Paired Watershed Studies

Evaluating the Impact of Watershed Management Interventions

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WELL LABS
WATER · ENVIRONMENT · LAND · LIVELIHOODS

Environmental Defense Fund

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About the MEL Toolbox

The MEL toolbox simplifies scientific methods for grassroots practitioners to effectively monitor, evaluate, and learn from watershed management interventions in India. It compiles existing methodologies into an accessible format to support impact assessments that are robust despite limited resources and short project timelines. By strengthening evaluation capacity, the toolbox enables users to maximise the benefits of watershed interventions. As a living document, it will evolve through testing with partner organisations and the inclusion of new methodologies to enhance MEL practices.

This document is Part 3 of the MEL Toolbox series. Click to view Part 1, Part 2 and Part 4.

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About WELL Labs

Water, Environment, Land and Livelihoods (WELL) Labs co-creates research and innovation for social impact in the areas of land and water sustainability. It collaborates with partners to design and curate systemic, science-based solutions to enable a high quality of human life and nurture the environment. WELL Labs is part of the Institute for Financial Management and Research (IFMR) Society.

About EDF

A global nonprofit, Environmental Defense Fund collaborates with governments, NGOs, research and academic institutions, corporates and others to support and advance India's vision of shared, sustainable prosperity. It combines scientific and economic foundations, a broad network of partnerships and a pragmatic approach in support of India's ambitions.

What is the approach?

Paired watershed studies is a research method that compares two neighbouring watersheds over time to understand how changes in land and watershed management affect hydrologic processes.

How is it useful?

It helps identify trends over a period of time, and is useful for improving hydrological models to ensure they reflect real-world conditions.

Who can use it?

CSOs can apply this methodology to assess the impact of large-scale watershed interventions. Its implementation requires a foundational understanding of GIS and remote sensing.

What are Paired Watershed Studies?

A paired watershed study is a research method that compares two neighbouring watersheds over an extended period to understand how changes in land and watershed management affect hydrological parameters like groundwater levels, runoff, and water quality. Such studies last anywhere from a year to a decade, generating long-term datasets that show trends over time. This data is also useful for improving and testing hydrological models to ensure they reflect real-world conditions.

How are they Conducted?

The paired watershed approach involves selecting two adjacent watersheds that share similar characteristics, such as size, climate, geology, and land cover. One, left undisturbed, serves as the **control watershed**, while the other—the **treatment watershed**—is subject to specific interventions like afforestation, watershed actions, or agricultural practices.

Proximity of the Watersheds
Proximity ensures that external factors like rainfall and temperature are consistent, allowing researchers to attribute any differences in hydrological responses—such as changes in the water table, runoff, or streamflow—to the intervention.

Size of the Watersheds
Paired watersheds tend to be relatively small, on the order of a few square kilometres or less, making it feasible to implement and monitor such experiments effectively.

Study Duration
A paired watershed study can range from a season to a year or even decades.

Although one would expect the paired watersheds to have identical hydrological responses, this is not always the case. Baseline assessments of outflows help identify the differences between the watersheds, ensuring these are not mistaken for treatment effects.

A paired watershed study typically includes two phases: a **calibration phase** and an **experimental phase**. During the calibration phase, baseline observations are collected over a period ranging from one year to a decade, focusing on key parameters. Once these baseline measurements are established, the experimental phase begins, involving planned land-use interventions in the treatment watershed. This phase typically requires long-term monitoring, with the study duration influenced by factors such as the type of intervention and available funding. Ideally, at least one year each is needed to record calibration and experimental observations.

The comparison between the calibration and experimental phases for both treatment and control watersheds helps separate the treatment's causal effects from temporal and spatial variations in climate and hydrology.

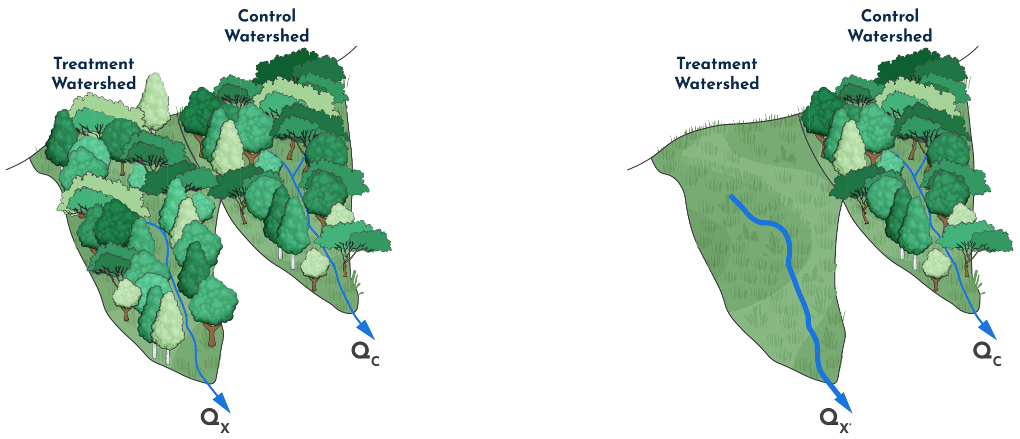
Ex-post Analysis

In cases where interventions are already in place and an ex-post analysis is necessary, selecting a well-matched pair of watersheds is critical. These watersheds should ideally be geographically adjacent and similar in geological and land-use characteristics, enabling a reliable comparison between control and treatment plots.

Role of Technology

Advances in open-source satellite imagery and the availability of tools for processing remote sensing data now allow researchers to analyse watershed behaviour over time. Metrics such as land use and land cover changes, the presence of surface water bodies, variations in the normalised difference vegetation index (NDVI), and energy balance-based evapotranspiration maps can work as proxies for long-term calibration observations.

Here is an example of a paired watershed experiment where the researcher is examining how deforestation affects stream flows. The control region remains forested (Qc), and stream flows are measured in both control and treatment regions (Qx), before and after the vegetation loss.



a) State of Watersheds During Caliberation Phase

b) State of Watersheds After Treatment

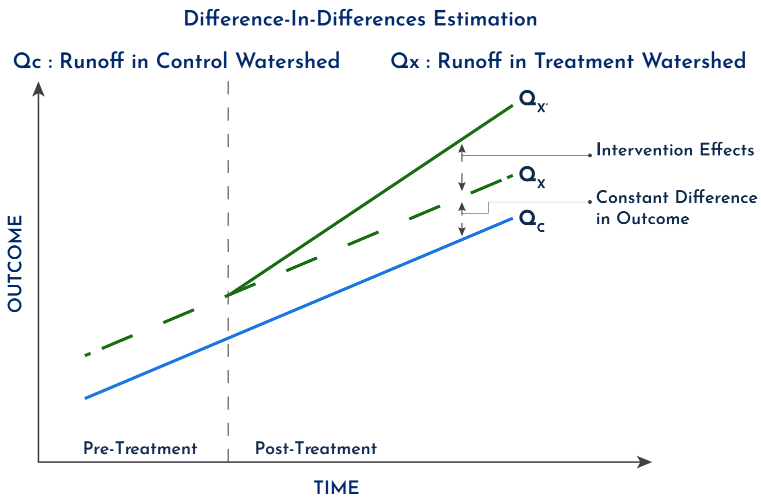


Figure 1: A schematic diagram of a paired watershed experiment.

In What Contexts Should they be Conducted?

The paired watershed approach is most effective when the intervention is expected to significantly impact groundwater levels or streamflow.

Where Should they be Conducted?

This method is particularly suited to **crystalline hard rock systems**, where the groundwater catchment is typically the same as watershed boundaries. In contrast, it is less effective in large **alluvial systems**, such as the Indo-Gangetic Basin, where the groundwater system is connected to a broader network outside the specific watershed. For **basaltic systems**, the approach generally works well when applied to the top aquifer that is directly linked to the watershed being treated.

How to Select Paired Watersheds[1]

1 Delineate the watersheds

- Use GIS tools to delineate and map first-order streams from digital elevation model (DEM) data. Use a threshold of 10 or 100 pixels (each 30x30 m) while delineating; this ensures a detailed representation of the stream network, capturing finer-order streams effectively.
- Ensure the two watersheds are hydrologically similar (shape, size, stream order, etc.).

2 Match the elevation ranges

- Select watersheds with similar elevations to maintain comparability.
- Ensure both watersheds fall within the same contour intervals to minimise slope differences.

3 Map open wells and borewells

- Identify and map open wells using satellite imagery and GIS platforms in both watersheds for monitoring purposes.
- If the watersheds depend on borewells for irrigation, conduct a reconnaissance survey (more on this in point 5) to map them.

4 Check land use and land cover (LULC), soil, and aquifer maps

- Analyse LULC patterns using satellite images to confirm similarities.
- Check the available data on soil, aquifers, and other hydrogeological parameters to check for similarities.

5 Conduct field reconnaissance

- Visit the sites to validate LULC, check aquifer and soil characteristics (top soil type, layering of soil, rocks across depths, etc.), and record well depths. Sample at least one well per square kilometre to achieve spatial coverage across the watersheds.
- Engage with local farmers to gain insights into the landscape, land management practices, and water use, to contextualise and refine the field observations.

6 Choose the control and treatment watersheds

- Choose the control (no intervention) and the treatment (with intervention) watersheds.

[1]*This course explains the basic GIS and remote sensing tools and techniques used in this document.*

7 Select the sites to monitor groundwater

- Choose wells or borewells to monitor at a resolution that can capture any changes due to intervention in the treatment watershed. One well per square kilometre works well if the area is fairly uniform.

8 Monitor streamflow

- Install streamflow measurement stations at the outlets of each watershed. If there is a budget constraint, use a staff gauge and periodically monitor water levels manually. A more expensive alternative is to use automated gauges.

- Streamflow measurements are optional for watersheds with no surface water discharge. Otherwise, it is a beneficial exercise to conduct.

9 Collect data at frequent intervals

- Collect data monthly or adjust frequency based on intervention requirements.

10 Analyse the data frequently

- Analyse the data after each monitoring cycle to understand the nuances. This can also help in recalibrating the monitoring frequency and locations.

Advantages	Limitations
• Provides insights into the combined effects of watershed interventions. • Identifies unexpected complexities, offering valuable feedback for refining and improving intervention designs. • Well-suited for watersheds with no boundary conditions and undulating terrain.	• Can be expensive and time-consuming to implement. • Requires a high density of interventions to observe a detectable change in hydrological responses. • Works best when complemented by plot- or farm-scale assessments, such as infiltration tests and water level monitoring, which can be tedious. The paired watershed approach captures the cumulative impact of such hydrological processes at the watershed scale.

Conclusion

The paired watershed approach is among the most rigorous tools for studying watershed-scale hydrology, as it integrates controlled experimentation with long-term field observations. By designating one watershed as a control and the other for a specific treatment, it helps reveal how land and watershed management practices impact hydrology and uncover key processes. Its long-term nature allows researchers to detect trends and separate treatment effects from climatic variability. The high-quality data collected also supports the conceptualisation and refinement of hydrological models and informs sustainable land and water management practices.

Case Study

WELL Labs and Environmental Defense Fund (EDF) conducted a paired watershed study in the Poorna river sub-basin, Maharashtra, to evaluate the impact of recharge pits on groundwater availability. We selected two sites: a control watershed with no recharge pits and a treatment watershed with 368 recharge pits (Figure 2).

We ensured the watersheds are on the same slope and elevation range. In addition, we compared their land use, water spread area, and average annual normalised digital vegetation index on QGIS to ensure they were similar.

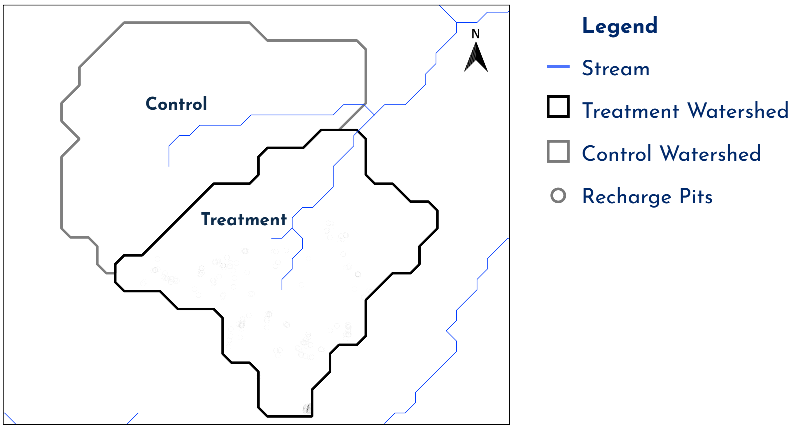


Figure 2: The control and treatment watersheds in the Poorna basin.

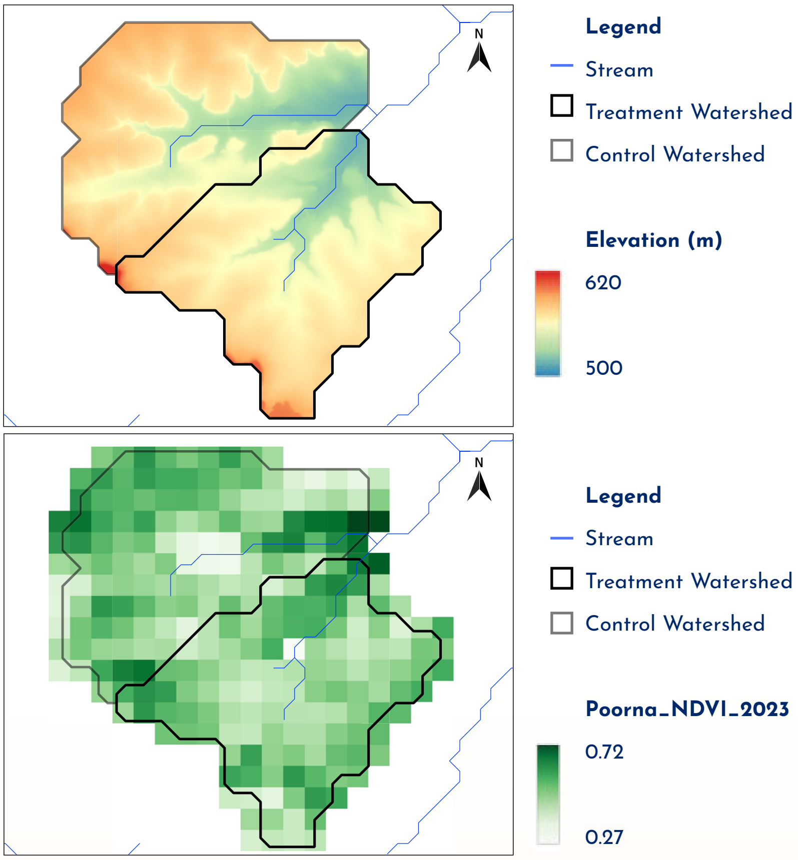


Figure 3: (Top) A digital elevation map and (bottom) an annual average normalised digital vegetation index (NDVI) map for the control and treatment watersheds in Poorna basin.

Using a Google satellite hybrid map layer in QGIS (at 1:1000 scale), we created a map of all the wells in the watersheds. Then, we made a grid and selected one well/sq km to monitor[2]. We conducted monthly water level checks in the wells from June 2024 to January 2025, which helped us understand whether the recharge pits were improving groundwater levels.

Figure 4: Mapping of wells to monitor groundwater levels in control and treatment watersheds. The watershed in the top-left watershed without recharge pits and the watershed at bottom-right is with recharge pits. The dots on the map indicate the mapped wells. Later one well per grid was selected for monthly water level monitoring.

The table below shows the parameters considered while selecting the paired watersheds for the study.

Watershed	Order of Stream	Slope (degrees)	Area (sq-km)	Presence of Reservior	Area of Reservior (sq-km)	Average Annual NDVI (for 2023)	Land Use	Number of Wells Monitored	Number of Recharge Pits
Control	1	0-10	24.18	Yes	0.48	0.51	Agriculture	34	0
Treatment	2	0-10	24.18	Yes	0.43	0.50	Agriculture	36	368

Table 1: Parameters considered for the selection of the paired watersheds.

[2]Ensure utmost caution while measuring water levels in wells, prioritising safety at all times. It is advisable to choose wells with secure parapet walls for added safety.

Figure 5 illustrates the change in water levels from June to October. The results indicated that there was no significant difference in water levels between the control and treatment groups in this study. This suggests that the treatment watershed, at the given scale, did not have a noticeable impact on the water table.

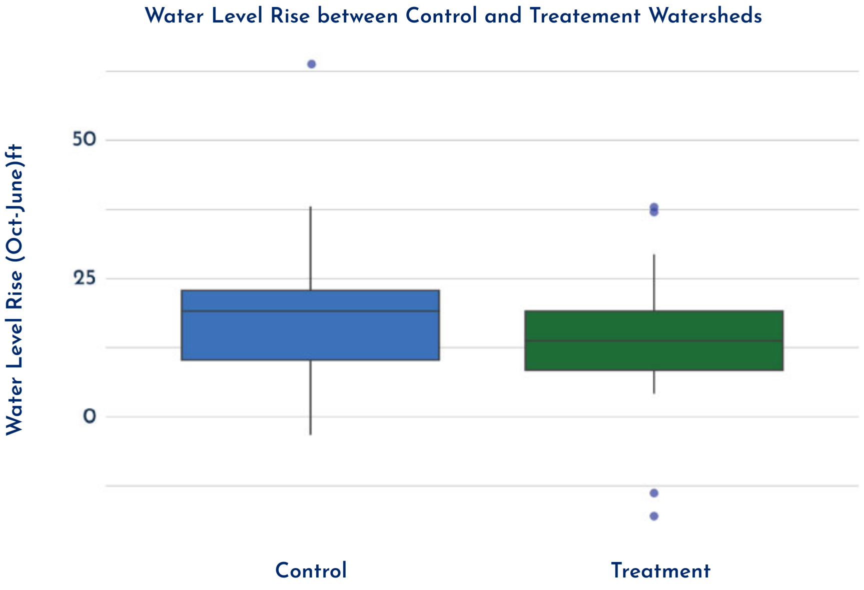


Figure 5: Groundwater level rise during monsoon between the control and treatment watersheds.

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