific conditions.

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