Design and performance assessment of a low-cost rain collector for stable isotope samples

Oxygen and hydrogen isotope ratios of precipitation encode valuable hydroclimatic information. The collection of rainwater samples destined for stable-isotope analyses must minimize fractionation due to evaporation to preserve the isotopic signature. Commercially available rainwater collectors are expensive, justifying the need for cheaper designs. We present a low-cost rain collector capable of limiting post-collection fractionation, confirmed by control experiments. Moreover, precipitation collected in Delhi during the 2023 summer monsoon has stable-isotope values close to the 40-year means. Our rain collector can thus be used to establish dense sampling networks for rainfall isotopes at low cost.

Stable isotope ratios ($^{18}O/^{16}O$ and $^{2}H/^{1}H$) of precipitation water are important for understanding hydroclimatic processes within a region. The isotopic composition of precipitation changes due to fractionation, which occurs during transitions of water between the solid, liquid and vapour phases. The degree of fractionation and thus, the isotopic composition of precipitation reflects a range of factors, including the amount and source of precipitation and ambient air temperature[1]. Variations in precipitation isotope values are observed both spatially and temporally. On a regional to global scale, values vary with latitude, altitude, continentality and rainfall amount[2]. The isotopic composition of precipitation also varies temporally at a site. Observations confirm that these changes occur on timescales from subhourly[3] to inter-decadal[4], and evidence from palaeoclimate archives and climate models has demonstrated longer-term variations as well[5]. Temporal and spatial precipitation networks of isotope records provide valuable insights into atmospheric processes[6] as well as contributing to our understanding of surface[7] and groundwater[8] resources, interpretation of palaeoclimate archives[9] and validation of climate models, especially those equipped with isotope diagnostics[10]. In short, precipitation isotope data provide important insights into past and present hydroclimate.

The Global Network of Isotopes in Precipitation (GNIP), initiated by the International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO), is a network of hydrogen and oxygen isotopes in precipitation and associated climatic data from various locations globally[11]. The majority of datasets are based on integrated monthly precipitation samples and records vary in length from several decades to less than one year. Research based on GNIP data have provided the basis for a number of important studies of the temporal[12] and spatial[13] variations of environmental isotopes in precipitation data.

Precipitation that is destined for stable isotope analyses must either be sampled into suitable containers almost immediately or collected in devices that minimize subsequent evaporative loss, because evaporation causes isotopic fractionation and thus

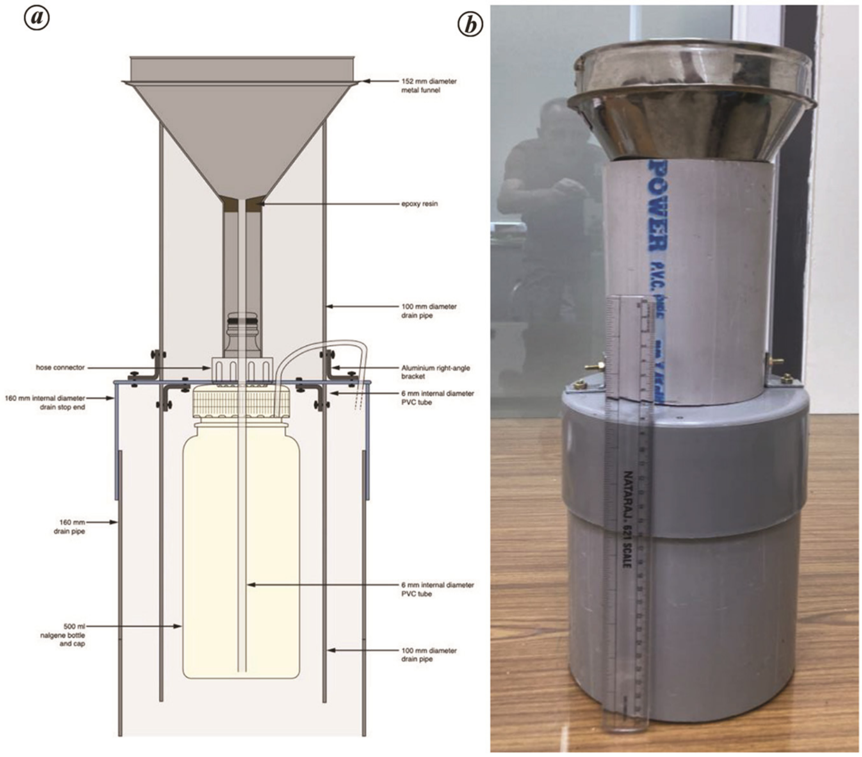

Figure 1. ***a***, Diagram showing rain collector construction. The 5 mm internal diameter tubing is 10 m long and winds around the inner, 100 mm diameter, drain pipe, but is omitted from the figure for clarity. ***b***, Photograph of rain collector exterior.

Table 1. Components and cost analysis of the rain collector

Components	No. of items needed	Rate (INR)	Approximate cost (INR)
PVC pipe (diameter: 10.16 cm)	1	60	60
PVC pipe (diameter: 15.24 cm)	1	70	70
End cap (diameter: 15.24 cm)	1	160	160
Steel funnel (diameter: 15.2 cm)	1	425	425
Nalgene bottle (1 L)	1	74	74
Hose connector	1	230	230
Metal brackets (L-shaped)	4	10	40
Inlet tube	1	10	10
Flexible hose tubing	1	300	300
Screw	8	2	16
Glue solution	1	130	130
Total cost			1515

alters the isotopic composition of the precipitation sample, rendering it of limited value. Traditionally, evaporation has been minimized by adding paraffin oil to the collecting vessel. This floats on the water surface, thereby preventing evaporation. However, paraffin oil can interfere with analysis and is time-consuming and sometimes difficult to remove, leading to other approaches being used[14].

Studies of precipitation isotopes aimed at understanding large-scale hydroclimate systems such as the Indian monsoon, require a large number of suitable rain collectors placed across a broad geographical area. Ideally, these collectors should have an IAEA-approved design. Although such collectors are commercially available, their high product and shipping costs mean their use in such studies is often unachievable. We describe the construction and testing of a low-cost rain collector built locally in India, which is both durable and portable. The collector follows a design that is IAEA-approved and available commercially, but constructed using cheap, easily-available materials.

Design and construction

A low-cost, robust, and portable rain collector using tube dip-in with pressure equilibration to minimize evaporation was customized at the Palaeoclimate Laboratory, Centre for Atmospheric Sciences, Indian Institute of Technology Delhi (IITD) following the design of Gröning *et al.*[15] (Figure 1). The materials used to build the rain collector were sourced from local Indian hardware stores (Table 1). In brief, the tube dip-in method uses a long inlet tube, the opening of which becomes submerged when water is collected, along with pressure equilibration, all designed to minimize evaporative loss of water and resultant isotope fractionation post-collection.

In detail, the IITD rain collector consists of a funnel (15.2 cm diameter) attached to one end of a hose connector that passes through both the end cap (15.2 cm diameter), which has the cap of the collection bottle attached to the inside using a domestic garden-hose-to-tap connector. To support the funnel, a PVC (10.2 cm diameter) pipe was placed around it, resting on the end cap. A small diameter (6 mm internal, 9 mm external diameter PVC) inlet tube, secured to the funnel outlet using epoxy resin, extends close to the base of the collection vessel. A similar, small-diameter (6 mm internal, 9 mm external diameter PVC) outlet tubing was fixed to the cap of the collecting vessel using epoxy resin, and was wrapped around a PVC pipe (10.2 cm diameter) surrounding the bottle to allow equilibration of air between the bottle and the atmosphere while minimizing evaporative loss of the sample (Figure 1). L-shaped metal brackets and screws secured the PVC pipes to the end cap. The long tube prevents water loss through the pressure-equilibration outlet. The entire set up,

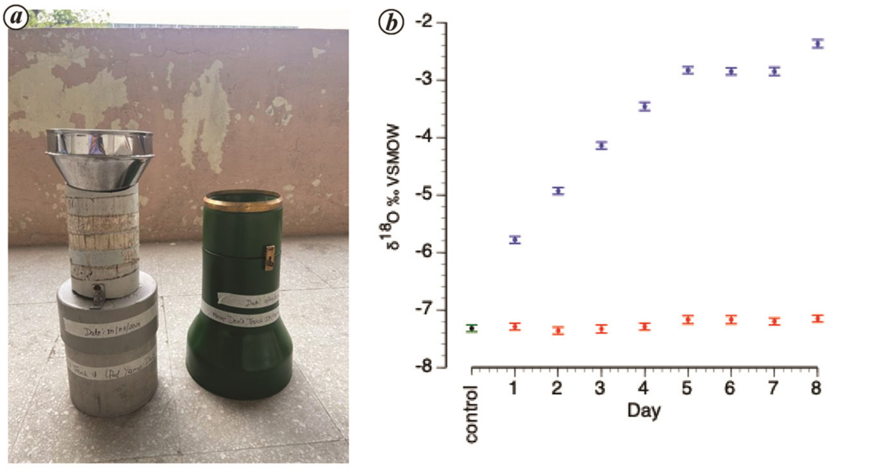

Figure 2. ***a***, Indian Institute of Technology Delhi (IITD) rain collector set alongside commercial rain gauge. ***b***, δ^{18}O values of aliquotes of water recovered from each of the two devices each day from 1 to 8 days after the start of the experiment. Control is tapwater. Error bars are ±1 standard deviation of internal and external errors associated with the analyses.

Table 2. Indian Institute of Technology Delhi (IITD)-rain collector performance test

	δ^{18}O ‰ VSMOW	δ^{18}H ‰ VSMOW	
Experiment I: Uncapped open bottle (OB), bottle in IITD-rain collector (RC) and fridge (control)			
INDIA_RC1	–9.10	–61.12	Tapwater
INDIA_RC2	–9.39	–63.50	Tapwater
INDIA_RC3	–9.14	–61.96	Rain collector 1
INDIA_RC4	–8.93	–60.92	Tapwater
INDIA_RC5	–9.09	–61.08	Rain collector 2
INDIA_OB	–5.58	–45.69	Uncapped bottle
Experiment II: Comparison of IITD-RC with commercial rain gauge (RG)			
RC test 2024 IAEA RG 11/07/24	–5.78	–45.94	
RC test 2024 IAEA RG 12/07/24	–4.93	–43.83	
RC test 2024 IAEA RG 13/07/24	–4.14	–41.99	
RC test 2024 IAEA RG 14/07/24	–3.46	–40.36	
RC test 2024 IAEA RG 15/07/24	–2.83	–38.71	
RC test 2024 IAEA RG 16/07/24	–2.85	–38.06	
RC test 2024 IAEA RG 17/07/24	–2.85	–37.73	
RC test 2024 IAEA RG 18/07/24	–2.37	–36.33	
RC test 2024 RC Delhi 11/07/24	–7.29	–48.37	
RC test 2024 RC Delhi 12/07/24	–7.36	–48.51	
RC test 2024 RC Delhi 13/07/24	–7.33	–48.38	
RC test 2024 RC Delhi 14/07/24	–7.29	–48.31	
RC test 2024 RC Delhi 15/07/24	–7.17	–47.78	
RC test 2024 RC Delhi 16/07/24	–7.17	–47.73	
RC test 2024 RC Delhi 17/07/24	–7.20	–47.82	
RC test 2024 RC Delhi 18/07/24	–7.15	–47.84	
RC 2024 Test control kept in fridge	–7.32	–48.22	
Experiment III			
Delhi GNIP 47 years average rainfall isotopes	–5.02	–31.38	
Delhi JJAS 2023 rainfall isotopes in IITD-RC	–5.15	–31.44	

VSMOW, Vienna standard mean ocean water.

excluding the funnel, is encased within a 17.8 cm long, 15.2 cm diameter PVC pipe, which is connected to the end cap on the top. The collector cost ~1500 INR (~18 USD) (Table 1), thus providing an economical alternative to the IAEA-approved commercially available version (http://www.rainsampler.com/) with a similar setup, which is significantly more expensive, costing over USD 220.

Testing and discussion

The performance of IITD rain collector was evaluated in three separate experiments. Firstly, we compared water samples stored in the rain collector and an uncapped bottle of an identical type to that used in the rain collector; both were kept under cover but outside on the rooftop of IITD for three days. A capped bottle of the original water in the refrigerator served as a control. Three 300 ml samples of Delhi tap water were kept from 20 to 22 April 2023 under these different conditions. At the end of the three-day period, 30 ml aliquots of water were removed from each vessel and transferred to 30 ml polyethylene sample bottles, which were then sealed to ensure minimal evaporative loss prior to analysis. Secondly, we compared the performance of the IITD rain collector with that of a commercial rain gauge. 300 ml of tapwater was added to both the IITD rain collector and the commercial rain gauge and both were placed outside under cover, in the same location as the first experiment, for eight days from 10–18 July 2024 (Figure 2). The 5 ml aliquots of water were removed from each device on days 2, 3, 4, 5, 6, 7 and 8. We also took one control sample, which was a 5 ml aliquot of water taken directly from the tap and placed in refrigerator to prevent any evaporation. Finally, we compared rainfall collected in the rain collector during the 2023 summer monsoon season with data from the Delhi GNIP station.

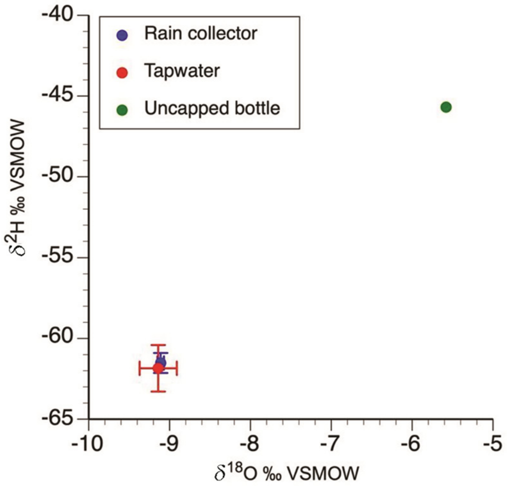

Figure 3. Test of rain collector performance. Tap water samples were drawn directly from mains tap at IITD, placed in 30 ml polyethylene bottles ($n = 3$), which were then capped securely and sealed with electrical tape; the rain collector samples ($n = 2$) comprised 300 ml of the same tapwater placed in one of two rain collectors of the design described in this article. For the 'uncapped bottle' sample, 300 ml of the same tapwater were placed in an uncapped bottle. After the test period (see text for further details), 30 ml samples of water were removed from the collecting bottles in the rain collector or the uncapped collecting bottle and transferred to 30 ml polyethylene bottles, which were then capped securely and sealed with electrical tape before transfer to vials for analysis. Error bars are ±1 standard deviation of measurements of multiple aliquots of the different samples (Table 2).

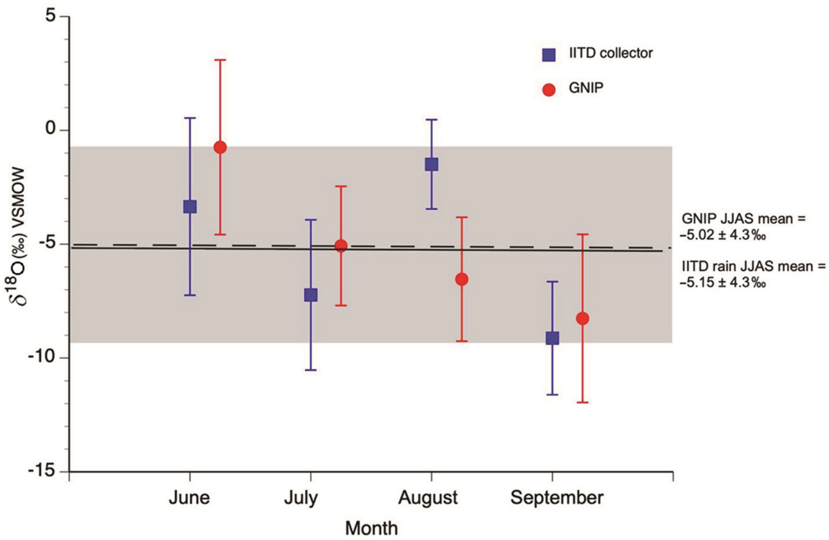

Figure 4. Comparison of mean ± 1 standard deviation oxygen-isotope values for June–July–August–September (JJAS) precipitation from Delhi collected in 2023 in the IITD rain collector and for the 47 years from 1961 to 2007 from GNIP. Dashed line denotes the mean JJAS δ^{18}O from the GNIP data and shading indicates ±1 standard deviation. Solid line denotes mean JJAS δ^{18}O from the 2023 samples from the IITD collector.

For isotope analysis, each water sample was transferred to 5 ml glass Thermo™ vials with PTFE septum and analysed using a Picarro L2140-i Cavity Ringdown Spectrometer (CRDS) at the Physics Institute, University of Bern, Bern, Switzerland (rain collector versus open bottle experiment) or a Picarro L2130-i CRDS at University College London, UK (all other determinations). The results were expressed in standard delta units, as parts per thousand or per mil (‰) deviations from the VSMOW (Vienna Standard Mean Ocean Water) standard, with δ‰ VSMOW = $((R_{sample}/R_{standard}) - 1) * 1000$), where $\delta = \delta^{18}$O or δ^2H and $R = {}^{18}O/{}^{16}O$ or ${}^2H/{}^1H$. Uncertainties were better than ± 0.07‰ and ± 0.38‰ for δ^{18}O or δ^2H respectively.

Results

Table 2 and Figure 3 indicate that tapwater samples transferred to and stored in sealed bottles and the rain collectors on IITD roof show very similar δ^{18}O and δ^2H values. In contrast, the open bottle sample showed elevated δ^{18}O and δ^2H values because of evaporation, which led to preferential loss of lighter isotopes. Similar findings were made in the second experiment (Table 2 and Figure 2), in which the progressive fractionation leading to increases in $\delta^{18}O$ and $\delta^{2}H$ values over the eight days of the test is observed in the commercial rain gauge, whereas once again the preservation of the isotopic characteristics of the original sample is observed for the IITD collector. The results of both experiments validate the IITD collector design and illustrate the importance of taking appropriate steps during rainfall collection to prevent evaporation and preserve sample integrity.

Following testing, the rain collector was installed on IITD rooftop to collect rainwater samples through the monsoon months from June to September (JJAS) 2023. Event-based water sampling was performed. The mean values for IITD-rain collector samples collected in JJAS 2023 are $-5.15 \pm 4.09‰$ (1σ) and $-31.44 \pm 30.55‰$ (1σ) for oxygen and hydrogen isotopes respectively, which lie close to the mean values of summer (JJAS) rainfall from the Delhi GNIP station for a period of 47 years from 1961 to 2007 ($-5.02 \pm 4.28‰$ and $-31.37 \pm 31.60‰$ for $\delta^{18}O$ and $\delta^{2}H$ respectively) (shown for $\delta^{18}O$ in Figure 4). It can be noted that the isotopic values from the IITD rain collector samples for the month of August differ markedly from those of 47 years-average GNIP value for the same month. This deviation is best explained by the differences in rainfall amount and an isotopic 'amount effect', in which there is often an inverse correlation between rainfall amount and isotope values in tropical regions[1,2]. The 47-year average amount of rainfall in the month of August in Delhi is ~242 mm, whereas in August 2023, it was only 91.8 mm. Nevertheless, the August 2023 isotope values are still within the standard deviation of the mean rainwater isotopic values (horizontal grey bar, Figure 4). These observations further attest to the reliability of IITD-rain collector design. This design has now been used to construct 17 collectors deployed across the eastern Indo-Gangetic Plain to collect regular rainfall samples as part of a citizen science project to investigate monsoon dynamics during the 2023 summer monsoon season. The results of this project will be published elsewhere.

The IITD-rain collector can be used for other short- or long-term networks to complement the existing IAEA stations, which are rather sparse in India. A similar design has been used to establish a small network in South Africa[16] and for a single-site study in the UK[17]. The design of Gröning *et al.*[15] preserved the isotopic composition of rainfall samples stored for over one year. However, the IITD-rain collector would require further testing to establish its capabilities over longer periods than were tested in the present study. Moreover, a collector used for integrated sampling of more than a few days would require a larger collecting vessel than the one used here, given the large rainfall amounts in many parts of India during the monsoon season.

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