

“Water Safety Plan for Six Villages in Panhala Region”

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ABSTRACT

Ensuring safe drinking water access remains a critical public health objective, particularly across rugged, topographically challenging terrains. This study presents a rigorous cross-sectional evaluation of household drinking water quality across six distinct rural habitations (Pombre, Undri, Ambarde, Bongewadi, Chavanwadi, and Golivade) in the Panhala region of the eco-sensitive Western Ghats, Maharashtra, India. Water quality dynamics were monitored across two consecutive hydrological cycles (2022–2023 and 2023–2024), capturing variations across pre-monsoon and post-monsoon phases. Laboratory analysis tracked key physico-chemical and bacteriological parameters including pH, Electrical Conductivity (EC), Turbidity, Total Hardness (TH), Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chlorides, Nitrates, and Most Probable Number (MPN) of coliforms per 100 mL. The empirical findings reveal that while crucial chemical indices—including pH (mean 7.2), TDS (mean 105.9 mg/L), and Total Hardness (mean 144.3 mg/L)—consistently complied with the safety limits defined by the Bureau of Indian Standards (BIS) and the World Health Organisation (WHO), critical systemic failures were identified in physical and microbiological indicators. Mean turbidity across five of the six monitored villages was 9.4 NTU, vastly exceeding the permissible 5 NTU threshold, peaking at 15.8 NTU in Pombre due to monsoonal runoff and heavy soil erosion. Crucially, every single sampled household tested positive for microbial contamination, with mean MPN values ranging from 58.0 to 337.4 coliforms/100 mL, and fecal coliform counts reaching up to 134 coliforms/100 mL in Chavanwadi. Field surveys established that these contamination profiles stem directly from unscientific, arbitrary bleaching powder dosing at centralized Gram Panchayat storage reservoirs, cross-contamination within aging distribution pipelines, and unhygienic household storage practices. The study underscores the immediate, vital need to transition from conventional retroactive water testing to proactive, source-to-consumer Water Safety Plans (WSPs) integrated with structured community training to mitigate waterborne disease burdens in rural environments.

Keywords: Water Safety Plan, Public Health, Turbidity, Microbial Contamination, Western Ghats

INTRODUCTION

Access to clean, microbiologically safe drinking water is a fundamental human right and a core pillar of public health, as recognized under Article 47 of the Constitution of India and United Nations Sustainable Development Goal 6.1. Despite progressive socio-economic development and structural capital investments since the inception of the First Five-Year Plan in 1951, water pollution remains a prime driver of public morbidity and mortality across rural India. Globally, waterborne diseases account for massive mortality rates, claiming thousands of lives daily. Diarrhoeal illnesses alone cause over 1.6 million deaths annually, disproportionately devastating children under the age of five. In India, an estimated 37.7 million citizens are impacted by waterborne pathogens every year, leading to the loss of 73 million productive working days and imposing an annual economic burden of approximately USD 600 million on the national economy.

The degradation of fresh surface and groundwater systems is driven by rapid industrialization, domestic sewage dump failures, population growth, and agricultural nutrient runoffs containing high concentrations of nitrogen, phosphorus, and toxic pesticides. When heavy rains occur, these non-point agricultural contaminants wash directly into nearby channels, sparking severe eutrophication and toxic blue-green algal blooms that render water systems completely undrinkable. Furthermore, excessive biodegradable organic loading triggers severe oxygen depletion within aquatic environments. As aerobic microorganisms rapidly multiply and exhaust dissolved

oxygen, aquatic life perishes, paving the way for anaerobic bacteria to multiply and generate toxic by-products like ammonia and hydrogen sulfide. In rural areas, shallow groundwater tables face secondary contamination as rainwater carries agricultural chemicals down through porous soils. Consequently, open wells and boreholes require systematic screening and treatment before consumption.

The Panhala taluka, situated in the rugged, eco-sensitive Western Ghats of the Kolhapur district, faces unique challenges in water governance. Characterized by steep gradients and distinct geological formations, the region lacks large-scale water-retaining structures, forcing rural communities to rely heavily on monsoonal rainfall, local springs, open wells, and piped water schemes. While the city of Kolhapur benefits from water drawn from the Panchaganga River basin—formed by the confluence of the Bhogawati, Kumbhi, Kasari, Tulshi, and Dhamani rivers—the surrounding rural and fringe villages are highly vulnerable to localized contamination.

Historically, global water management has focused on retroactive testing against an increasing list of water quality parameters. This strategy fails to protect public health effectively because consumers often ingest pathogens and fall ill long before laboratory reports are finalized and corrective actions are taken. This problem is magnified in rural tracts like Panhala, which lack competent local testing laboratories or standardized monitoring procedures.

To address these vulnerabilities, the World Health Organisation (WHO) advocates for the implementation of Water Safety Plans (WSPs). A WSP is an all-encompassing, preventive risk-management framework that monitors water quality from catchment to consumer. WSPs operate through three core components: a comprehensive system assessment to verify if the supply chain can meet safety targets, continuous operational monitoring of specific control barriers, and structured management plans detailing clear actions under varying operational conditions. This research provides a comprehensive assessment of household drinking water quality across six representative rural habitations in Panhala. By documenting distinct seasonal contamination profiles, this study establishes the scientific justification for transitioning to proactive Water Safety Plans to secure rural public health.

METHODOLOGY

Study Area and Geomorphological Settings

The cross-sectional study was carried out across six representative rural habitations within the Panhala Taluka of the Kolhapur District, Maharashtra, India: Pombre, Undri, Ambarde, Bongewadi, Chavanwadi, and Golivade. According to census data, the Panhala Taluka contains 129 villages with a total population exceeding 251,603. The region is characterized by the eco-sensitive geomorphology of the Western Ghats, featuring steep slopes and lateritic rock formations that limit natural water retention. Piped water supply infrastructure has been expanded across these villages under the Central Government's Jal Jeevan Mission (JJM), which focuses on providing functional household tap connections through sustainable local measures, including rainwater harvesting structures.

Table 1. Geospatial Coordinates of Selected Rural Habitations in Panhala Taluka

Sr. No.	Name of the Village	Latitude	Longitude
1	Pombre	16.8094° N	74.1182° E
2	Undri	16.8094° N	74.1182° E
3	Ambarde	15.85735° N	73.9045° E
4	Bongewadi	16.8094° N	74.1182° E
5	Chavanwadi	16.8794° N	74.1682° E
6	Golivade	16.8118° N	74.0894° E

Sampling Design and Sample Collection

Field sampling was conducted over a two-year period spanning the 2022–2023 and 2023–2024 academic calendars. To evaluate the impact of monsoonal weather patterns on water quality, samples were collected during two distinct periods: the pre-monsoon phase (December to May) and the post-monsoon phase (June to November). Following a pilot infrastructure survey, two consumer-end sampling nodes were established in each village, targeting the most heavily utilized public piped taps, open wells, or boreholes.

At each node, water samples were collected using clean, 2-litre capacity high-density polyethylene (HDPE) containers for physico-chemical analysis, alongside sterilized borosilicate glass bottles for microbiological evaluation. To ensure representative collection from piped systems, public taps were opened and allowed to flush for 2–3 minutes to clear stagnant water before filling. Each sample container was rinsed 2–3 times with the target water source before final collection. The bottles were tightly sealed, labeled with unique identification codes, placed inside insulated ice chests maintained at approximately 4°C, and transported to the laboratory for analysis within 24 hours of collection.

Analytical Laboratory Procedures

Physico-chemical and bacteriological parameters were evaluated using standard protocols outlined in the Standard Methods for the Examination of Water and Wastewater (22nd Edition, 2012) published by the American Public Health Association (APHA) and the Manual on Water and Wastewater Analysis by the National Environmental Engineering Research Institute (NEERI). Water temperature and pH were recorded in the field using a calibrated portable digital pH meter. Electrical conductivity (EC) was determined via a digital conductivity meter at a reference temperature of 20°C.

Turbidity was quantified using a digital Nephelometric Turbidity Meter calibrated against standard 40 NTU formazin suspensions. Total Solids (TS), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) were determined gravimetrically; samples were filtered through standard glass-fiber filters and dried to a constant weight in a laboratory oven at 103–105°C. Total Hardness (TH) was measured via the EDTA complexometric titrimetric method using Eriochrome Black T indicator and an ammonium chloride-ammonium hydroxide buffer solution to maintain a stable pH of 10.0.

Chlorides were quantified via argentometric titration against standard silver nitrate (AgNO_3) using a potassium chromate (K_2CrO_4) indicator. Nitrate and phosphate concentrations were determined colorimetrically using a UV-Visible Spectrophotometer at target maximum wavelengths. The evaluation of bacteriological quality was conducted using the Most Probable Number (MPN) multiple-tube fermentation technique with MacConkey broth. Inoculated tubes were incubated at 37°C for total coliforms and 44.5°C for fecal coliforms, with acid and gas production recorded after 24-hour and 48-hour periods.

Table 2. Analytical Methods Utilized for Physico-Chemical and Bacteriological Evaluations

Sr. No.	Target Parameter	Standard Analytical Method
1	pH	Glass Electrode Digital pH Metry
2	Turbidity (NTU)	Nephelometric Method
3	Total Solids (mg/L)	Gravimetric Evaporation Method (103-105°C)
4	Total Suspended Solids (mg/L)	Gravimetric Filtration Method
5	Total Dissolved Solids (mg/L)	Gravimetric Evaporation of Filtrate
6	Chlorides (mg/L)	Argentometric Volumetric Titration (AgNO_3)
7	Total Hardness (mg/L)	EDTA Complexometric Titrimetric Method

8	Most Probable Number (MPN)	Multiple-Tube Fermentation (MacConkey Broth)
9	Phosphate (mg/L)	Ammonium Molybdate Spectrophotometry
10	Nitrate (mg/L)	UV-Visible Spectrophotometric Method

Statistical Treatment of Data

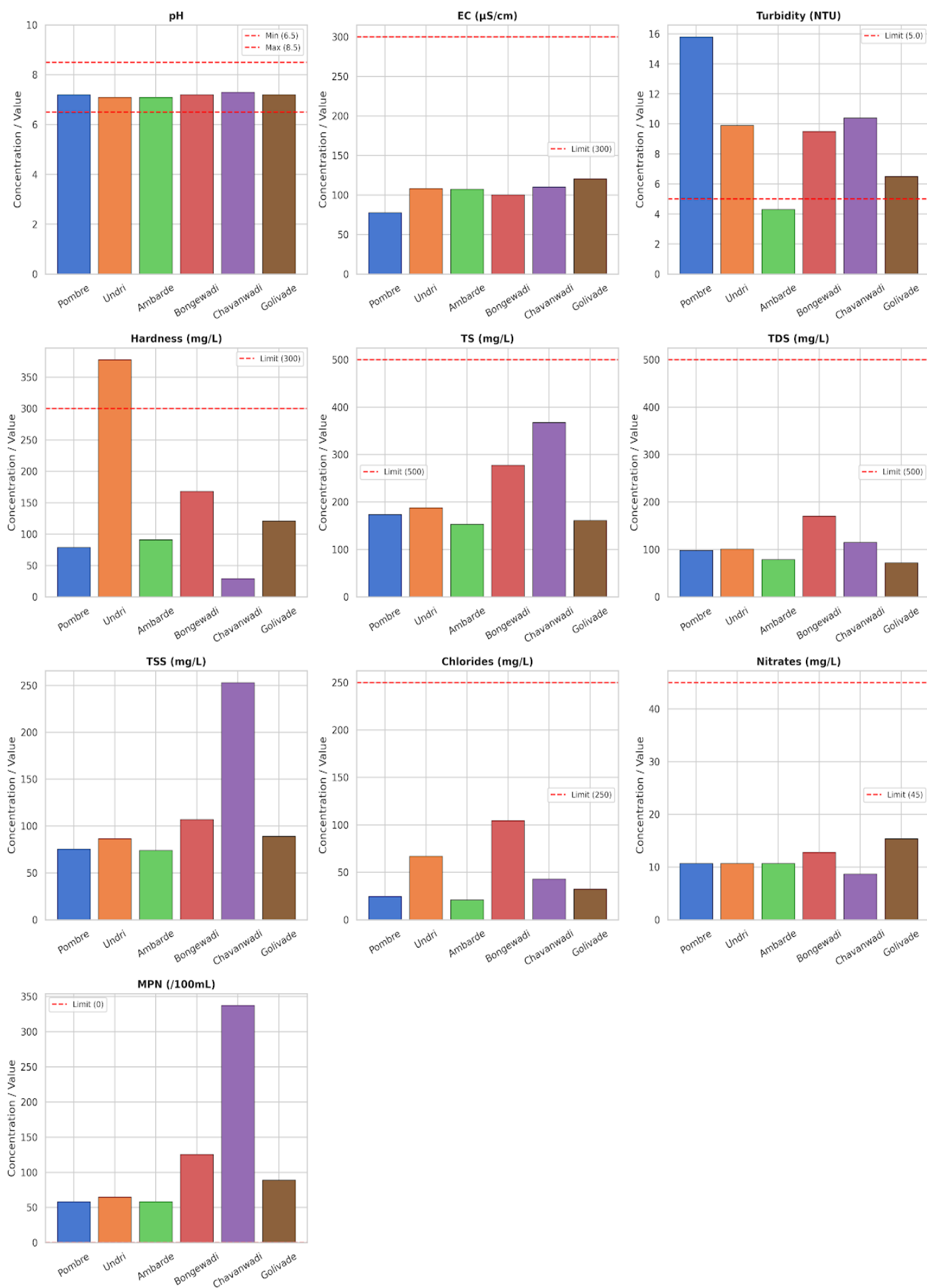
To quantify data distribution and variability across seasons and sampling nodes, laboratory measurements from triplicated sample sets were subjected to basic statistical analysis. Standard deviations ($\pm$ SD) were calculated to evaluate data dispersion around the calculated mean values using the standard formula. Experimental values were systematically compared against the water quality standards established by the World Health Organisation (WHO) and the Bureau of Indian Standards (BIS: 10500).

RESULTS AND DISCUSSION

Laboratory evaluations across the two-year testing period revealed distinct seasonal changes in water quality across the six rural habitations. The empirical datasets obtained for individual villages across pre-monsoon and post-monsoon cycles are comprehensively tracked against global standards.

Table 9. Consolidated Regional Average Values Matrix vs Statutory Safety Limits

Sr.	Parameter	Pombre	Undri	Ambarde	Bongewadi	Chavanwadi	Golivade	POTABLE LIMIT
1	pH	7.2	7.1	7.1	7.2	7.3	7.2	6.5 - 8.5
2	EC (μ S/cm)	77.7	108.2	107.3	100.2	110.1	120.4	300 μ S/cm
3	Turbidity (NTU)	15.8	9.9	4.3	9.5	10.4	6.5	5.0 NTU
4	Hardness (mg/L)	79.1	377.9	91.0	168.2	29.0	120.7	300 (BIS)
5	TS (mg/L)	173.5	187.6	152.8	277.6	367.9	161.1	500 mg/L
6	TDS (mg/L)	98.0	101.0	78.7	170.5	115.0	71.9	500 mg/L
7	TSS (mg/L)	75.5	86.5	74.1	107.1	253.1	89.1	Not Specified
8	Chlorides (mg/L)	24.7	67.1	21.0	104.6	43.0	32.4	250 mg/L
9	Nitrates (mg/L)	10.7	10.7	10.7	12.8	8.7	15.4	45 mg/L
10	MPN (/100mL)	58.0	65.0	58.2	125.6	337.4	89.1	0 / 100 mL



Detailed Parameter Dynamics and Public Health Vulnerabilities

The regional mean pH value remained exceptionally stable at 7.2 across all testing cycles, falling well within the standard statutory threshold of 6.5–8.5. Variations in pH are driven by carbon dioxide interactions and solute loading. The recorded temperature maintained a baseline around 25.2°C, aligning with local ambient air patterns. While these chemical values fall within safe limits, they do not guarantee safety on their own, as dangerous pathogen tracking depends on physical and bacteriological factors.

Turbidity tracks the presence of insoluble suspended materials—such as clay, silt, fine organic matter, and microscopic organisms—that scatter light rather than letting it pass through directly. Regional turbidity averaged 9.4 NTU, with five out of six villages exceeding the 5 NTU safety standard. Pombre exhibited the most severe contamination, averaging 15.8 NTU and peaking at 22.1 NTU during post-monsoon testing. This spike is caused by monsoonal rains washing heavy soil loads from lateritic slopes into the primary river source. Ambarde was the sole habitation to maintain a safe average of 4.3 NTU, primarily because it hosts the main intake for Kolhapur city, which benefits from better regional source management.

Total Dissolved Solids (TDS) measure the concentration of dissolved mineral matter in water. High TDS concentrations can cause unpleasant taste issues, driving consumer complaints. The regional mean TDS remained safe at 105.9 mg/L, well below the 500 mg/L target threshold. Total Hardness (TH) depends directly on the concentration of polyvalent metallic cations, primarily calcium and magnesium salts. The regional hardness mean was 144.3 mg/L, which fits comfortably within the 300 mg/L BIS limit. Undri recorded a high hardness baseline of 377.9 mg/L, due to deep open wells dissolution kinetics.

The most critical public health concern identified was widespread bacterial contamination across all six habitations. Standard regulatory guidelines require zero coliform or fecal coliform colonies per 100 mL of potable water. However, the regional mean MPN stood at 122.2 coliforms/100 mL. Chavanwadi exhibited severe fecal contamination, averaging an MPN of 337.4 coliforms/100 mL, with fecal coliform counts reaching up to 134 coliforms/100 mL. The presence of coliform groups indicates significant fecal contamination from humans or warm-blooded animals.

CONCLUSION

This two-year study demonstrates that rural household drinking water across the Panhala taluka is unsafe for human consumption due to high turbidity and severe microbial contamination. While basic chemical parameters—including pH, Total Hardness, and Total Dissolved Solids—remain within safe legal limits, every single monitored node tested positive for fecal coliform bacteria, with regional MPN levels averaging 122.2 coliforms/100 mL. These issues worsen during the post-monsoon season as heavy rainfall drives soil erosion and surface runoff into local water catchments.

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