Performance Evaluation of Solar Energy-Based Distillation System for Groundwater Purification: A Green Concept for Rural Development of Indian Villages

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Abstract Globally, increasing water pollution and lack of safe drinking water has raised an alarming situation. There are breaching water treatment systems which are increasing the rate of mortality by severely affecting the health and severe health effects due to lack of potable water. This guides us to develop and initiate sustainable solutions for both urban and rural communities. A common solution for many water-related key issues like an assurance to its availability, its reliability, and purity can be dealt with the development of low-tech systems which reflect and promote long-term sustainable solutions. The following chapter discusses a process that harnesses the solar energy for the removal of arsenic contamination in water, followed by phytoremediation to treat the generated waste to meet the disposal requirements. The chapter also throws light on alternative solutions relying on solar energy for rural development, with economic evaluation to address the vulnerability of residents in context to the changing environment, climate change, and groundwater pollution, etc. The chapter opens new roads of environmental sciences taking the lead for agricultural biotechnological problems of groundwater contamination.

Keywords Groundwater pollution · Solar energy · Public health · Remediation Rural development · Climate change and vulnerability

1 Introduction

Sustainability means the use of natural resources with principle of—equity, efficiency, optimization, and decentralized planning. Resources include both natural

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endowments and man-made. Water is one of the most fundamental and versatile resources among all natural resources. It is both unitary and finite with few substitutes or no substitute for many applications. Indiscriminate use and toxic discharges have polluted groundwater and made it unfit for human consumption. "Water and health" is the theme that poses major challenge to sustainability of man on earth. Nearly, 1 billion people in developing countries, particularly the rural poor, lack access to potable water and 2.6 billion has to contend with inadequate sanitation facilities [1]. It is now globally accepted that water- and sanitation-related diseases are the single most cause of mortality and morbidity. The two inseparable aspects of sustainable water management are water quantity and its quality. In recent times, other than microbial diseases, chemical characteristics of water, such as arsenic metal, fluorides, and nitrates are increasingly being recognized. Among the present contaminants in drinking water, the risk of dissolved arsenic in its various forms is life-threatening. The factors responsible for this include industrial discharge, climate change, and the large variability in rainfall and hence more dependence on groundwater sources with the large-scale abstraction of groundwater (at times more than that of recharge potential). The risks associated with consumption of arsenic and nitrates, etc., and affected drinking water are both toxicological as well as environmental. Coincidentally, most of the arsenic-affected areas are rural and the economically poor population is the most vulnerable.

The menace of arsenic has been reported very high in groundwater especially in countries like India, Bangladesh, Pakistan, and Nepal. The condition is such that these countries have the elevated levels more than 10 times in comparison to the drinking water standards as mentioned by WHO of 0.01 mg/L [2]. Nearly, 100 million people are at a health risk due to the elevated arsenic metal presence in groundwater [3]. From the 33–77 million affected patients, approximately 70 million people are in India itself who are vulnerable and residing in arsenic affected areas, respectively [4, 5]. Numerous methods for its treatment have been investigated time and again like coagulation; filtration and ion-exchange for arsenic removal; methods like these have been developed and tested on the field. But, ironically, it has also been mentioned in the literature that these methods either need electricity to run or require monitoring of certain performance parameters on a regular basis. They are also found to generate hazardous waste that limits the sustained performance of these technologies in rural field application. Now in context to a rural area that has no access to skilled manpower and electricity, these treatment alternatives will be defunct and futile with time. The following three major barriers have been highlighted which make safe drinking water supply and sanitation programs in rural areas unsuccessful over the time. Firstly, due to focus on other major priorities, the rural infrastructure projects in low- and middle-income countries are found to be financially unattractive. Secondly, an uninterrupted electrical form of energy for 100% operation of treatment units is needed for most of the water treatment process (energy intensive). Thirdly, the reliability of treated water gets questionable in such systems based on the adsorption method as most of the natural systems suffer from the lack of information about the completion of media or its replacement. Therefore, sustainable management of water in rural areas which is consistent and reliable requires an innovative approach that takes into account ground realities before operation. In light of this, the present study aims to provide a renewable energy-based cost-effective and sustainable solution for drinking water and sanitation in rural areas. One such approach is exploring and harnessing solar energy for this purpose. The solar energy on earth is most efficiently tapped in two forms which are—solar energy as heat (thermal capturing) and solar capturing through plant biomass-based remediation and biomass production (photon or radiation capturing).

The objective of this research is to not only to address this issue through the use of solar energy for water purification in the context of rural water supply and removal of metal like arsenic, but to also evaluate the sustainability equation in terms of application. This research study outlines and investigates a concept for drinking water supply in rural household, which is provided through the process of (1) capturing solar heat using solar still technology, (2) the wastewater generated from solar still (brine) is disposed after post-treatment options like plant biomass remediation.

2 Solar Distillation and Water Purification: Historical Perspective and Types

Water and energy are two indivisible items that have governed our lives and promoted civilization [6]. Desalination is the oldest technology and has been used for water purification globally especially salt water to drinking water. Between the several possible options for desalination, renewable energy technology is the most promising technique for water purification in terms of economic stability and technological feasibility [7]. The various technologies that have been invented and employed for desalination purpose include vapor compression distillation, reverse osmosis, and electrodialysis where electric energy is the source energy. Considering the rising energy crises, renewable energy-driven desalination technologies such as distillation desalination using solar energy becomes a widely acceptable solution.

Distillation has been considered as a way of making salt water drinkable from sources in remote locations [8]. The history of using solar energy to treat water dates back to the era of the Renaissance, when desalination was the natural method used to treat brackish water [6]. It was Arab alchemists in the sixteenth century, who were the first known to have used the solar distillation system for treating water [8]. Wheeler and Evans received the first American patent in 1870 for solar distillation [6, 9]. Later on, after two years, in 1872, the first large solar still was built in Las Salinas, Chile, by Carlos Wilson, which had 64 basins designed from wood and timber framework with sloping glass covers [6, 8]. From 1950 onwards, developments have been made in solar still for developing larger plants to treat water globally. In 1978, Bhavnagar got the first largest solar distillation plant with 90 still units, installed by Central Salt and Marine Chemical Research Institute to supply drinking water to non-electrified Awania village of the system are (1) raw water, (2) enough sunlight, and (3) black

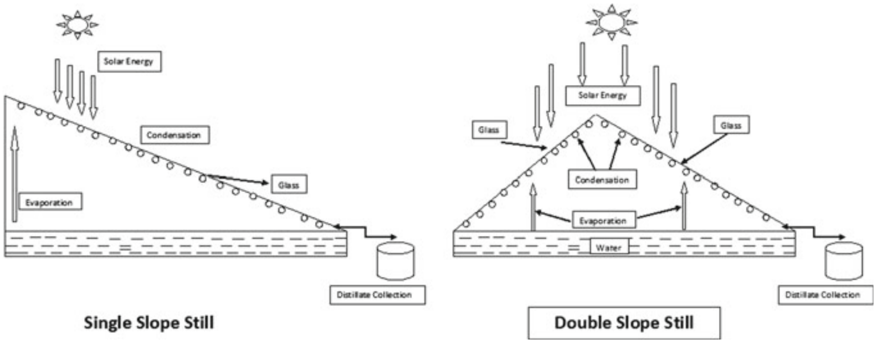

Fig. 1 Single and double slope still

basin body. Unlike a community water supply system, it does not require any other infrastructure like water pipelines, heavy maintenance, and Chhachi lighthouse [8].

Solar stills are sealed units with glass cover, which evaporate brine/brackish water for household or large community supplies [9]. As these stills have the capacity to produce limited quantities of drinking water for a household and require no grid electricity or skilled labor or heavy technology, they can be a viable solution in rural areas where above-mentioned limitations are not a constraint [9, 10].

Numerous types of solar still like single slope, double slope multi-basin (Fig. 1) have been reviewed by various researchers. [11, 12]. Among the existing solar still types like conventional type, single and multiple basin, wick type, multiple effect, basin-type stills have been used for the supply of large and small quantities of water [11]. In this study, single slope, single basin (SSSB) was selected for the study and application for rural location as it's the cheapest and most easily constructed basins [13].

The **objective** of the research is to eliminate metal from the water identifying and testing cost-effective, simple to operate and maintain and is sustainable on long runs on test field site. Also, the research investigation targeted to check the system success for arsenic-free water supply in terms of three important components, i.e., social viability and acceptance, technical and economic viability.

Methodology for solving the problem: The research used solar still technology for drinking water production, which is metal ion free and also treatment of leftover brine with natural options like plant biomass. The schematic representation for the same is given below (Fig. 2). The study consisted of four phases as described below:

- Phase I: Investigations on solar distillation unit suitable for domestic water supply, field trials for entire village.
- Phase II: Investigations for project design for application of the system in rural village with remediation and analysis per unit cost of water from the system.
- Phase III: Analysis of system in terms of sustainability parameters—social acceptance technical and economic viability.
- Phase IV: Monitoring the health targets and benefits attained by rural people.

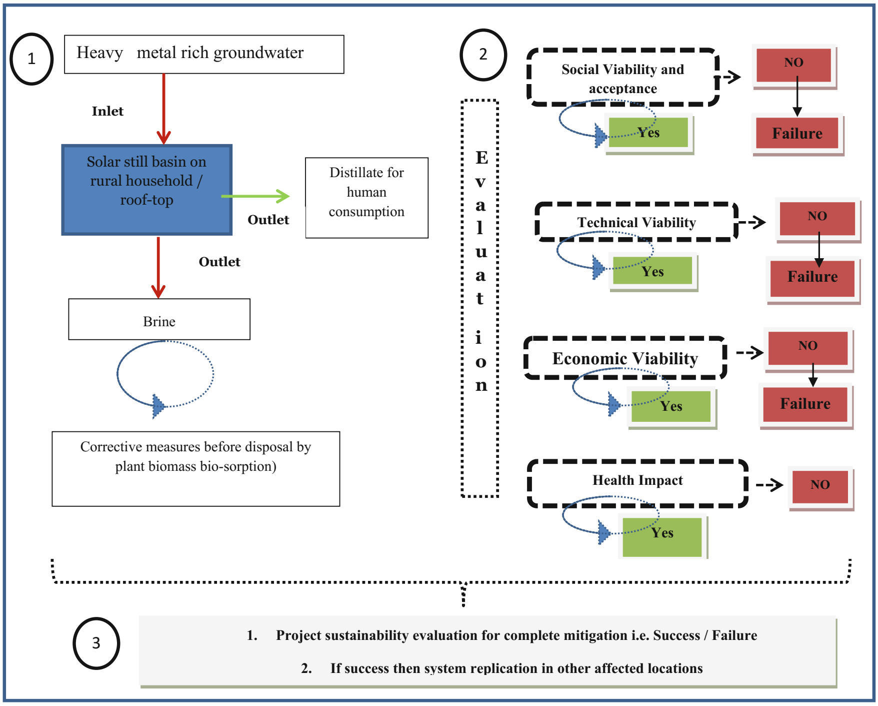

Fig. 2 Schematic representation of the concept for arsenic removal and system evaluation for sustainability

3 Experimental Set up

Figure 3 shows the unit of SSSB (single slope, single basin)-type solar still for which performance was evaluated. The unit was 1 m^2 (both length and breadth) in dimensions with a tilt angle of 8.6°. The basin was made of black fiber with a total carrying capacity of about 40 L for the basin and had a glass top ranging to 4 mm thickness. SSSB was placed in east to west direction and had both the inlet and the outlet pipes made of steel material (this helped to avoid corrosion). Different combination of sample water spiked with the variability of arsenic was added to the basin body through the inlet pipe for the 10-day study period. For the operations of the unit and experimental analysis, batch study was done, and every 10th day of outlet, distillate was collected (approximately ranged between 1.5 and 3 L) for sample analysis against different input water load.

Fig. 3 Single slope, single basin-type solar still with distillate collector [7]

4 Results for Solar Still Investigations for Rural Water Supply

This section brings forth the results of the study where inlet water quality has been compared to outlet water quality with reference to WHO drinking water standards. Referring to Fig. 4, it is evident that there exists a sharp decline in the values of TDS and chlorides both, for the outlet distillate in comparison to initial inlet water quality. TDS value was found to be lowered down to nearly 95% (i.e., from 1200–1350 range mg/L to 25–50 mg/L). Similarly, chlorides value was reduced to 96% (i.e., from 300–500 mg/L to 25–50 mg/L). No odor emissions were found in the run. The brine therefore had only 3.5–4.0% of TDS and chloride salts as leftovers. The same trend of similarity was found for dissolved arsenic, iron, nitrates, alkalinity, pH, hardness and sulfate salts.

In compliance to the drinking water standards (WHO), the level of nitrate salts should be less than 50 mg/L; for arsenic, it should be less than 0.01 mg/L and fluorides should exist as 1.5 mg/L. These were found in regulation to WHO limits. In reference to WHO standards, to make the distillate water potable and for human drinking use, some additional fluoride salts can be added as a supplement. As per WHO standard, as safe drinking water should not have coliform in any 100 ml of sample (Table 1). There were no such Coliforms found in the sample post-treatment.

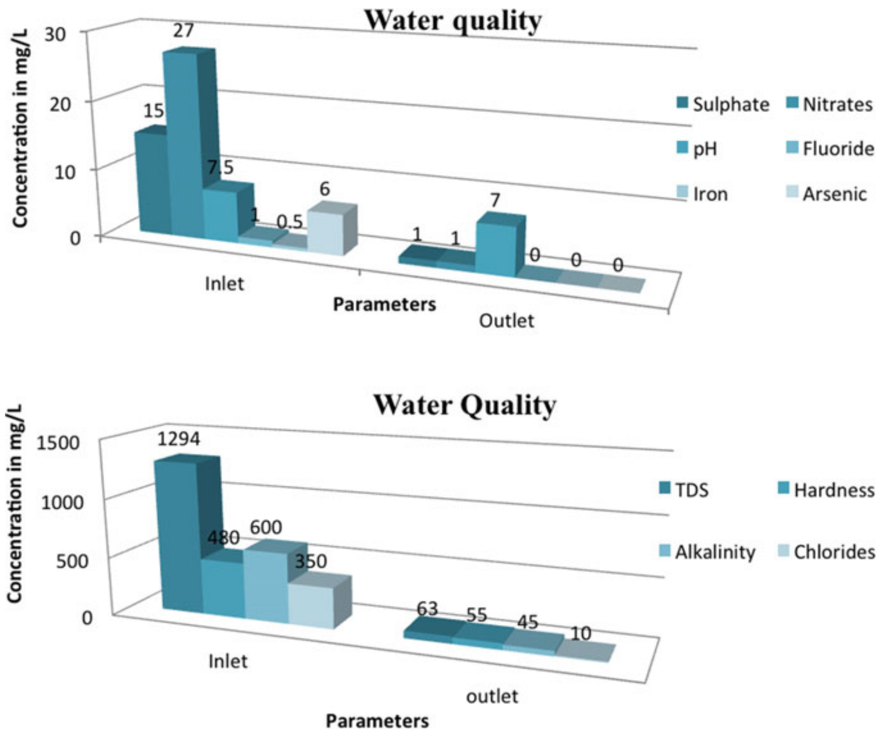

Fig. 4 Inlet and outlet water quality after distillation

5 Discussion and Conclusions

The literature has already established that the solar energy application in form of distillation using a solar still has very high treatability potential for various parameters of water to make it potable at different situations. In the study, two major conclusions can be drawn with respect to arsenic rich-groundwater—a) treated water was found to be free from pathogens and Coliforms both and b) the study results also highlighted that the selected basin has an efficiency to remove pollutant (arsenic) for more than 97%. The study results strikingly also brought forward that the other remaining parameters do meet the required drinking water standards as in accordance with WHO limit [14, 15] but with some addition of salts. This is in reference to making potable water fit for drinking; some post-treatment measure is required as the distillate water is deficient in essential salts (needed for human metabolism). Therefore, these essential salts have to be added to the distillate for drinking purpose. This would be in accordance with the current requirements as per drinking water quality standards that need 1.5 mg/L of fluoride, 240 mg/L of chlorides, etc.

The present study aimed at addressing the global problem of arsenic as a heavy metal dissolved in groundwater blocking access to potable water supply to many

Table 1 Comparison of distillate water quality with drinking water standards

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

Taken from reference no. 15

vulnerable residents [16]. The research study was a contribution made for this global concern-wide spreading at an alarming rate. The study can be identified as one the most sustainable—novel concepts as (a) it's a simple concept with no requirement of skilled labor, (b) it runs on renewable energy-solar sunshine, (c) environment friendly as brine is also co-treated before release, and (d) it is sustainable on long run with less maintenance cost-effective.

The method explained in Fig. 2 clearly defines these points of credit for this unique system as a novel concept meant for human betterment. It is actually due to the ease of working and operation of the selected solar still basin SSSB (single slope, single basin) that the system is considered to be sustainable with a novel concept. The following inferences can be summed from this study:

1. Treatment offers a simple and easy to operate method for the water supply and sanitation in arsenic affected rural areas.
2. The method is independent of any requirement of electric power as it uses solar energy.
3. It does not generate any hazardous by-products and has a negligible operating cost.

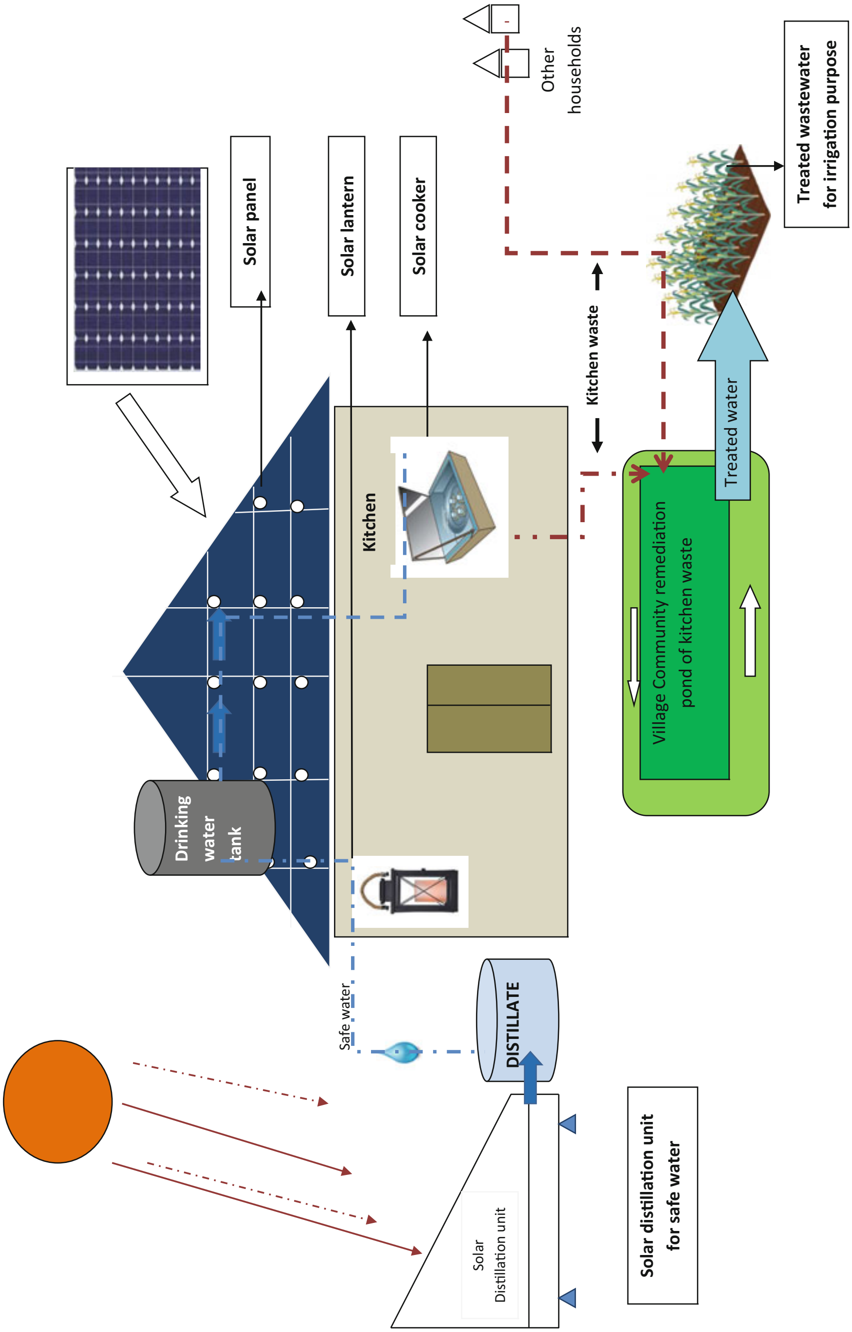

Fig. 5 Schematic for utilization of solar energy solution and distillation unit for rural household [9]

4. The experimental results show that the treated water meets WHO drinking water standards.

The co-benefits of the system are health improvement of the community, hygiene and public welfare, and a complete removal of arsenic from water ecosystem. It is actually the women with families who are required to fetch water for family use in the general rural household. Installation of solar stills on the ground or rooftops can help them save their time and runs to different locations in search for water. The time saved can be further be used by them for personal interest or education, etc. There exists ample sunlight and space in rural areas; therefore, solar distillation along with other solar-dependent energy-saving options for rural household could be a green and safe solution in upcoming time (Fig. 5).

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