Application of Sustainable Solar Energy Solutions for Rural Development—A Concept for Remote Villages of India

Shivakshi Jasrotia, Arun Kansal, Madhuben Sharma and Swati Gupta

1 Introduction

Approximately 50% of the world's population lives in rural areas. Another fact also brings about the information that the rural population exceeds 70% of the country's population, especially in low- and middle-income countries. In many countries, the share of rural GDP is much more than that of urban GDP; however, in terms of quality of life, the rural population is far behind than that of the urban population and lacks access to basic services such as electricity, water supply, transport, sanitation [1]. Water is a basic necessity of life, and the provision of potable drinking water is a prime priority for improving health of rural and poor sectors of Indian society. As per the report of UNICEF in 2001, nonavailability to potable drinking water resulted in nearly 1.5 million losses of lives of children with 37.7 million yet affected [2]. In rural areas, the groundwater or earmarked surface water

S. Jasrotia (✉)
Centre for Global Environmental Research, Earth Science and Climate Change Division, The Energy and Resources Institute (TERI), IHC Complex, Lodhi Road, New Delhi 110003, India
e-mail: shivakshi_jasrotia@yahoo.com

A. Kansal
Coca-Cola Department of Regional Water Studies, TERI University, Vasant Kunj, New Delhi 110070, India
e-mail: akansal37@gmail.com

M. Sharma
Department of Environment Sciences, University of Petroleum and Energy Studies (UPES), Dehradun, India
e-mail: madhubensharma06@gmail.com

S. Gupta
TERI University, New Delhi 110070, New Delhi, India
e-mail: swatiboond71@yahoo.co.in

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has been considered to be safe for public water supplies. But recent times, enough evidences have brought out the fact that present groundwater is becoming increasingly contaminated with elevated concentrations of heavy metals. Also, it is a known fact that worldwide, nearly 1.0 billion people remain without access to electricity and 2.9 billion are still cooking on harmful and inefficient stoves. Easy management and disposal of domestic wastewater is another key issue for rural residents. Many rural residents still live in the remote rural locations, and until they have access to energy services, little progress can be made to develop and improve their lives.

In India, one such village which lacks all the above-mentioned basic amenities is Kaudikasa. Figure 1a shows the location of the village located in Rajnandgaon, a district of Chhattisgarh, India. Figure 1b shows the dry location where there exists some local, seasonal ponds for fishing, bathing and washing, etc. The other common practices for using local water are for both cooking and drinking. As per the 2011 census, 400 households (HH) are present where the population count was 1970 [3]. The average shows around 5–6 members lived together in each household. The village does not have a very high literacy rate with nearly one primary and one secondary school opened a few years ago.

The housing style included both "*Kacha* and *Pakka*" houses. Locally available bricks and mud tiles were used for construction of *Pakka* houses. *Kacha* houses were constructed using mud, grass and bamboo. The figures reflect the real situation where ample space is present on both house roof and on the ground area. Figures 2a and 2b show the roof structures and village drainage system which are not that well maintained. Nearly 6.1 mg/L arsenic has been found in the village. The numbers of groundwater hand pumps, open dug wells, pond in the village were 6, 2 and 1, respectively [4]. About 110 people are currently suffering from arsenic-related diseases such as keratosis (skin burning and irritation blackening of skin) paralytic attacks and early greying of the hair due to drinking this unsafe water [4]. Very recently a piped water supply scheme has been implemented by PHED, Rajnandgaon. Also, four neighbouring houses share a common tap.

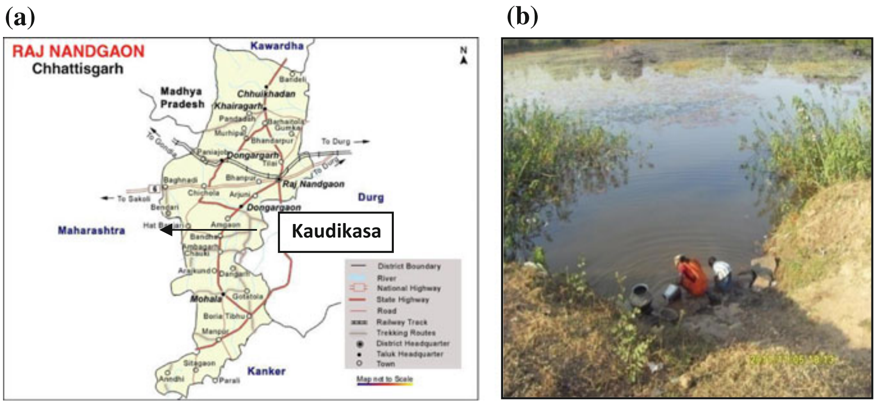

Fig. 1 **a** Map of Rajnandgaon (Kaudikasa location) and **b** local usage of pond for cleaning

(a) (b)

Fig. 2 **a** Kacha–pakka house (Kaudikasa village) and **b** common drainage of hand pump water

There exists a wide range of available solutions for above-mentioned drinking water and sanitation issues, but with their own set of limitations on the front of long-term sustainability. For instance, like water treatment methods applied today for the purpose of drinking water supplies conventionally require energy-intensive technologies such as coagulation, filtration and flocculation. The treatment technologies include ion exchange, electro dialysis, ultra-filtration, which are not only dependent on a reliable supply of grid electricity supply but are also expensive and require skilled operators. But such technologies are not economically viable in rural areas and are found to be deficit in terms of reliable power supply as well as per capita income. Another health impact issue is the using the conventional cook stoves. Many rural household females still rely on conventional cook stoves for cooking, which risking their health in many forms [5].

Therefore, innovative approach for sustainable management of water, sanitation and other important issues like alterative safe and healthy cooking practices is required in rural areas. The innovative approach should also consider the local custom and environmental conditions so as to provide a long-term and reliable solution. One such approach is harnessing solar energy for this purpose. For a country like India, which is blessed with ample amount of sunshine, i.e. about 5000 trillion kWh of solar energy annually, relying on solar energy is upcoming frontline of research as new initiatives. Not only does it uses the naturally present solar flux, but also promotes the independency of local villagers to smarter green technologies. These technologies and systems that are more cost-effective, natural, grid free, sustainable, bear less operation and maintenance cost and can be used by both males and females of the family [6]. The solar energy on earth is most efficiently tapped in two forms which solar energy as heat (thermal capturing) and solar capturing through biomass production (photon or radiation capturing).

The following study brings forth the application of solar energy as an alternative for producing safe drinking for per capita basis, as per the set drinking water standards of BIS and WHO. This paper presents the results obtained by using solar energy in the form of solar still for water treatment. Also, the study concludes the smart rural household concept, schematic with various solar-energy-dependent solutions such as solar cooker, solar panels for generating power and solar lanterns. The study also relates solar-flux-dependant phyto-pond for remediation of wastewater for rural sanitation and further irrigation usage.

2 Methodology for Drinking Water Quality Evaluation

2.1 Experimental Set-up for Drinking Water Treatment by Solar Distillation Unit

Performance evaluation was done on a plastic-type solar distillation unit (Fig. 3) for a period of one year in 2011. The dimensions of the solar still were 1 m^2 (length = 1 m, width = 1 m,) and have a glass top of thickness 4 mm with tray capacity of 40 L. The basin was made of black fibre with inlet and outlet ports made of stainless steel to avoid corrosion and rust. East-to-west direction is the most stable direction for unit alignment with the glass cover panel in the north-to-south direction which produces a maximum yield of distillate. The still was operated on batch mode where spiked water samples were loaded /introduced into the unit on every 10th-day basis. This system was placed at 8.6° tilt angle, and a daily yield of 1.5–3.5 L approximately was collected in the collector box positioned at bottom of still. A total of six batch run for three different samples were conducted where in each batch, water remains in the tray for 10 days. Evaluation efficiency was based on various types of input waters used.

Fig. 3 Single basin-type solar still with distillate collector

Table 1 Sample preparation

S. No.	Sample	Source	Location	Additional information
1	S1/GW	TERI university	New Delhi	Used for preliminary trials
2	S2	Simulated sample	Prepared in TERI university laboratory	Rich in arsenite salts
3	S3	Simulated sample	Prepared in TERI university laboratory	Rich in arsenate salts
4	S4	Simulated sample	Prepared in TERI university laboratory	Rich in arsenate + arsenite
5	S3 + 5	Simulated sample	Prepared in TERI university laboratory	Rich in Arsenite + Arsenate +Fluoride + Fe + Nitrate and coliforms

The experiments pertaining to the study were conducted in a research laboratory in New Delhi, India. Five different inlet samples were simulated in the laboratory which resembled the groundwater conditions found in arsenic- and fluoride-affected Kaudikasa village (Table 1). Samples 2, 3 and 4 consisted of arsenite and arsenate. Sample 5 consisted an elevated % of salts such as total arsenic, iron, fluoride and nitrate as per the ranges found across affected locations. Different samples that were used in the still are listed below:

Spiked samples with variable concentrations were loaded in the basin for a 10-day study and further evaluation. Distillate was recovered from unit on a daily basis, and various water quality parameters were checked. Nearly 50 samples of distillate have been analysed for parameters such as TDS, arsenic, pH, iron, fluorides, nitrates, sulphates, total coliform. Standard method references have been used for analysis of parameters [7].

3 Results for Solar Still Investigations for Rural Domestic Water Supply

Figure 4 represents the results of study and in comparison to the limits of WHO standards the quality of outlet—treated water. It shows comparisons between initial values of TDS and hardness to their distillate qualities. The TDS which ranges from 1200–1300 mg/l was lowered down to nearly 30–60 mg/l. The residual had only 2.5% of the initial TDS load remaining in the basin, with no odour emissions. Similarly, initial chlorides with a range of 270–500 mg/l were lowered to 9–13 mg/l in distillate, i.e. 2.6% was found in brine residue. Similar, a decrease was also found in the initial concentration of sulphates, arsenic, pH, nitrates and iron. Throughout the experiment, pH of distillate was between 7 and 7.3.

Based on drinking water guidelines by WHO for drinking water quality, the level of nitrates should be below 50 mg/l, arsenic should be below 0.01 mg/l, and

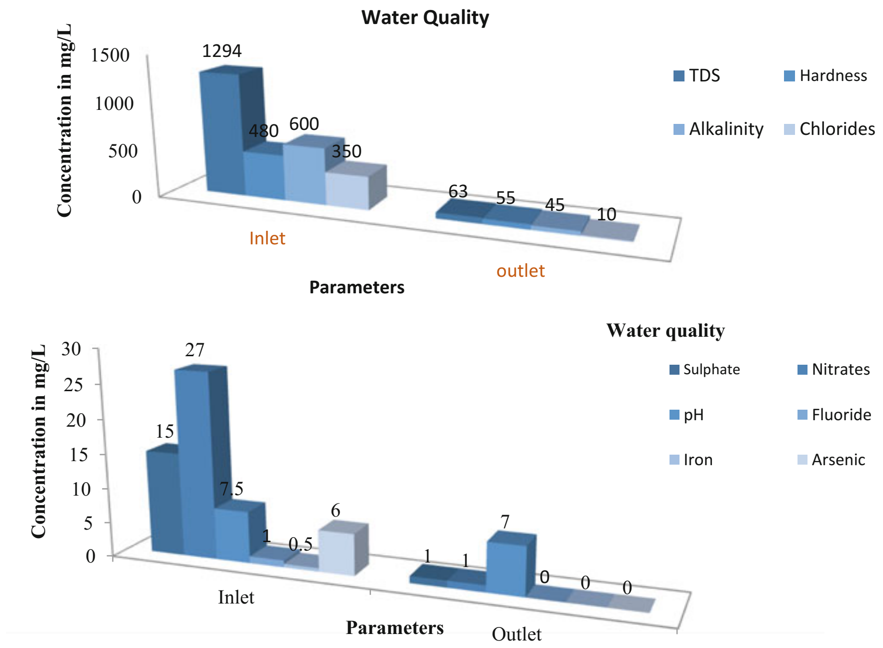

Fig. 4 Comparison between inlet and outlet water quality parameters

fluoride should be below 1.5 mg/l. The values for all the health-based parameters for distillate fall well as per the listed WHO standards. In terms of drinking, some fluoride salts may be added to the distillate as the distillate water is deficient in fluoride concentration. Another important health-related concern is the presence of *coliforms* in the drinking water. As per the WHO standard, safe drinking water should not have coliform in any 100 ml of sample. This was not found in any of the samples of distillate water analysed (Table 2).

3.1 Feasibility Study for Adoption of Solar Distillation Technology for Kaudikasa Village, Rajnandgaon

The benefits of the usage of the solar still distillation unit were discussed with the community people. It was found that the technology was found to have high acceptance as it would help provide safe drinking and cooking water, and the solar distillation can be easily installed on the rooftop or above the ground [4]. This system for treatment of brine and kitchen waste could further be attached to phyto-pond with hyperaccumulator plant species [8]. The Public Health Engineering Department (PHED) also found that the concept and the implementation are highly acceptable and were ready to extend support for the same. It is

Table 2 Comparison of distillate water quality with drinking water standards (Jasrotia et al. 2015)

S. No	**Parameter**	**Outlet average**	**WHO limits** (mg/L)	**Remarks**
1	pH	7.14	6.5–8.0	No post-treatment polishing is required
2	TDS	45	600	No post-treatment polishing is required
3	Arsenic	<0.01	0.01	No post-treatment polishing is required
4	Alkalinity	38.3	Not defined	No post-treatment polishing is required
5	Hardness	33.8	200	No post-treatment polishing is required
6	Sulphate	0.72	250	No post-treatment polishing is required
7	Fluoride	0.02	1–1.5	Requires addition of fluoride salts
8	Chlorides	10.8	251	Requires addition of fluoride salts
9	*T.coli*	NA	Should not be detectable in any 100 mL of sample	No post-treatment polishing is required
10	Iron	0.00	0.3	No post-treatment polishing is required
11	Nitrates	0.74	51	No post-treatment polishing is required

estimated that the daily drinking water and wastewater treatment using the proposed unit would require a capital investment of Rs 68,795 (Jasrotia et al. 2013). Therefore, it is estimated that a total cost of INR 2,75,18,000 will be required for setting up the solar distillation technology for the village which has approximately 400 households.

For a village in Chhattisgarh (Kaudikasa) where approximately 5–6% of the total population is suffering from arsenic- and/or fluoride-related medical conditions, such a treatment system would be a good and easily affordable initiative. Replicability in other affected regions also could be aimed once this is implemented. It is expected that access to clean drinking water and better sanitation will result in improved health of many rural residents. The initiative will significantly improve the lives of women and children who have to travel 3−5 km daily to bring water. The time saved by the women and children will give them the opportunity to engage in educational activities and especially women can engage in some employment [4].

Figure 5 shows a schematic for the final set-up of the system, which can be installed at household level and can be easily scaled to community level. Other than

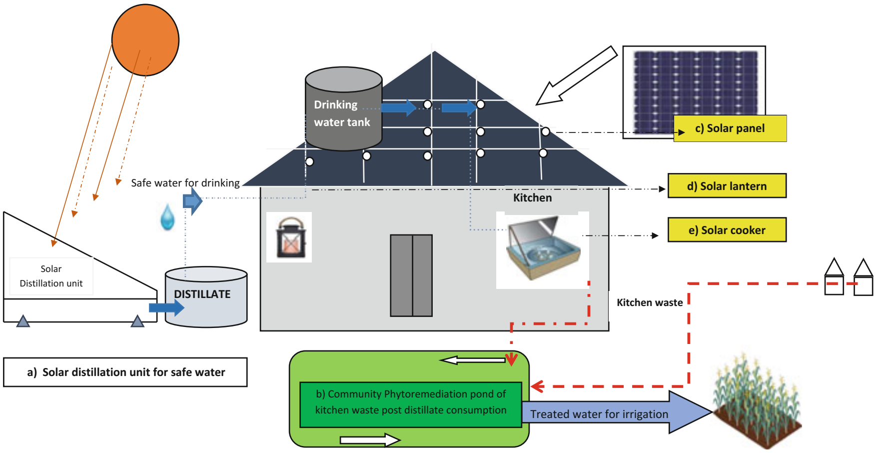

Fig. 5 Schematic for utilization of solar energy solutions for rural household

solar distillation unit, more renewable energy concepts such as the addition of solar cookers, solar lanterns and solar panel could also promote the development of rural front.

4 Conclusion

4.1 Application of Solar Distillation and Phyto-pond for Domestic Water Supply

Various controlling parameters such as depth of water in the still, input water quality, solar radiation intensity were studied to optimize the performance of a solar still. The performance of the system was studied by varying the parameters such as nitrates, fluorides and arsenic using stock solutions. Other parameters such as pH, alkalinity, hardness, chlorides and sulphates which have an influence on the solubility of various metals including were also simultaneously studied. Sewage water was added to the feed water to gauge the pathogen removal potential of solar still. A number of trials were run over a period of two years.

It was found that the solar still has very high treatment potential. The removal efficacy for the pollutant (arsenic) is more than 97%. The treated water was free from pathogens. Coliforms and the other remaining parameters meet the drinking water standards set by WHO [8]. The treated water was found deficient in essential salts, and therefore, some salts have to be added to the distillate for drinking purpose. The added salts were in accordance with the current requirements as per drinking water quality standards—1.5 mg/L of fluoride, 240 mg/L of chlorides, etc. [9].

This study was aimed towards the global efforts in addressing the problem of heavy metal and pathogen-free clean water supply which is a major concern in many parts of the world. This study and its results do strive to make a contribution. This could be termed as a novel approach against other arsenic treatment as it is a simple concept which is easy to operate and does not need skilled labour. This does not need any electrical power and it majorly runs on direct sunlight.

As rural locations have ample sunlight and space, this could be a safe solution in upcoming time.

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