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# Spring Water Quality Assessment and Its Utilization through Gravity and Solar-based Micro Irrigation System for Hilly Region

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**Abstract**

This study aims to assess the spring water quality and its potential use in agriculture through gravity-fed and solar-powered micro-irrigation system. Water samples from *naula* at experimental farm of ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand, were collected and analysed for irrigation quality parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness and concentrations of $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $HCO_3^-$, and $Cl^-$, including, sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), and coliform counts. Based on these parameters, all spring samples were classified as ranging from excellent to good in terms of irrigation suitability. The spring water stored in polylined tank and its effective utilization through gravity and solar based micro irrigation system done at site. The variation in emitter discharge was up to 42% as the gravity head increased from 1.75 m to 5.7 m. For micro-sprinklers, the maximum discharge variation was 8.53% under gravity heads of 3.6 m to 5.7 m, respectively. A solar pump with a capacity of 0.25 HP was tested at 5 m head for operating both drip and micro-sprinkler irrigation systems, and performed satisfactorily with coverage area 290 $m^2$ and 198 $m^2$, respectively. The coverage area reduced slightly to 220 $m^2$ for drip and 137 $m^2$ for micro-sprinklers at 10 m head condition, reflecting the influence of pressure head on system efficiency and water distribution satisfactorily.

***Key words:*** Micro irrigation system, Spring water, Gravity head, Solar energy, Hilly region

## Introduction

The State of Uttarakhand is rich in water resources but has poor irrigation facilities and is highly vulnerable to food insecurity due to low agricultural water productivity, uneven terrain, lack of location-specific farming techniques, limited market access, and exposure to natural hazards. However, various climatic, geographical, and socio-economic challenges have resulted in low agricultural productivity (Sinha *et al.,* 2021). Notably, the hill districts which contribute around 70% of the State's total cropped area have only about 11% of their net sown area under irrigation (NITI Aayog, 2017). Most of the farming in the state is rainfed, and development of irrigation infrastructure is difficult due to the hilly terrain. The region's terrace farming system offers significant potential to harness solar energy and gravity-fed irrigation, reducing the need for fuel or electricity in running efficient irrigation systems. Despite this potential, farmers currently rely on small, low-discharge springs (with discharge rates of less than 20 liters per minute) in an unorganized and scattered manner for vegetable cultivation. During lean periods, farmers in the hills suffer from a serious shortage of water for crop production (Barakat *et al.*, 2018). Majority of population residing in the Himalayan region depend primarily on springs as their main source of water. These springs are fed by rainwater that infiltrates underground aquifers. In Uttarakhand, approx. 90% of fresh water comes from springs and rivers, rural and urban communities rely on spring water for drinking, agriculture, and domestic use (Jasrotia *et al.*, 2018). In the hilly regions, springs typically originate from seepage through shallow, weathered, and fractured rock zones. In the Kumaon region specifically, nearly

60% of the rural population relies on natural springs for their water supply. Traditional spring sources in the region are locally known as *Chal*, *Khals*, *Naulas*, and *Gharats* (Sharma, 2016). The formation and flow of springs are primarily influenced by rainfall patterns and the hydrogeological characteristics of the region. However, a range of increasing anthropogenic activities including deforestation, land-use changes, inadequate sanitation practices, population growth, and climate change have significantly impacted the availability, quality, and quantity of spring water (Chen *et al.*, 2019). These concerns have been widely documented in national and international studies (Fonollosa *et al.*, 2016; Taloor *et al.*, 2020). In Uttarakhand, more than 58% of the state's area receives solar radiation exceeding 4 kWh $m^{-2}$ $day^{-1}$ throughout the year (Mishra *et al.*, 2020). Despite this abundant solar energy, its effective utilization especially in the hilly regions remains limited due to challenging topography. There is an urgent need to develop site-specific, solar-based technologies for applications such as irrigation, crop drying, and domestic use. Integrating solar-powered pumping systems for irrigation in hilly terrains takes advantage of the region's abundant solar radiation to deliver a reliable, off-grid water supply. This approach reduces both operational costs and environmental impact (Sontake and Kalamkar, 2016). Key factors for successful implementation include site-specific solar resource assessment, appropriate pump sizing and selection, integration of water storage and control systems, and evaluation of economic viability particularly under government support programs such as India's PM-KUSUM scheme (NITI Aayog, 2017). Combining solar photovoltaic (PV) pumping systems with improved springshed management such as water harvesting utilize through gravity fed micro irrigation system, recharge trenches, and traditional *naula* tanks can significantly enhance water availability and irrigation sustainability in these challenging landscapes (Shinde and Wandre, 2015). To address this water crisis, it is essential to adopt appropriate springshed and water management practices. These include the revival and restoration of perennial springs, and storing excess water during periods of high availability and its effective utilization. The present study aims to evaluate the quality and suitability of spring water for irrigation and its utilization through gravity and solar based micro irrigation system for enhancing water productivity of hilly region.

## Material and Methods

### Study area

The experiment was conducted at experimental farm of ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, (ICAR-VPKAS) Almora, Uttarakhand. Two *naulas* (collection of water through natural spring) located at experimental farm Hawalbagh were used for collecting runoff water from the underground spring/seepage and stored in water harvesting tank to utilize it by gravity fed micro irrigation system at farm. The oak (*Quercus L.*), and uttish (*Alnus nepalensis*) tree planted along with trenches at catchment areas of *naulas* for runoff, silt retention and enhancing discharge. This has brought significant improvement in discharge and it has increased from 0.8 to 3.3 litre $minute^{-1}$ from the year 2000 to 2021. The excess discharge of spring water in months were collected in water harvesting tank and utilized through gravity fed micro irrigation system for enhancing farm water productivity.

### Approaches and methodology for spring water quality assessment

To assess the suitability of runoff cum spring water available at site for irrigation, several key parameters were analysed. The electrical conductivity (EC) and pH of the spring water samples were measured in the laboratory using a digital EC/pH meter. Bicarbonate, calcium, and magnesium concentrations were determined using standard titrimetric methods, while potassium and sodium were analysed using a flame photometer. Water samples were collected in 1000 ml beaker, which were pre-cleaned by soaking in 10% nitric acid overnight and rinsed thoroughly with distilled water on the day of sampling. At the sampling site, the bottles were further rinsed with the spring water to be collected before being filled. In laboratory, each sample was immediately filtered using filter paper and stored in the dark for further analysis.

**Experimental set up**

The study was conducted to evaluate a gravity-fed micro irrigation system at site aimed at enhancing water productivity in hilly region. The runoff cum spring water was harvested and stored in a polytank with a capacity of 83 cubic metres, which was integrated with a micro irrigation setup including drip and micro-sprinkler designed to operate entirely by gravity. The 40 mm diameter pipe outlet installed at the bottom of polytank was fitted with a screen filter (25 $m^3 h^{-1}$) close to the tank. The develop system potential to irrigate 340 square metre area at first terrace 3.75 m gravity head, 350 square metre in second terrace at 6.45 m gravity head and 280 square metre in third terrace at 8.3 m head under gravity based irrigation.

**Hydraulic performance of micro irrigation system**

The hydraulic evaluation of micro irrigation system in hilly region was most important for assessment of gravity head for operation of drip and micro sprinkler with coverage area with uniform application of water to the crops. Uniformity of irrigation water application using mini-sprinklers was evaluated using two commonly adopted methods: Distribution Uniformity (DU) and Christiansen's Uniformity Coefficient (CU) (Christiansen, 1941). A higher value of DU or CU indicates a more uniform application of irrigation water by the sprinkler system. Emitter flow variation, which indicates the consistency of water delivery by emitters, is typically quantified using the coefficient of variation (CV) or a formula based on the maximum and minimum emitter discharge rates. This metric is essential for evaluating the uniformity of water application in drip irrigation systems, a key factor for achieving efficient and effective irrigation. Variations in flow rate caused by soil properties can significantly impact the performance of drip irrigation systems, often resulting in insufficient water application to the crops (Ren *et al.*, 2017). Variation in emitter flow rate were calculated by measuring the discharge from first to last emitter of lateral as equation given below:

$$\text{Emitter flow rate variation} = \frac{Q_{max} - Q_{min}}{Q_{max}} \times 100 \quad \ldots(1)$$

Distribution Uniformity (DU) calculated as the ratio of the average irrigation depth in the lowest quarter of the irrigated area to the overall average irrigation depth (Beales, 1964).

$$DU\ (\%) = \frac{\text{Avg. depth in the lowest 25\% of observations}}{\text{Overall average depth}} \times 100 \quad \ldots(2)$$

To determine the lowest quarter average, the irrigation depth data collected from multiple points around the sprinkler are sorted in ascending order. The average of the lowest 25% of these values is taken as the low-quarter average. The average irrigation depth was the arithmetic mean of all measured values. Christiansen's Uniformity Coefficient (CU) is another widely used metric for assessing the uniformity of water distribution in sprinkler systems (Christiansen, 1942).

$$CU\ (\%) = 1 - \frac{\text{Average absolute deviation from the mean}}{\text{Mean depth}} \times 100 \quad \ldots(3)$$

On undulating terrain, achieving high uniformity in drip irrigation system design is limited by the pressure sensitivity of emitters. Immediate solutions include the use of pressure-compensating emitters or pressure-regulated inlets on short laterals. Another approach is to vary emitter sizes to offset pressure variations due to elevation changes, although deploying multiple emitter sizes in the same field is generally impractical. Even on level ground, lateral lengths must be limited to prevent significant pressure differences (Rajput, 2012). Factors influencing the maximum recommended lateral length include discharge per unit length, desired emission uniformity, emitter flow characteristics, lateral layout, terrain, and pipe diameter. In most cases, field dimensions and cultural practices ultimately determine feasible lateral lengths.

## Result and Discussion

**Evaluation of spring water qality for irrigation**

The water sample were collected from naula and water harvest tank and analysed irrigation quality parameters *i.e.* electrical conductivity (EC), pH, Total hardness, total dissolved solids (TDS), and concentrations of major ions such as sodium ($Na^+$), potassium ($K^+$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), bicarbonate ($HCO_3^-$), chloride ($Cl^-$), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), and residual sodium carbonate. The pH value of water sample varied from 6.8-7.2 under different months at site. TDS ranged from 250- 560 mg $L^{-1}$, Total hardness 68 mg $L^{-1}$, and highest coliform count of 16/100 ml was found in the study area. The excess amount of salt present in water adversely affect the plant growth due to the increased osmotic pressure of the soil water, which prevents plant roots from absorbing water effectively. The EC of study water varied from 100 to 450 µS $cm^{-1}$, Sodium adsorption ratio less than 10 and RSC (meq $L^{-1}$) was less than 1.25, therefore the spring water was found most suitable for irrigation. Based on these parameters, the spring waters were classified as ranging from excellent to good in terms of their suitability for agricultural irrigation. These springs have traditionally been crucial sources of both drinking and irrigation water in the region for many decades. The present study focuses on evaluating the irrigation suitability of spring water, recognizing that this suitability largely depends on the mineral composition of the water, as well as the characteristics of the soil and the types of crops grown. The presence of salts in irrigation water can adversely impact plant growth physically by reducing water uptake due to osmotic stress, and chemically by introducing toxic effects that interfere with plant metabolism. The spring water available at site having sodium and calcium are the dominant cations, contributing approximately 44%-63% and 17%-34% of the total cation concentration, respectively. Among the anions, bicarbonate is the most prevalent, accounting for about 52%-67% of the total anionic content. The similar results related to quality assessment of naula and dhara water for irrigation were reported by Sinha *et al*. (2021) and Bhandari *et al*. (2013). Sodium is of particular importance in irrigation water due to its potential phytotoxic effects when present at elevated levels. In contrast, potassium showed minimal variation across the samples and had a negligible impact. Both calcium and magnesium, which are essential plant nutrients, can help counteract the harmful effects of sodium under certain soil and water conditions (Singh *et al*., 2005). Therefore, key factors such as salinity, and ion toxicity must be carefully considered when determining the suitability of spring water for irrigation. These concerns have been reported by many researcher (Al-Bassam and Al-Rumikhani, 2003; Alexander and Mahalingam, 2011; Ali *et al*., 2009).

### Hydraulic evaluation of gravity-fed micro irrigation system under terrace condition

The hydraulic evaluation of gravity based micro irrigation system was found satisfactory as per the average dripper discharge, dripper flow variation and distribution uniformity varies in the range of 1.71-2.14 L $h^{-1}$, 2.7%-9.93% and 91.76%-98.93% respectively as shown in Table 1. The system was tested on vegetable pea crop (*variety VL Matar 12*) using different irrigation methods: drip, micro-sprinkler, check basin, and furrow irrigation. The water requirement of the crop was estimated using the FAO CROPWAT model. Field demonstrations were conducted at the site under the

**Table 1.** Hydraulic performance of gravity based drip irrigation under terrace conditions

| Gravity Head | Replication | Avg. dripper discharge(l $h^{-1}$) | Variation in dripper flow rate (%) | Drip system distribution uniformity (%) |
|---|---|---|---|---|
| 3.75 m | R1 | 1.71 | 6.89 | 95.29 |
| (1st Terrace) | R2 | 1.71 | 9.93 | 91.76 |
| | R3 | 1.82 | 6.45 | 95.60 |
| (6.45 m) | R1 | 2.0 | 3.125 | 98.93 |
| (2nd Terrace) | R2 | 1.96 | 3.03 | 96.88 |
| | R3 | 1.96 | 9.09 | 94.93 |
| 8.3 m | R1 | 2.14 | 2.7 | 98.13 |
| (3rd Terrace) | R2 | 2.08 | 5.55 | 98.07 |
| | R3 | 2.04 | 5.71 | 97.05 |

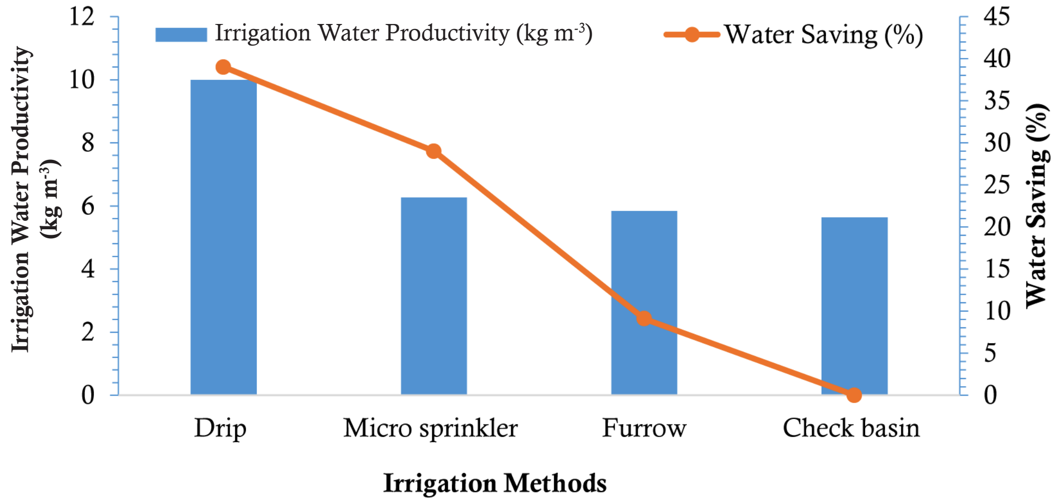


**Fig. 1** Irrigation water productivity (kg $m^{-3}$) and water saving (%) under different irrigation methods

various irrigation methods. Results showed that lowest irrigation water productivity were obtained in Check basin *i.e.* 5.64 kg $m^{-3}$, and highest 10 kg $m^{-3}$ under drip irrigation along with 39% water savings compared to check basin irrigation as shown in Fig. 1.

**Evaluation of adjustable head structure for efficient operation of micro irrigation system**

An adjustable framing head structure aimed at enabling the efficient operation of micro irrigation system under gravity-fed conditions has been designed, developed and evaluated at site. The developed structure allows for the maintenance of an adjustable pressure head up to 5 m in hilly region, depending on site-specific requirements, to optimize irrigation performance. Hydraulic performance of the gravity-based micro irrigation system was assessed, with dripper flow variation ranging from 2.78% to 9.09%, and distribution uniformity between 94.04% and 99%, indicating high system efficiency as shown in Table 2. Comparative performance analysis revealed water savings of 33.06% and 31.40% under gravity-fed drip irrigation when compared to the micro-sprinkler system, at 3.6 m and 5.7 m gravity head, respectively. The emitter flow rate varied from 1.23 to 2.13 L $h^{-1}$, with a maximum variation of 0–42% recorded as the gravity head increased from 1.75 m to 5.7 m. In the case of micro-sprinklers, discharge variation ranged from 0–8.53% between 3.6 m and 5.7 m head condition. These significant results confirm the effectiveness of the adjustable framing head structure in stabilizing pressure conditions, improving water distribution efficiency, and reducing water use in gravity-based micro irrigation systems.

**Assessment of solar pump for operation of micro irrigation system under terrace condition**

The gravity-fed and solar based pumping system for irrigation in hilly regions have gained importance in recent years due to their environmentally friendly nature and potential to reduce dependence on fossil fuel-based energy sources. However, the use of large-capacity pumps is often cost-prohibitive and primarily intended for extracting groundwater, which may contribute to the depletion of groundwater tables. Considering these limitations, the performance of small-sized solar PV pump (0.25 HP capacity) was evaluated for lifting water from a polylined storage tank to irrigate terraced agricultural fields in hilly areas. The solar irradiation was measured using pyranometer installed at site. Its value varies from 2.75 to 5.42 kWh $m^{-2}day^{-1}$ during august to December month 2022 at site. A 0.25 HP solar pump has been selected for conduct the experiment and lift water from polylined water storage tank capacity 135 cubic metre. It was observed that solar energy (0.25 HP) based drip irrigation system was operated satisfactorily as per dripper flow variation and distribution uniformity varies in the range of 3.03%-9.89% and 91.74%-94.7% respectively with coverage area 290 $m^2$ at 5 m head and 220 $m^2$ at 10 m head condition.

**Table 2.** Performance evaluation of MIS system under different head condition in terrace land

| Gravity Head | Replication | Dripper discharge (l $h^{-1}$) | Micro sprinkler discharge (l $h^{-1}$) | Dripper flow rate variation (%) | Micro sprinkler flow rate variation (%) | Drip system distribution uniformity (%) | Micro sprinkler system distribution uniformity (%) |
|---|---|---|---|---|---|---|---|
| 1.75 m (1st Terrace) | R1 | 1.27 | Not operated due to lower pressure head (<0.2 kg/$cm^2$) | 9.09 | Not operate due to lower pressure head (<0.2 kg/$cm^2$) | 94.74 | Not operated due to lower pressure head (<0.2 kg/$cm^2$) |
| | R2 | 1.2 | | 9.09 | | 97.56 | |
| | R3 | 1.21 | | 4.76 | | 98.90 | |
| 3.6 m (2nd Terrace) | R1 | 1.84 | 10.60 | 6.25 | 5.93 | 97.82 | 94.04 |
| | R2 | 1.82 | 10.90 | 3.22 | 4.91 | 98.90 | 95.09 |
| | R3 | 1.78 | 11.28 | 3.33 | 3.48 | 97.75 | 96.52 |
| 5.7 m (3rd Terrace) | R1 | 2.12 | 12.06 | 2.78 | 1.65 | 99.05 | 98.35 |
| | R2 | 2.02 | 11.78 | 5.71 | 3.77 | 98.02 | 96.23 |
| | R3 | 2.02 | 12.02 | 3.03 | 1.0 | 98.99 | 99 |

Similarly, in case of micro sprinkler system, The variation of nozzle flow rate was ranged from 3.12%-9.09 % and distribution uniformity 83.40%-90.65% having 7 sprinkler set with coverage area 198 $m^2$ at 5 m head and 137 $m^2$ at 10 m head condition. Collecting and storing spring and runoff water in harvesting tanks, followed by its use through solar- or gravity-based micro irrigation systems, can be a viable solution to achieve the objectives of the 'More Crop per Drop' mission in hilly regions (Abraham and Mathew, 2018). Many study have demonstrated significant potential of solar pumping under such condition (Hossain *et al.*, 2015; Wazed *et al.*, 2017; Bassi, 2018). The hydraulic evaluation of solar-based pressurized irrigation system has been done and reported that the solar irradiance directly affects the discharge rate of the pump, irrigation uniformity expected to vary throughout the day (Santra, 2021; Zaman *et al.*, 2018). Therefore, it is essential to assess the influence of solar radiation on discharge of pump and irrigation uniformity to optimize irrigation scheduling and improve water productivity in hilly region.

## Conclusion

The Indian Himalayan Region holds significant potential for crop production through the sustainable management of water resources. This study highlights the urgent need for efficient, productive, and intelligent use of water in agriculture to enhance water productivity. This study assesses the quality of spring water and its utilization through the optimal design of micro irrigation systems to improve water productivity in hilly regions. The findings are particularly valuable for designing gravity-based micro irrigation systems and selecting appropriate site-specific solar pumps for irrigation. The findings of this study are crucial for the design and implementation of micro irrigation systems tailored for small and marginal farmers, and developing operational guidelines for precise irrigation management in hill agriculture. The study recommended that solar and gravity-fed micro irrigation system must be integrated with water harvesting structures to enable the efficient and cost-effective utilization of water resources for irrigating terraced agricultural land in hilly regions.

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