TECHNICAL BRIEF

Managing Water Quality Risks for Expanding Managed Aquifer Recharge from Village Ponds: Evidence from the Ramganga Basin in India

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Key Message

Small village pond-based managed aquifer recharge (MAR) systems in the Ramganga Basin are safe from a chemical viewpoint, but remain vulnerable to microbial contamination; however, these risks are typically transient and manageable. With basic water quality protection measures and routine maintenance, they can reliably enhance groundwater storage and resilience. Water quality risks are strongly influenced by catchment land use: ponds receiving runoff from croplands pose the lowest risk, whereas those receiving inflows from built-up areas or small industries carry higher risk. These findings provide practical guidance for strengthening state and national MAR policies and are the basis for several key recommendations to improve safety and performance.

1. Importance of Water Quality for MAR

Groundwater is the dominant source for India's irrigation and drinking water supplies. Across the Gangetic Plain, depletion is accelerating, prompting greater investment in managed aquifer recharge (MAR)[1] through national initiatives such as *Amrit Sarovar*, *Jal Shakti Abhiyan*, MGNREGS and state-level groundwater programs. Collectively, they have resulted in thousands of recharge structures (ponds, check dams, and percolation tanks) being implemented across the region.

While these are very useful programs by the government with encouraging results on enhanced water availability, attention to the quality of recharge water is also important. Recharge from contaminated sources can pose unacceptably high health and environmental risks, especially in rural areas where groundwater provides for both household and agricultural use. National and state policies in India do recognize these concerns (Central Ground Water Board, 2021), but provide limited evidenced-based guidance to ensure the safety of small, decentralized MAR systems that rely on agricultural runoff, especially from cultivated areas with potentially intensive use of chemical fertilizers and pesticides.

The Ramganga Basin, as a major tributary of the Ganges, provides an important setting to address this knowledge gap. Here, village ponds, often dormant, are increasingly being rejuvenated to capture monsoon runoff for enhancing recharge. This study assesses whether water in these ponds is suitable for MAR and what management measures may be needed to protect groundwater quality.

[1] Literature from India also refers to MAR as 'artificial recharge', 'UTFI' or simply 'groundwater recharge'

2. Study Approach

2.1 Study Area and Scope

Nine ponds across Moradabad and Rampur districts in western Uttar Pradesh were monitored over two monsoon seasons: 2024 and 2025 (Figure 1). These ponds represent typical small-scale MAR systems in the region, characterized largely by local agricultural catchments, minimal industrial activity, and multiple uses such as fish culture and livestock watering.

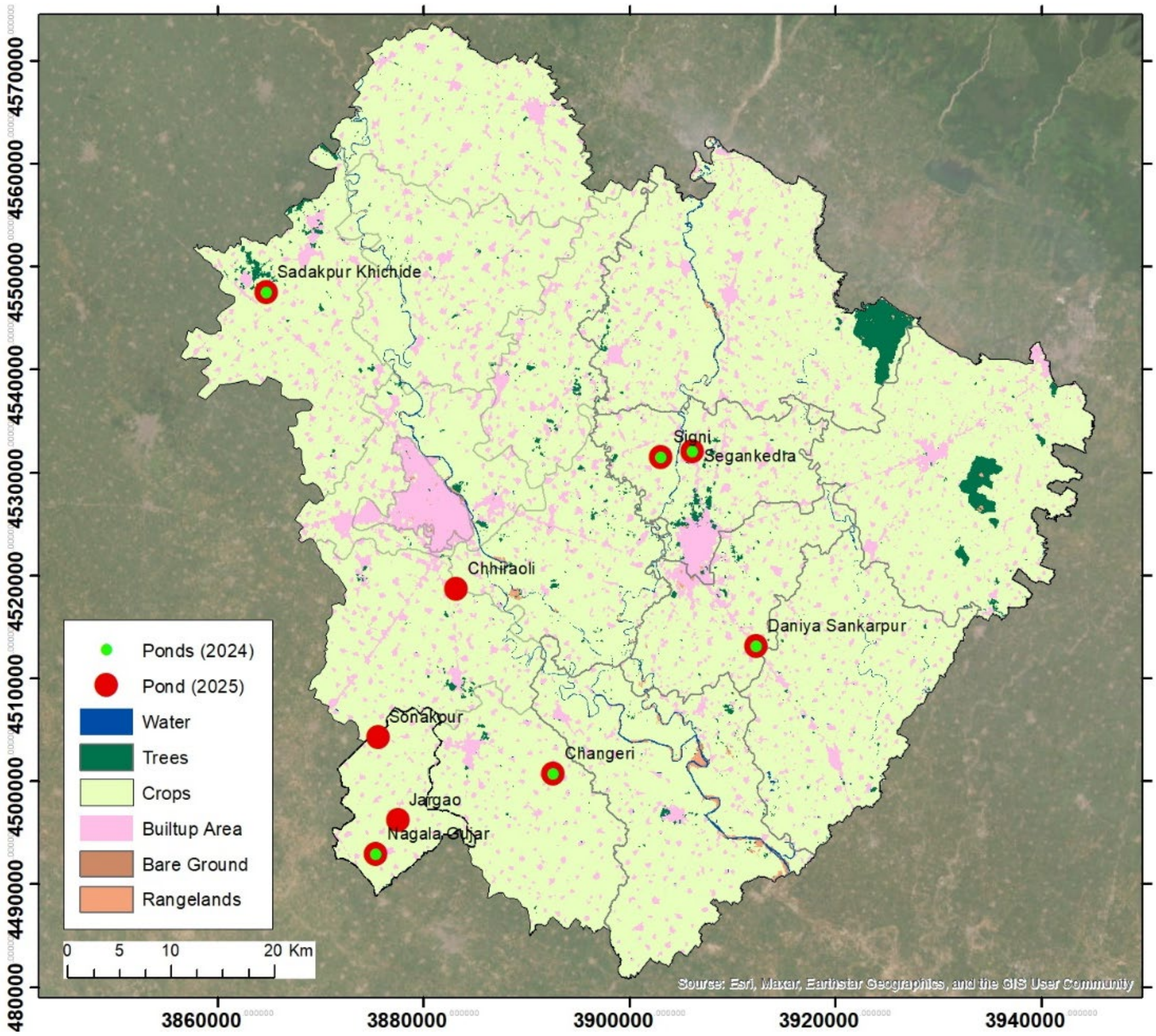

Figure 1. Location of study sites in the Ramganga River Basin, Uttar Pradesh. Source: Esri, (2024)[2]

[2] Land use / land cover (LULC) for 2024 from Sentinel-2, 10-meter resolution; accessed from https://livingatlas.arcgis.com/landcover/

2.2 Sampling and Analysis

Pond water was sampled in both years, and groundwater samples were collected from nearby wells in 2024. Each sample was analyzed for general chemistry, nutrients, trace metals, pesticides, and microbial indicators by an accredited commercial laboratory. Results were assessed against Indian national drinking water standards (Bureau of Indian Standards, 2012).

Figure 2. Collection of groundwater samples from a shallow handpump at Sadakpur Khichide village (left). Pond water sample collection from Signi village (right). Photo: IWMI India

3. Key Findings

3.1 Chemical Suitability for Recharge

Across all ponds, chemical water quality was good (Figure 3):

- Waters were fresh, neutral to slightly alkaline (pH 7–8), and low in dissolved solids and nutrients.
- Total dissolved solids and major ions (Ca, Mg, Na, Cl, SO_4) were well below drinking water standards.
- Nitrate concentrations averaged only 3 mg/L, far below the 45 mg/L standard, whereas ammonia exceeded the standard of 0.5 mg/L at two sites.
- Trace metals (As, Pb, Cr, Ni, Hg) were mostly below detection limits; arsenic occasionally reached 0.014 mg/L but remained within the permissible limit.
- A comprehensive suite of pesticides was tested, but detections were rare and always below the permissible limits.

These findings generally indicate that agricultural runoff into small ponds does not pose significant chemical risks.

3.2 Turbidity and Microbes are the Main Risks

Two parameters consistently exceeded national standards: turbidity and faecal coliforms.

- Turbidity exceeded the upper limit of 5 NTU in most ponds, reflecting sediment and clay mobilization during monsoon runoff events.
- Faecal coliforms also exceeded the upper limit of 0 MPN/100 mL and averaged 11 MPN/100 mL in 2024 and rose to 53 MPN/100 mL in 2025, linked to livestock access and local domestic wastewater inputs.
- Groundwater samples had lower microbial counts (mean 6 MPN/100 mL), because of natural filtration during infiltration.

While these microbial indicators do not suggest persistent contamination, they highlight the need for basic site protection measures such as fencing, controlled livestock access, and periodic desilting to maintain infiltration performance and ensure hygienic conditions.

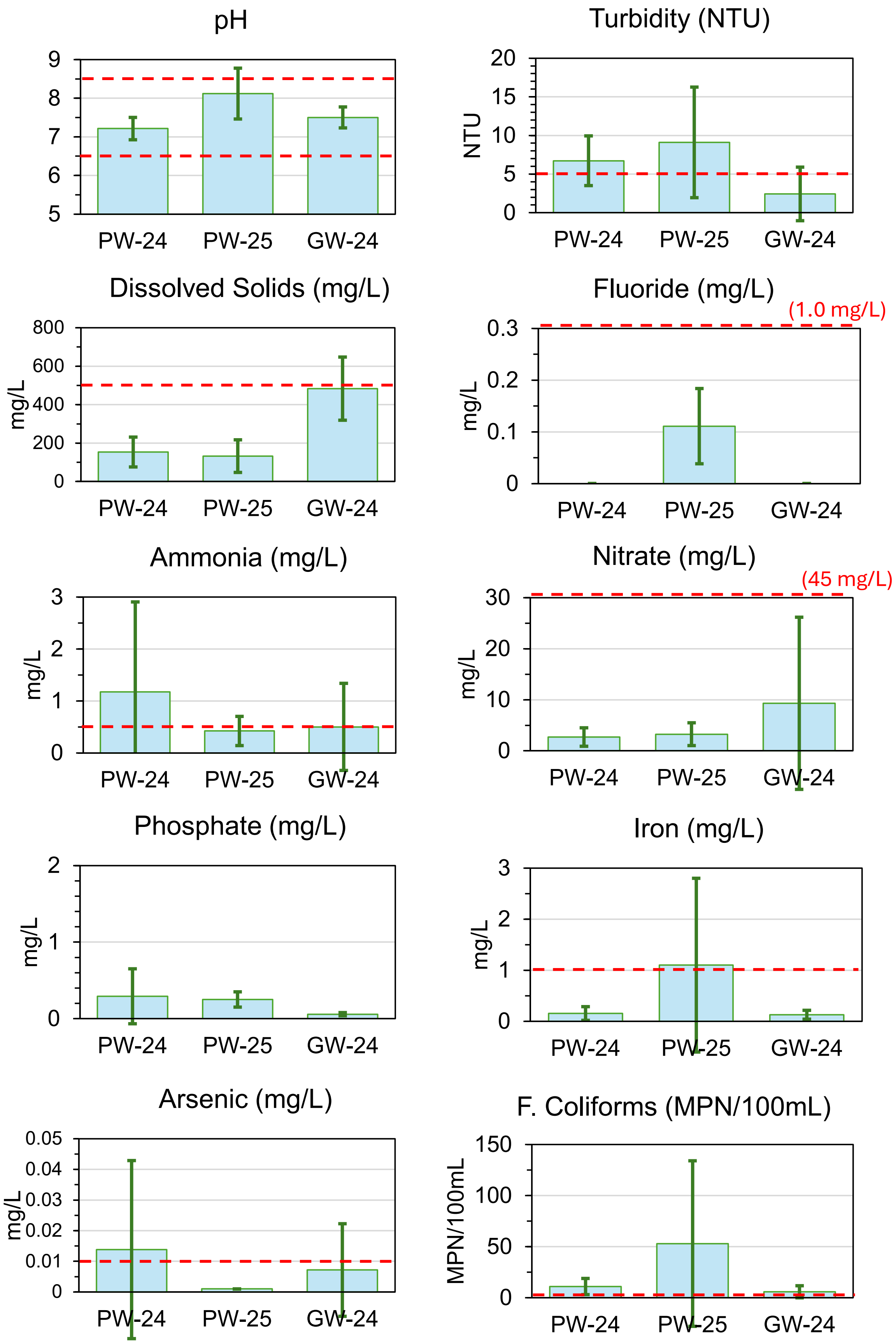

Figure 3. Summary of key water quality parameters for pond water (PW) in 2024 and 2025, and groundwater (GW) in 2024. The bars show the arithmetic averages and the ranges represent the maximum and minimum values measured. Bureau of Indian Standards, (2012) standards are shown by the dashed red line.

3.3 Local Catchment Conditions Strongly Affect Risk

Analysis of land use within the pond catchment area by satellite imagery and ground verification (Table 1) shows clear relationships between dominant activities and observed exceedances:

- Cropland-dominated catchments (e.g., Changeri, Segankedra, Sadakpur Khichide) mainly showed higher turbidity and moderate microbial contamination, typical of agricultural runoff.
- Some cropland dominated sites (e.g., Nagala Gujar, Chhiraoli) showed lower exceedances, likely due to minimal development within the catchment.
- Sites near settlements or small industries (e.g., Signi, Sankarpur) had additional exceedances for ammonia or pH, likely from wastewater or other waste inputs.

This pattern confirms that MAR water quality risk is mostly localized and strongly associated with the prevailing land use.

Table 1. Catchment land use and observed exceedances (red) and non-exceedances (green) in pond water.

	Catchment Characteristics							Water Quality									
								pH		Turbidity		Ammonia		Iron		Faecal coliforms	
Pond	Area (ha)	Crop-land (%)	Agro-forest (%)	Bare land (%)	Settle-ment (%)	Indus-try (%)	Water body (%)	’24	‘25	’24	‘25	’24	‘25	’24	‘25	’24	‘25
Changeri	10.8	83.3	0.93				15.7	Green	Green	Red	Red	Green	Red	Green	Red	Red	Red
Chhiraoli	18.1	95.6					4.4	-	Green	-	Red	-	Green	-	Green	-	Green
Sankarpur	19.5	49.1	6.62	2.10	2.7	37.8	1.7	Green	Green	Red	Green	Green	Red	Green	Green	Red	Red
Jargao	27.8	86.2		3.96	2.0		7.8	-	Green	-	Red	-	Green	-	Red	-	Red
Nagala Gujar	77.6	87.4	1.29		8.3	1.4	1.5	Green	Red	Red	Red	Red	Green	Green	Green	Green	Green
Sadakpur Khichide	34.7	81.7	2.70		12.9		2.6	Green	Green	Red	Red	Green	Green	Green	Green	Red	Red
Segankedra	52.4	92.0	3.91		0.95		3.1	Green	Green	Red	Red	Red	Green	Green	Green	Red	Red
Signi	27.5	63.7	0.68		26.0		9.7	Green	Green	Green	Green	Green	Green	Green	Green	Red	Red
Sonakpur	13.9	74.8		15.5	4.5		5.0	-	Red	-	Green	-	Green	-	Green	-	Green

3.4 Comparison with Other Studies

To contextualize these results, water quality data from a related investigation was compared with the UTFI[3] pilot in the Ramganga Basin, which used canal water from a 202,000-ha catchment that receives mixed agricultural, urban and industrial inflows (Jha *et al.,* 2021; Pavelic *et al.,* 2021); and

Table 2 shows that for both studies, a clear pattern emerges:

- Locally fed ponds are chemically safe but prone to moderate levels of microbiologic contamination.
- Ponds fed from large, canal- or river-fed systems are prone to elevated trace metals (As, Hg, Ni) with moderate to high levels of microbial contamination.

This demonstrates that catchment scale is a strong indicator of exposure to contaminants. This is an important insight for MAR planning and regulation.

Table 2. Comparison of water-quality risks across three MAR cases

Parameter	Standard [1]	This Study		UTFI Pilot [4]	
		PW [2]	GW [3]	SW [5]	GW [6]
pH	6.5-8.5	7.8±0.51	7.5±0.27	7.6±0.4	7.6±0.45
Turbidity	1 / 5 [8]	8.1±5.6	2.4±3.5	-	-
TDS [8] (mg/L)	500	140±82	484±164	360±90	470±130
Fluoride (mg/L)	1	0.09±0.04	<0.1	0.23±0.07	0.32±0.11
Nitrate (mg/L)	45	3.0±2.1	9.3±16.9	13.3±1.3	11.0±3.2
Arsenic (mg/L)	0.01/0.05 [7]	0.006±0.019	0.01±0.02	0.015±0.009	0.013±0.005
Chromium (mg/L)	0.05	<0.002	<0.002	0.038±0.004	0.034±0.036
Iron (mg/L)	0.3	0.7±1.3	0.1±0.1	0.20±0.08	0.21±0.09
Lead (mg/L)	0.01	<0.002	<0.002	0.006±0.006	0.003±0.001
Mercury (mg/L)	0.001	<0.0002	<0.0002	0.004±0.004	0.002±0.002
Nickel (mg/L)	0.02	<0.002	<0.002	0.03±0.04	0.03±0.04
Faecal coliforms (MPN [9] /100mL)	0 [10]	36±52	6±6	730±780	410±580

[1] Drinking water standards (Bureau of Indian Standards, 2012)
[2] PW = pond water samples
[3] GW = all groundwater samples
[4] Values reported by Pavelic *et al.,* (2020)
[5] SW = all surface water from recharge pond and adjacent canal
[6] GW = all wells situated within 100 m of the pond and assumed to be potentially influenced by UTFI groundwater recharge
[7] 'Acceptable' and 'maximum permissible' limits are both given
[8] TDS = total dissolved solids
[9] MPN = most probable number
[10] Standard refers to *E. coli* and therefore, faecal coliform values are used here as a conservative indicator of potential exceedance

[3] UTFI = Underground Transfer of Floods for Irrigation; a particular form of MAR

3.5 Overview of the Main Findings

As highlighted above, differences in the size of the pond's catchment area leads to distinct levels of risk and specific management needs. Table 3 compares water quality risks, contaminant sources, management responses, and policy implications for small locally fed ponds and large canal- or river-fed MAR systems.

Table 3. Summary of the relative risks, contamination sources, management response and policy implications for small locally fed versus large canal- or river-fed MAR ponds

	Small locally fed ponds	Large canal- or river-fed ponds
Chemical (metals, pesticides)	Low risk	High risk
Microbial (faecal indicators)	Moderate risk	Moderate to high risk
Main sources	Livestock, local runoff	Industrial/urban inflows
Management response	Maintenance & filtration	Source control, pretreatment
Policy implication	Safe or promote with safeguards	Restrict or promote with safeguards

4. Conclusions and Recommendations

Field evidence from the Ramganga Basin shows that small-scale, locally sourced MAR systems in agricultural catchments are largely safe from a chemical viewpoint. Microbial risks are generally transient, due to natural degradation, and can be managed with basic safeguards. Compared with large canal- or river-fed systems, small village ponds offer a low-cost, low-risk approach to enhance groundwater security in the Gangetic Plain. Continued expansion of decentralized MAR under programs such as *Amrit Sarovar* and *Jal Shakti Abhiyan* is warranted, but should incorporate stronger water quality safeguards, particularly in moderate- to high-risk areas, such as those with intensive fertilizer or pesticide use.

These findings support two integrated recommendations, highlighting that locally sourced MAR, managed with simple safeguards and community engagement is a safe, scalable, and practical pathway to replenish groundwater while protecting public health.

4.1 Establish National Risk-Based Water Quality Guidance for MAR

India requires national guidance on water quality considerations in MAR planning, siting and implementation. A risk-based approach is essential to reflect the diversity of recharge typologies and catchments contexts, that range from predominantly agricultural landscapes to mixed rural-settlement or industrial areas, and from surface- to subsurface-based recharge structures. The Bureau of Indian Standards (BIS), in coordination with the Central Ground

Water Board (CGWB) and state technical agencies, should lead the development of practical, risk-based standards that clarify acceptable source water conditions and monitoring expectations across different MAR typologies.

Water quality protection principles should prioritize achieving potable standards at the place of recovery rather than at the place of recharge. Requiring treatment of source water to drinking water standards prior to recharge across thousands of small, decentralized structures is neither technically nor economically feasible. Instead, guidance should explicitly allow flexibility where source water exceeds drinking water guidelines during recharge, provided that natural attenuation processes in soils and aquifers are demonstrated to be effective and sustainable through field investigations. International experience with risk-based management from countries with extensive operational experience in MAR can provide a useful reference for this approach (e.g., Australian Guidelines for MAR: NRMMC–EPHC–NHMRC, 2009).

This guidance must be supported by a well-coordinated national monitoring framework that defines critical parameters, sets standardized sampling and testing protocols, and specifies minimum reporting requirements across states and territories. Improved national-state coordination would allow for comparable data and long-term trend analysis, ultimately supporting adaptive management and evidence-based regulation of MAR programs at scale.

4.2 Mainstream Operational Safeguards and Community Capacity to Manage Sediment and Microbial Risks

While chemical risks in small-scale agricultural MAR are generally low, elevated sediment loads and transient microbial contamination are common operational challenges. These risks can be effectively managed through practical, low-cost design and operational practices. Sediment capture through vegetative buffers strips or settling areas, desilting at frequencies informed by recent evidence (Alam *et al.,* 2025), restriction of livestock access, diversion of wastewater inflows, and maintenance of safe separation distances from domestic wells should become standard elements of MAR design and operation. Integrating these measures into technical guidelines and program plans would significantly enhance recharge efficiency, system longevity and water quality protection.

At the same time, the safety and sustainability of decentralized MAR systems depend strongly on local practices. Community activities such as livestock access, fish raising, waste disposal and agrochemical use directly influence contamination risks and hence source water quality for MAR. Strengthened awareness and training are therefore essential to ensure that communities understand how daily activities affect groundwater quality and recharge performance. Embedding water quality safeguards within existing MAR programs will be critical to ensuring that infrastructure expansion under national initiatives is supported by responsible local management and sustained public health protection.

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