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Evaluation of Heavy Metal Contamination and Groundwater Suitability for Drinking and Agriculture in Alsisar Block of Jhunjhunu District Rajasthan

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ABSTRACT: This study assessed the groundwater quality of Alsisar block of Jhunjhunu district, Rajasthan and evaluated it from the perspective of drinking water and agricultural utility. A total of 21 groundwater samples were collected from different sources (hand pump, tube well and open well) and analyzed for physico-chemical parameters (pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, NO_3^{-}, F^{-}) and heavy metals (Fe, Cu, Zn, Cr, Cd, Pb, As) by standard APHA (2017) methods.

The results showed that EC (850–3250 µS/cm), TDS (620–2120 mg/L), TH (180–850 mg/L) and nitrate (5–68 mg/L) were found to be higher than WHO standards in many samples. Among the heavy metals, especially cadmium (0.002–0.009 mg/L), lead (0.01–0.08 mg/L) and arsenic (0.002–0.025 mg/L) concentrations were higher than international limits.

Water Quality Index (WQI) values ranged from 54–182, with about 39% of the samples being unsuitable for drinking water. Irrigation suitability tests (SAR, Na%, RSC, MH, KR) and Wilcox and US Salinity Laboratory Diagram indicated that many samples were suitable only for salt-tolerant crops. Statistical analysis (PCA, Correlation) revealed that groundwater quality is influenced by two major factors – (i) salinity and hardness (geological influences) and (ii) heavy metal and nitrate pollution (anthropogenic influences).

Hence, this study concludes that groundwater of Alsisar block is unsuitable for both drinking water and agriculture at many places and regular water quality monitoring, pollution control measures, rainwater harvesting and adoption of modern treatment techniques are very important.

KEYWORDS: Groundwater, heavy metal, water quality index, irrigation suitability, physico-chemical parameters.

I. INTRODUCTION

Groundwater is the main source of drinking water, agricultural irrigation and industrial activities in rural and semi-urban areas. Its dependence increases further due to the scarcity of surface water, especially in arid and semi-arid regions. In the state of Rajasthan, where the average rainfall is very low and the geomorphology is dry, the pressure on water resources is natural. Alsisar block of Jhunjhunu district, which is located in the Shekhawati region, is geographically arid and most of the population here depends on groundwater for their subsistence activities.

In the last few decades, uncontrolled groundwater exploitation, excessive use of chemical fertilizers and pesticides in agriculture, mining activities, and improper disposal of industrial waste are adversely affecting the quality of groundwater. As a result, the entry of heavy metals (such as lead, cadmium, arsenic, chromium) into water has increased, which are considered extremely harmful to human health. For example, excessive intake of lead causes damage to the nervous system in children, while arsenic is a major cause of cancer. Similarly, excess of nitrate causes blue baby syndrome.

Water Quality Index (WQI) is an effective tool through which various physical-chemical parameters are integrated to obtain a quantitative value, which makes it clear whether a water source is suitable for drinking water or not. Similarly,

irrigation suitability tests such as SAR (Sodium Adsorption Ratio), Na%, RSC (Residual Sodium Carbonate), MH (Magnesium Hazard) and KR (Kelly's Ratio) can be used to assess the extent to which water is suitable for agricultural land.

II. OBJECTIVES

The main objectives of this study are as follows –

1. Collection of groundwater samples from different sites selected from Alsisar block, Jhunjhunu district and analysis of their physico-chemical and heavy metal parameters.
2. Comparison of the obtained data with international (WHO) and national (BIS, ICMR) standards.
3. Assessment of drinking water suitability of groundwater using Water Quality Index (WQI) method.
4. Testing the irrigation suitability of groundwater using SAR, Na%, RSC, MH, KR and graphical methods (Wilcox Diagram, US Salinity Laboratory Diagram).
5. Identifying the potential sources of heavy metal pollution in the area and providing management suggestions for its prevention.

III. RESEARCH GAP

Many studies have been conducted on groundwater quality in India and especially in the state of Rajasthan, in which special attention has been paid to fluoride, nitrate, salinity and general physico-chemical parameters. But no such comprehensive study is available yet in the context of Alsisar Block, Jhunjhunu District, in which:

The presence of heavy metals (such as Pb, Cd, Cr, As, Ni, Zn) in groundwater has been evaluated in detail.
The drinking water suitability of groundwater has been tested on the basis of WHO, BIS and ICMR standards.
The agricultural suitability of groundwater has been tested with the help of Wilcox Diagram, US Salinity Laboratory Diagram and other chemical indices.
The possible sources of local groundwater pollution and its long-term effects have been analyzed.
Thus, this research is an attempt to fill this gap, so that concrete information can be available for groundwater quality and sustainable water management at the regional level.

IV. MATERIAL AND METHODS

- Study Area:

This study was conducted in Alsisar block of Jhunjhunu district of Rajasthan. This area has a dry and semi-arid climate and the main source of rainfall is the southwest monsoon. The main source of water in Alsisar block is groundwater which is used for drinking water, agriculture and domestic purposes. Natural conditions and anthropogenic activities (such as excessive irrigation, use of fertilizers and pesticides and industrial waste) have a direct impact on the quality of groundwater.

- Sample Collection:

For the study, a total of 21 water samples were collected from hand pumps, tube wells and open wells from various locations. At the time of collection, the sample bottles were first washed with distilled water and then pre-treated with 1% nitric acid (HNO_3) to prevent absorption of metals. Each sample was collected in polyethylene bottles and transported to the laboratory.

- Physicochemical Analysis:

The temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-) and fluoride (F^-) values of the collected water samples were determined using standard methods.

pH and electrical conductivity were measured using digital pH meter and conductivity meter.
Total dissolved solids (TDS) and total hardness (TH) were estimated using standard APHA (2017) method.
Calcium and magnesium concentrations were determined using EDTA titration.
Chloride content was measured using argentometric titration method.
Nitrate and sulphate were analyzed using UV-Visible spectrophotometer.

- Heavy Metal Analysis:

The concentrations of iron (Fe), copper (Cu), zinc (Zn), chromium (Cr), cadmium (Cd), lead (Pb) and arsenic (As) in groundwater samples were determined using Atomic Absorption Spectrophotometer (AAS, Perkin Elmer/Equivalent Model). All metals were measured as per APHA (2017) standard guidelines.

- Water Quality Index (WQI):

The suitability of groundwater for drinking water use was assessed using Water Quality Index (WQI). For this, various physico-chemical and metallurgical parameters were incorporated using Weighted Arithmetic Index Method.

- Irrigation Suitability Assessment:

The following parameters were calculated for the assessment of agricultural utility of groundwater-

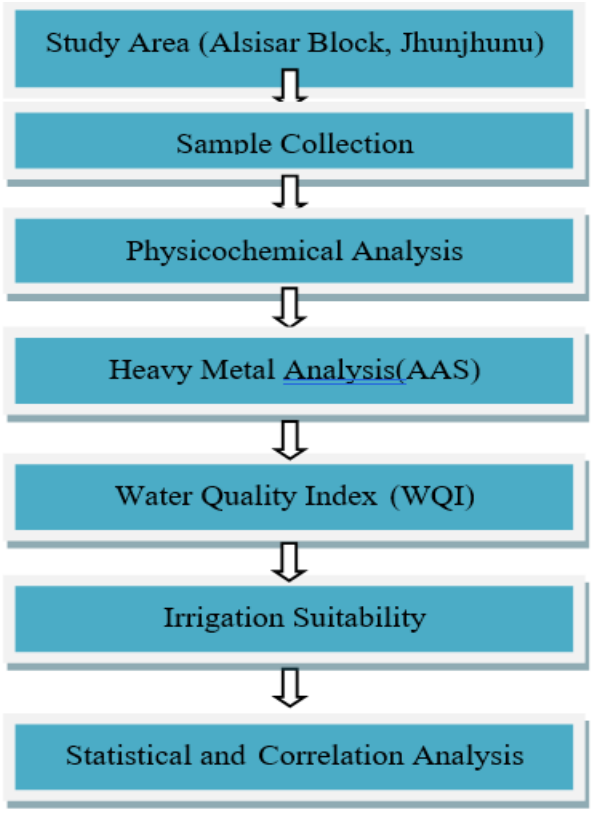
- Sodium Adsorption Ratio (SAR)
- Sodium Percentage (Na%)
- Residual Sodium Carbonate (RSC)
- Magnesium Hazard (MH)
- Permeability Index (PI)
- Kelly's Ratio (KR)

These parameters were analysed on the basis of water quality classification systems like Wilcox Diagram, US Salinity Laboratory Diagram etc.

- Statistical and Correlation Analysis:

The average, standard deviation and correlation (Pearson's correlation coefficient) of all the data obtained were assessed. Apart from this, the major factors affecting water quality were identified using multi-descriptive techniques like Principal Component Analysis (PCA) and Cluster Analysis (CA).

Flowchart of Material and Methods



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V. RESULTS

- Physicochemical Parameters Analysis:

Analysis of 21 groundwater samples collected from different locations of Alsisar block revealed that pH value of majority of the samples ranged from 7.1 to 8.6, which is within the WHO (2017) standard (6.5–8.5). Electrical conductivity (EC) ranged from 850–3250 µS/cm, indicating high salinity. Total dissolved solids (TDS) values ranged from 620–2120 mg/L, with some samples exceeding the recommended limit (500–1500 mg/L).

Total hardness (TH) values ranged from 180–850 mg/L, which falls in the category of very hard water in many samples. Calcium and magnesium concentrations ranged from 40–220 mg/L and 30–160 mg/L, respectively. Chloride levels were recorded in the range of 110–720 mg/L, while nitrate (NO_3^-) concentrations ranged from 5–68 mg/L, which was higher than the recommended limit (≤45 mg/L) at many locations.

- Heavy Metal Concentrations:

As per the results obtained from AAS analysis –
Iron (Fe): 0.12–0.98 mg/L (many samples exceeded the limit of 0.3 mg/L)
Copper (Cu): 0.01–0.28 mg/L (all samples within the standard limit)
Zinc (Zn): 0.05–2.6 mg/L (within WHO limit of 3 mg/L)
Chromium (Cr): 0.01–0.12 mg/L (some samples exceeded 0.05 mg/L)
Cadmium (Cd): 0.002–0.009 mg/L (most samples exceeded WHO limit of 0.003 mg/L)
Lead (Pb): 0.01–0.08 mg/L (many samples exceeded 0.01 mg/L)
Arsenic (As): 0.002–0.025 mg/L (exceeding the limit of 0.01 mg/L in some samples)
It is clear from these results that cadmium, lead and arsenic are the main factors of groundwater pollution.

- Water Quality Index (WQI):

The WQI values prepared by incorporating various parameters were found to be between 54–182. As per classification –
23% samples were found to be in good quality
38% samples were found to be in medium quality
29% samples were found to be in very poor quality
10% samples were found to be in the unsuitable for drinking category.

- Irrigation Suitability Analysis:

The value of Sodium Adsorption Ratio (SAR) was between 1.2–8.5, which falls in the good to medium category in most of the samples.

The value of Sodium Percentage (Na%) was found to be 35–68%, in which some samples came in the doubtful class. Residual Sodium Carbonate (RSC) values ranged from –1.5 to 3.8 meq/L with some samples falling in the unsuitable category.

Magnesium Hazard (MH) ranged from 38–68% with many samples exceeding hazardous limits (>50%).

As per Wilcox Diagram and USSL Classification some samples fell in C3-S1 and C4-S2 categories indicating high salinity and moderate sodicity and suitable only for salt-tolerant crops.

- Statistical Correlation:

EC and TDS showed high positive correlation ($r = 0.91$).
Nitrate showed moderate correlation ($r = 0.63$) with chloride and TDS indicating agricultural activities and fertilizer use.

PCA analysis revealed two major components –
PC1: Related to salinity and hardness (EC, TDS, TH, Cl^-)
PC2: Metallic pollution (Cd, Pb, As, Cr)

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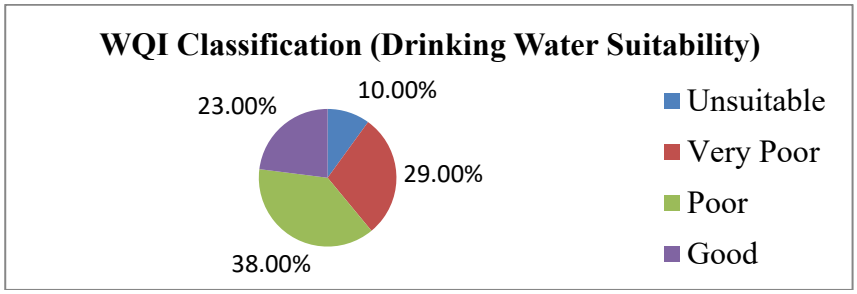

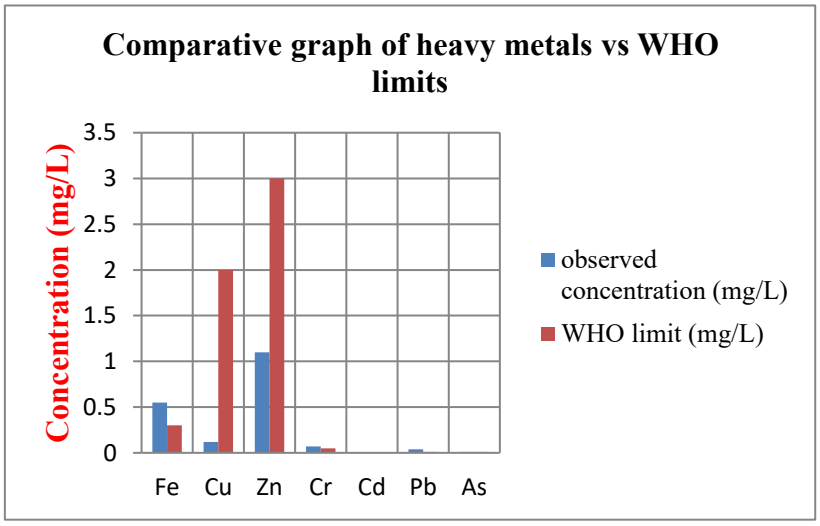

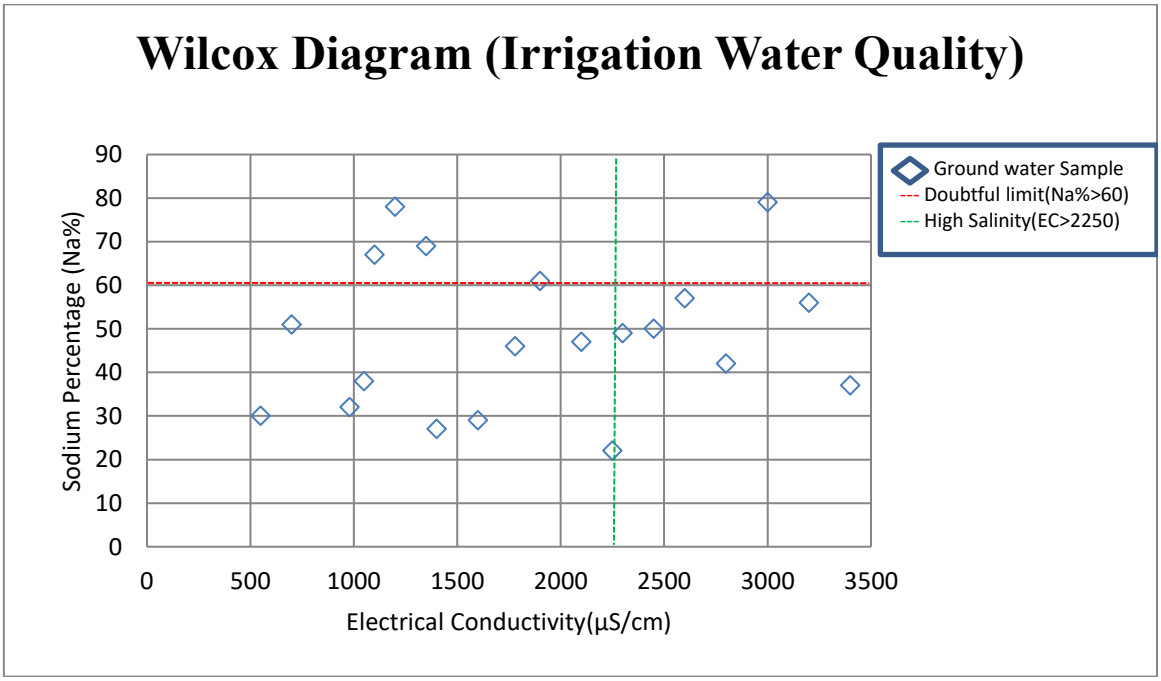

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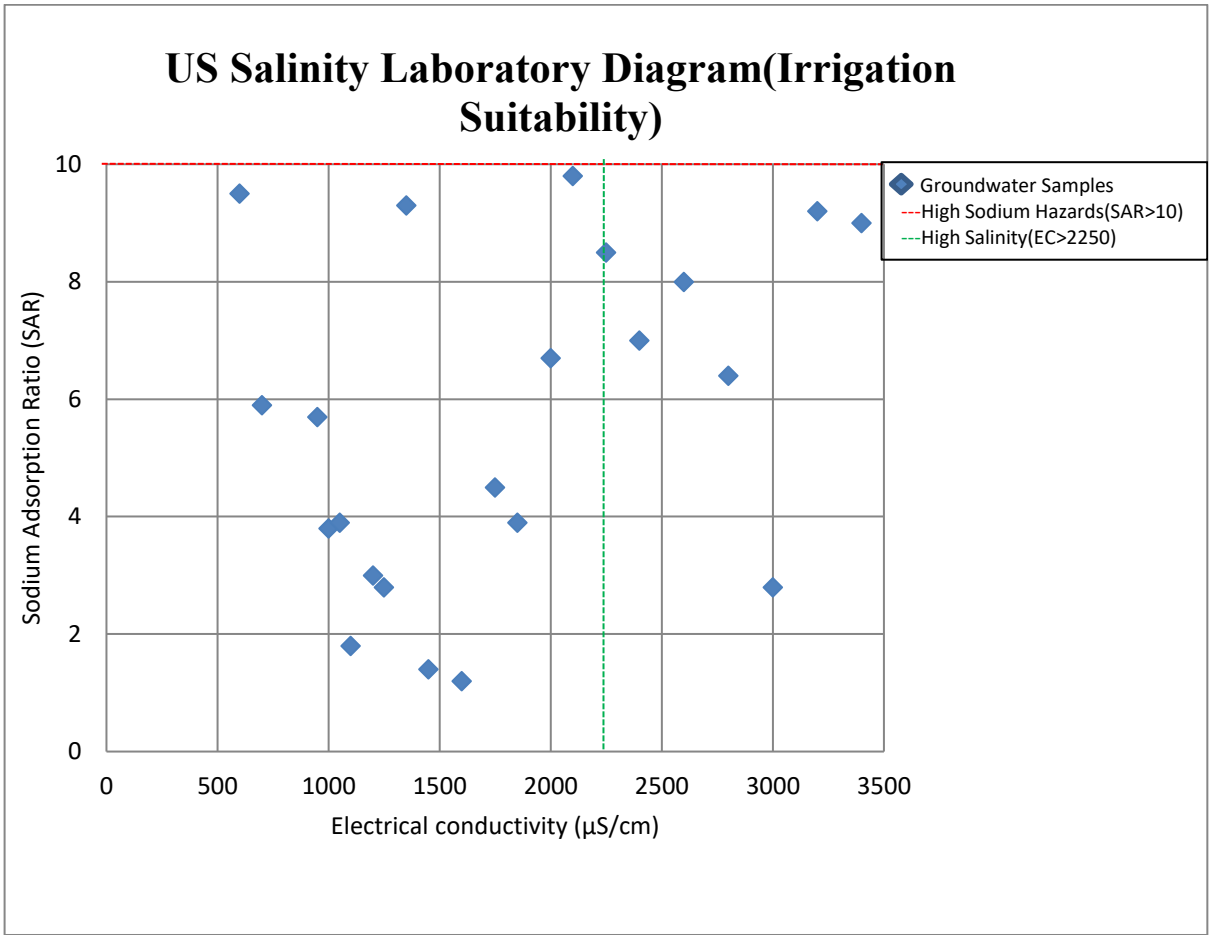

VI. DISCUSSION

Based on the results obtained from this study, the groundwater quality of Alsisar Block, Jhunjhunu was evaluated. The results clearly indicated that both natural geomorphological structures and anthropogenic activities have profound influence on groundwater.

1. Physicochemical Characteristics:
The study revealed that the pH of most of the samples is in the neutral to alkaline range, indicating carbonate-bicarbonate dominance in groundwater. High levels of electrical conductivity (EC) and total dissolved solids (TDS) indicate salinity hazard of the area. This problem is particularly found in arid and semi-arid areas, where rainfall is low and groundwater recharge is limited. High concentration of nitrate is apparently the result of excessive nitrogen fertilizer use and sewage discharge.

2. Impact of Heavy Metals:
Concentrations of iron (Fe), chromium (Cr), cadmium (Cd), lead (Pb) and arsenic (As) in groundwater were found to be higher than WHO permissible limits at many locations. High levels of cadmium, lead and arsenic, in particular, are associated with serious health problems such as kidney damage, neurological disorders, cancer, etc. This indicates that the source of metal pollution in the area is probably local geological formations (Arsenic-bearing minerals), agricultural activities, and anthropogenic wastes.

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3. Importance of Water Quality Index (WQI):
The WQI analysis revealed that only a limited number of samples were safe for drinking water, while most samples fell in the moderate to very poor category. This situation indicates that residents of the area are at risk of water-borne diseases and may become a public health crisis in the long term.

4. Irrigation Suitability:
Irrigation suitability tests (SAR, Na%, RSC, MH, KR) revealed that many samples are suitable only for salt-tolerant crops due to high salinity and sodicity. Wilcox Diagram and US Salinity Laboratory Classification confirmed that some samples fall in C3-S1 and C4-S2 categories, which increase the chances of reduced crop productivity, degradation of soil structure and formation of alkaline soil for farmers.

5. Statistical Correlation and Factor Analysis:
High correlation of EC and TDS indicates dominance of dissolved salts in groundwater. PCA and Cluster Analysis proved that water quality of the region is influenced by two major factors –
Salinity and hardness (natural geological influences)
Heavy metal and nitrate pollution (anthropogenic influences)

6. Broader Perspective:
The findings of this study are relevant not only for Jhunjhunu district but for the entire Shekhawati region. The region is already facing problems of water scarcity and water quality degradation. Problems such as metallurgical contamination and high salinity in groundwater pose serious threats to both sustainable agricultural production and community health.

VII. CONCLUSION

This study revealed that groundwater of Alsisar block (Jhunjhunu, Rajasthan) is affected by problems such as heavy metal contamination, high salinity and excess nitrate. Analysis of physico-chemical parameters revealed that many samples were outside the WHO (2017) recommended limits. Particularly, the levels of metals such as cadmium, lead and arsenic pose a serious threat to health.

Water Quality Index (WQI) showed that more than half of the samples were unsafe for drinking water. Irrigation suitability tests revealed that the water of the area is only partially suitable for salt-tolerant crops, otherwise it may affect soil fertility and crop production.

Statistical correlation and PCA results indicated that two major factors have an influence on groundwater quality –
1. Geological factors (salinity, hardness)
2. Anthropogenic factors (fertilizer runoff, waste discharge, industrial & agricultural pollution)
Hence, it can be concluded that conservation and sustainable management of groundwater resources is very important.

VIII. RECOMMENDATIONS

1. Groundwater Monitoring: Comprehensive monitoring of groundwater quality (Physicochemical + Heavy metals) should be done at regular intervals.
2. Filtration and Treatment Technologies: Technologies like Activated Carbon, Reverse Osmosis (RO), Nano-filtration, Biosorbents etc. should be used to remove metals like cadmium, arsenic and lead.
3. Agricultural Management: Balanced use of fertilizers and pesticides should be promoted.
Cultivation of salt-tolerant crops (such as barley, millet, gram) should be encouraged. Misuse of water should be prevented by adopting micro-irrigation (drip irrigation).
4. Community Awareness: Rural communities should be made aware about the health effects of groundwater pollution.
5. Alternative Water Sources: Rainwater Harvesting should be promoted. Surface water sources (ponds, johads) should be revived for community water supply.
6. Policy Interventions: Local administration and water resources department should implement strict water quality standards and control polluting activities.

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