

INTEGRATION OF TREATED WASTEWATER REUSE AND SOLAR-POWERED SPRINKLER IRRIGATION FOR CLIMATE-RESILIENT SMALLHOLDER

INTÉGRATION DE LA RÉUTILISATION DES EAUX USÉES TRAITÉES ET DE L'IRRIGATION PAR ASPERSION ALIMENTÉE À L'ÉNERGIE SOLAIRE POUR UNE AGRICULTURE DE PETITE EXPLOITATION RÉSILIENTE AU CHANGEMENT CLIMATIQUE

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ABSTRACT

Global agriculture consumes 70-80% of available water resources and drive high rural energy demands. However, depleting ground water, rising energy costs, climate variability, and untreated sewage disposal threaten agricultural sustainability, particularly for smallholders in developing countries. Utilizing Treated Wastewater (TWW) via solar-powered irrigation offers a viable solution to enhance water efficiency, curb pollution, and advance SDG 6.3.

This study designs, develops, and evaluates an integrated irrigation system that pairs TWW with a solar-powered, low-pressure Rainport Sprinkler Irrigation (RPSI) system. Tailored for small, fragmented landholdings, this configuration reduces reliance on freshwater and conventional energy. The engineering design integrates crop evapotranspiration (ET), solar radiation, soil water-holding capacity, sprinkler application rates, and distribution uniformity, targeting a Christiansen Coefficient of Uniformity (CDU) above 80%. Crucially, TWW quality—including BOD, COD, TSS, SAR, electrical conductivity, and fecal coliform—was benchmarked against irrigation standards to ensure safe application.

The system was implemented across 1,400 acres in Haryana, India, utilizing 8–13 MLD of effluent from a sewage treatment plant. Field evaluations demonstrated that combining solar micro-irrigation with TWW significantly slashed operational energy costs, enhanced water distribution uniformity, and boosted crop productivity. This translated into tangible economic gains, yielding a benefit-cost ratio of 1.63 for vegetable cultivation. Ultimately, integrating solar-powered micro-irrigation with TWW fosters circular water management, mitigates environmental pollution, and strengthens climate resilience in water-scarce zones. This scalable, adaptable model provides a sustainable blueprint for peri-urban, smallholder farming systems across arid and semi-arid regions in developing nations.

Keywords: Treated wastewater reuse; Solar-powered irrigation; Rainport sprinkler irrigation; Smallholder agriculture; Water-energy efficiency; Climate resilience.

RÉSUMÉ

L'agriculture mondiale consomme 70 à 80 % des ressources en eau disponibles et génère une forte demande énergétique en milieu rural. Cependant, l'épuisement des nappes phréatiques, la hausse des coûts énergétiques, la variabilité climatique et le rejet d'eaux usées non traitées menacent la durabilité de l'agriculture, en particulier pour les petits exploitants des pays en développement. L'utilisation des eaux usées traitées (EUT) via un système d'irrigation alimenté par l'énergie solaire offre une solution viable pour améliorer l'efficacité hydrique, réduire la pollution et contribuer à la réalisation de l'ODD 6.3.

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Cette étude conçoit, développe et évalue un système d'irrigation intégré qui associe les eaux usées traitées à un système d'irrigation par aspersion Rainport (RPSI) à basse pression et alimenté par l'énergie solaire. Adaptée aux petites exploitations fragmentées, cette configuration réduit la dépendance à l'égard de l'eau douce et des énergies conventionnelles. La conception technique intègre l'évapotranspiration des cultures (ET), le rayonnement solaire, la capacité de rétention d'eau du sol, les débits d'application des arroseurs et l'uniformité de la distribution, en visant un coefficient d'uniformité de Christiansen (CDU) supérieur à 80 %. Il est essentiel de noter que la qualité des eaux usées traitées — notamment la DBO, la DCO, les TSS, le SAR, la conductivité électrique et les coliformes fécaux — a été comparée aux normes d'irrigation afin de garantir une utilisation sans risque.

Le système a été mis en œuvre sur 1 400 acres dans l'Haryana, en Inde, en utilisant 8 à 13 MLJ d'effluents provenant d'une station d'épuration. Les évaluations sur le terrain ont démontré que la combinaison de la micro-irrigation solaire et des eaux traitées réduisait considérablement les coûts énergétiques d'exploitation, améliorait l'uniformité de la distribution de l'eau et augmentait la productivité des cultures. Cela s'est traduit par des gains économiques tangibles, avec un rapport coûts-avantages de 1,63 pour la culture maraîchère.

En fin de compte, l'intégration de la micro-irrigation solaire à la réutilisation des eaux usées traitées favorise une gestion circulaire de l'eau, atténue la pollution environnementale et renforce la résilience climatique dans les zones souffrant de pénurie d'eau. Ce modèle évolutif et adaptable offre un schéma directeur durable pour les systèmes agricoles périurbains des petits exploitants dans les régions arides et semi-arides des pays en développement.

Mots-clés : Réutilisation des eaux usées traitées ; Irrigation solaire ; Irrigation par aspersion Rainport ; Agriculture paysanne ; Efficacité eau-énergie ; Résilience climatique.

1. Introduction

Glasgow, 10th Nov 2021, The UNEP, and India signed an agreement on climate change and committed to achieving the target of SDG 6.3, and water conservation, energy conservation, environmental protection, and green energy are the task to achieve. Agriculture is the world's largest consumer of water and power. To minimize the consumption of water and power in agriculture, use of TWW coupled with a solar-powered Rain-port plays an important role. TWW management and solar power(green energy) are the prime target of the UN's Sustainable Development Goals (SDG 6.3) & environment protection (COP26), is explicit focuses on reducing water pollution, renewal energy, treatment of wastewater, and re-reuse for agriculture landscape, forestry, and gardens.

Use treated wastewater (TWW) for irrigation in small-scale agriculture, coupled with solar powered Rainport sprinkler system, is innovative and sustainable solution. This approach not only addresses water scarcity issues but also harness renewable energy for efficient irrigation. Here's an outline of the key components and benefits along with case study and economics.

2. Wastewater Treatment Means (WWT)

The WWT means removal of impurities from wastewater, before reaching aquifers or natural bodies of water such as rivers, lakes, and Oceans. Water pollution, therefore, is caused primarily by the drainage of contaminated wastewater into surface water or groundwater & agriculture-irrigation activity is one of the major causes of water pollution. 'UNWWDR2017' report said more than 80 percent of the world's wastewater flows back into the environment without being treated and unfortunately proper data on wastewater treatment and reuse is not available at this stage. Some European Countries has made a significant contribution to wastewater treatment and reuse for agriculture, construction, and cleaning purpose. Because of a lack of political will, technical know-how, R & D database, and mindset, this subject is least highlighted at national –international forums. Haryana & Punjab State Governments (India) have started implementing the use of TWW for agriculture at a small scale and growers are also coming forward to use TWW for agriculture. The pressure of growing global water resources demand

combined with impacts of climate change and food production has brought to focus need for alternative and sustainable irrigation approaches. Agriculture accounts for the largest consumption of freshwater and energy in the world, and groundwater overdraft and heavy reliance on conventional energy sources for pumping in many developing countries has created a severe environmental and economic situation. Simultaneously, vast amounts of urban wastewater are discharged into rivers, lakes, and natural environment, without any treatment. UNWWDR (2017) reported that over 80% of global wastewater is released untreated into environment, making treated wastewater reuse a critical option to conserve water and mitigate environmental pollution. UN SDG 6.3 is aimed at improving water quality by reducing pollution and safe wastewater reuse, while international climate-change related commitment under COP frameworks is aimed at development and implementation of renewable energy technologies and sustainable water management practices. Therefore, integration of treated wastewater reuse with solar driven irrigation system becomes a potential tool for sustainable small-scale farming. The present research intends to evaluate the effectiveness of integrated approach, combining the use of low-pressure Rainport Sprinkler Irrigation (RPSI) system powered by solar photovoltaics with treated wastewater. The main objective of the research were to: To test and confirm technical feasibility of using treated wastewater for the RPSI system; To check applicability and feasibility of solar-powered pumping system for operation during daytime irrigation hours; To achieve improvements in water-use and energy-use efficiency on small farm; To test and analyze economic viability and environmental advantages of the integrated system.

India has few on-going projects for use of treated wastewater in agriculture on pilot and semi-commercial scale, mostly in states like Haryana and Punjab. The farmers have been recognizing and accepting the economic and environmental advantage of reusing wastewater.

For safe usage of treated wastewater in agriculture, landscape, municipal gardens, road side plantation etc the water quality standards for BOD, COD, TSS, Salinity, SAR, microbial load etc must be maintained as per recommended standards.

3. Rain-Port Sprinkler Irrigation (RPSI)

Rainport Sprinkler irrigation is an artificial stimulation of rainfall and water is sprayed through the air over a large surface area under pressure. The pressure is usually obtained by a solar powered motor pumpset or electrical motor pump set or Diesel Engine Pump set. Sprinklers are grouped as Micro/Mini Sprinkler, Overhead Sprinkler, Rain Gun Sprinkler called as Sprinkler family. The utility of each sprinkler varies with respective features, performance & cost-effectiveness.

A Rain-port Sprinkler Irrigation system is intermittent sprinkler irrigation, where the option to choose the droplet size of water particles with respect to nozzles is available as per the demand of crops. RPSI system comprising of Solar Photovoltaic Module, Control Head Unit, Piping network, Driplines, Control Panel, and Motor Pump-set. Architect of Solar Powered Rainport Sprinkler System is displayed in Figure 1.

3.1. Key Components

3.1.1. TWW system

- Establish a wastewater treatment system to purify water from various sources like sewage treatment plants or industrial effluents.
- Ensure that the treated water meets quality standard for agricultural irrigation.

Treated effluent was obtained from sewage treatment plants (STPs) at sewage treatment level (secondary or tertiary) and fed to storage, and then distributed through the irrigation system.

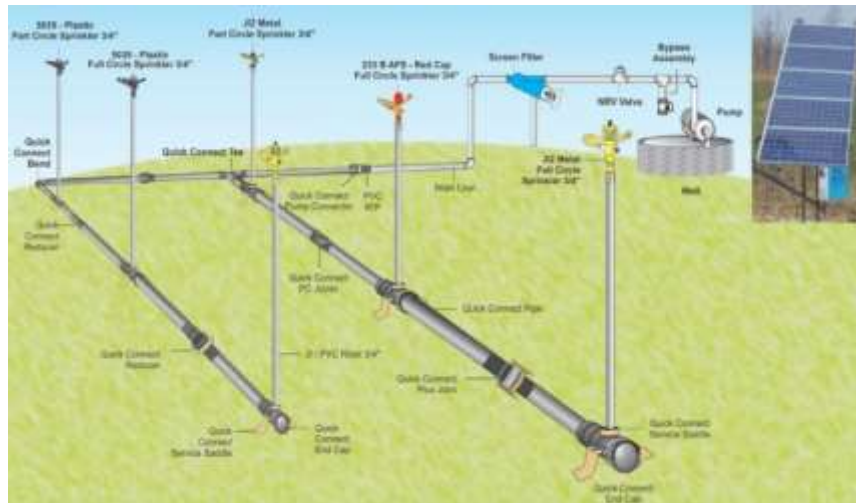


Figure.1. Architect of Solar Powered Rain-port Sprinkler Irrigation System

3.1.2. Storage Tank

Provision of storage tank to hold treated waste water (TWW), ensuring a consistent and reliable supply for irrigation.

3.1.3. Solar Powered System

- Utilize solar panels to generate electricity for powering the irrigation system.
- Install a battery storage system to store excess energy for use during non-sunny periods.

3.1.4. Rainport Sprinkler System

- Implement a Rainport Sprinkler System, which is low pressure, energy efficient irrigation technology.
- This system is designed for small landholders and uses pipes with small perforations to distribute water evenly over crops.

4. Advantages

4.1. Water conservation

- TWW reduces dependence on freshwater sources, promoting sustainable water use.
- The Rainport Sprinkler System minimizes water wastage by delivering water directly to root zones of plants.

4.2 Energy efficient

- Low pressure system of Rainport requires less pumping energy than conventional sprinkler. Solar energy reduced the operational costs of the pump energy required for the irrigation.
- Solar Power provides a clean and renewable energy source, reducing the environmental impact.

4.3 Improved crop yield and Quality

- Uniformity and regulation of application water enhances crop yield and consistency and improve the water-use efficiency of crops.
- Consistent and Controlled irrigation leads to better crop growth and yield.

- The Rainport Sprinkler System ensures uniform water distribution, preventing overwatering or under watering of crops.

4.4 Environmental benefits

- Usage of treated wastewater reduced pollution from the effluent of river and lake and the use of solar energy reduced the emissions of greenhouse gases.
- Using treated wastewater helps mitigate pollution by repurposing water that would otherwise be discarded.
- Solar power reduces reliance on fossil fuels, contributing to a lower carbon footprint.

4.5 Economic benefits

Despite relatively higher capital investment for setting up the system, low operational cost of utilizing the saved fresh water and electrical energy reduced overall expenditure.

4.6 Cost Savings

- While the initial setup cost may be higher, the long term operational costs are reduced due to free solar energy and the efficient use of treated wastewater.

4.7 Community Health

Properly treated wastewater reduces the risk of water borne diseases, contributing to community health improvement.

5. Design Engineering Considerations

The following design engineering considerations shall be considered. Since solar radiation is available in a daytime for the generation of power, the entire irrigation to crops has to be concluded in a daytime most preferably. Obviously, all the design calculation is based on the fluctuation of solar radiation from morning to evening and season to season to meet the crop water demand. However, the following factors have to be considered and integrated while designing a Rain-port Sprinkler irrigation system while using TWW.

- Average solar radiation- morning to evening on a monthly and seasonal basis.
- Optimization of ET_{crop} (Net Crop water demand) on a daily or alternate basis.
- Soil-based water retention capacity.
- Master plan of crops.
- TWW Water availability and assessment to meet crop water demand.
- Operation/management of the system.
- Optimization of the requirement of motor-pump-set (solar-powered)
- Photovoltaic Solar Module.

Average solar energy can be harvested to 200-300 watts/m² in various countries based on latitude and longitude. It varies from season to season and mainly affects the clouds and haziness. Maximum solar power can be harvested in the summer season and minimum in rainy seasons due to cloudiness. Hence, the frequency of irrigation in the rainy season is low and maximum in summer. Similarly, in a daytime, solar energy is minimum in the morning, maximum at the noon, and again minimum during the evening. In figure 2, clearly show the solar power harvesting in a day, it is very clear that the design of Rain-port Sprinkler irrigation should be done to meet the water demand of crops in day time corresponding to available solar radiation only.

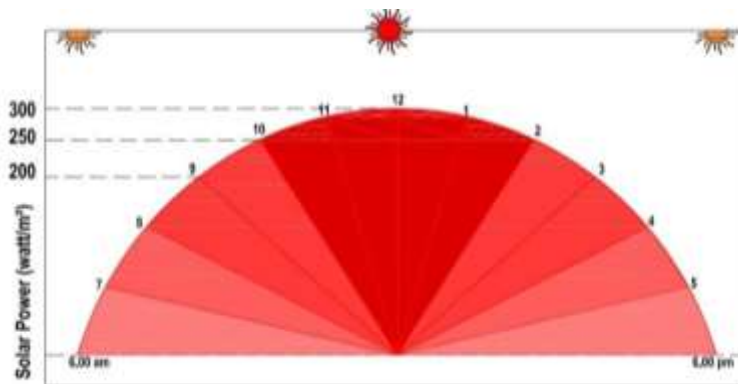


Figure. 2. Solar Power Harvest Monochrome

5.1. Water Quality Monitoring

Regularly monitor the quality of treated wastewater to ensure it meets the required standards for irrigation.

5.2. Maintenance

Regular maintenance of solar panels, rainport sprinkler system and other components is essential for optimal performance.

5.3. Community Engagement

Educate and involve local communities in the implementation and benefits of the system to ensure long term sustainability.

5.4. Adaptability

Design the system to be adaptable to different crops types and changing agricultural needs.

5.5. Criteria for selection of Nozzle of Rain-port Sprinkler

- Nozzle should have a low discharge rate.
- Nozzle should have a larger diameter than the throw.
- Nozzle should have low operating pressure.
- Nozzle should have a higher CDU (more than 80%).
- Nozzle should be easy to replace.
- Nozzle should be cost-effective.

5.6. Placement and overlapping of Rain-port Sprinkler

Based on the sprinkler precipitation profile, crop root spread, canopy, soil & slope of the ground, Rain-port Sprinklers preferred to be placed in a square fashion and from radius to radius as shown in figure 3. LLDPE Polytube of sizes 16 mm, 20 mm, 25 mm 32 mm, 40 mm, 50 mm & 63 mm is used as sprinkler laterals.

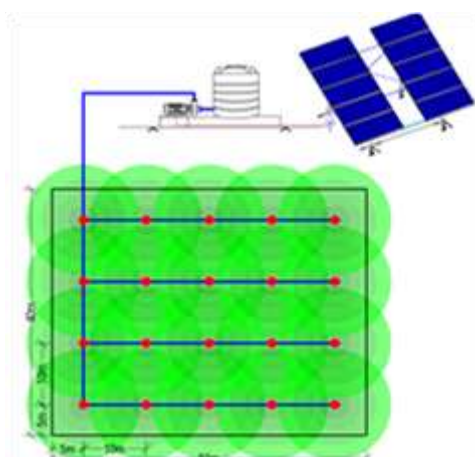


Figure. 3. Layout of Rain-Port Sprinkler

6. TWW Quality norms for agriculture (India)

The success of (TWW) Treated Waste Water use for crop production largely depends on adopting appropriate strategies aimed at optimizing crop yields and quality, maintaining soil productivity, and safeguarding the environment. Several alternatives are available to use TWW for agriculture via various irrigation methods. The user should have prior information on TWW supply and its quality as per Table 1 for reference to ensure the formulation and adoption of an appropriate on-farm management strategy.

Table 1. TWW Quality Norms (Ref-PPCB)

Sr	Parameters	TWW Standard Norms
1.	Temperature	Not more than 50C.
2.	pH	5 - 9
3.	BoD	<= 10 ppm
4.	COD	<= 50 ppm
5.	TSS	<= 20 ppm
6.	Sulfates	<= 200 ppm
7.	TKN	<= 50 ppm
8.	Faecal coliform	<= 100 MPN/100 ml
9.	Total Phosphorus	<= 2 ppm
10.	Ammonical Nitrogen	<= 20 ppm
11.	SAR	<=3.5 ppm
12.	EC	<=2000 micro siemens/cm
13.	RSC	<= 2.5 meq/l

7. Government Policy

An effective Government policy on TWW available to farmers for unrestricted irrigation or to irrigate public parks and urban green areas is a deciding factor to promote the use of TWW at a large scale and to minimize the water stress and pollution of the environment. Instead of using TWW 100%, the option of blending TWW with other water supplies – canal water, groundwater etc. It is possible that a farmer may have saline groundwater and, if he has non-saline treated wastewater, could blend the two sources to obtain a blended water of acceptable salinity level.

Adopting blending strategies of TWW is normally advantageous in respect of allowing greater flexibility, increased financial security and more efficient use of the wastewater throughout the year coupled with solar powered motorpump set, whereas a single-use strategy will give rise to seasonal surpluses of effluent for unproductive disposal. A case study is highlighted in Table 2 along with photos 1 & 2.

Table 2. Case study: Use of TWW with Solar Powered Rainport Irrigation System for vegetable.

Sr	Parameters	Value
1.	Grower	CADA, Jhajjar, Haryana (India).
2.	Project (*)	Solar Powered Integrated Irrigation Project with STP water.
3.	Capacity of STP	8-13 MLD
4.	Command Area	1400 ac.
5.	Design Discharge	2.4-3.6 cusec per 1000 ac.
6.	Crop	Green Chilly and others
7.	Irrigation time	4 to 7 hours depending on solar radiation available, crop water demand and agro-climatic conditions.
8.	Irrigation type	Rainport Sprinkler Irrigation System.
9.	Area	1 acre representative area out of 1400 ac.
10.	Yield	12 Quintal
11.	Market rate	USD 50 per Quintal. (For calculation purpose assumed exchange rate 1\$ = 74 INR year 2020-21)
12.	Total Income	USD 600
13.	Farm Expenses	USD 300 (estimated).
14.	Net Income	USD 300
15.	BC Ratio	2
Disclaimer: Due to COVID-19 pandemic lockdowns, field data collection for this case study was restricted.		



Photo 1. Solar Panel, TWW tank, Control Head



Photo 2. Rainport Sprinkler Irrigation System

8. Conclusion

In conclusion, integration of treated wastewater reuse with solar powered low-pressure Rain port sprinkler irrigation could be a sustainable and climate resilient option for smallholder farmers. It would minimize the use of freshwater sources and traditional energy resources and increase water use efficiency and minimize pollution. The results from the field trials in Haryana indicated economic feasibility and efficient system performance. It would result in circulation of water resources, use of renewable energy and sustainable increase in agriculture production. The approach, if implemented with suitable policy support, proper water quality monitoring and increased farmer awareness could be widely applicable in the peri-urban and water scarcity zones.

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