

Summary: Multi-Stage Water Purification System

This research presents a **Smart Water Monitoring and Purification Device** developed to detect and purify **five major water quality parameters** — pH, Lead (Pb), Mercury (Hg), Manganese (Mn), and Magnesium (Mg) integrating ESP32-S3 sensors for real-time monitoring. The system employs a **three-stage purification process** combining oxidation, adsorption, ion exchange, and remineralization techniques.

Stage 1: Oxidation for Manganese Removal

- Purpose:**

Removes dissolved manganese (Mn^{2+}) responsible for black staining, metallic taste, and potential health effects.

- Method:**

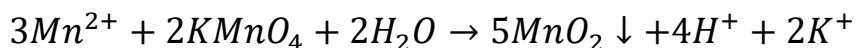
- Aeration:**

Uses dissolved oxygen to oxidize $Mn^{2+} \rightarrow MnO_2$.

- Greensand Filtration:**

Catalyzes oxidation using manganese-coated media.

- Chemical Reaction:**



- Outcome:**

Insoluble MnO_2 is filtered out; water aesthetics and safety improve.

Stage 2: Heavy Metal Adsorption & Chemical Reduction

- Purpose:**

Eliminates toxic heavy metals—**Lead (Pb²⁺)** and **Mercury (Hg²⁺)**—via adsorption and redox processes.

- Filtration Media:**

Activated Carbon + KDF (Kinetic Degradation Fluxion) media.

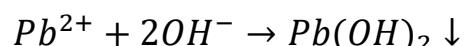
- Mechanisms:**

- Mercury:**

$$Hg^{2+} + 2e^- \rightarrow Hg^0;$$

then adsorbed on carbon.

- Lead:**



or complexation with carbon surfaces.

- Result:**

Heavy metals are converted into insoluble or adsorbed forms, safely removed during backwashing.

Stage 3: pH Balancing and Remineralization

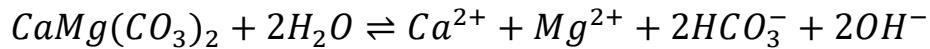
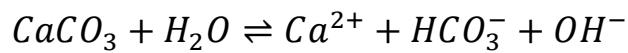
- Purpose:**

Adjusts pH and reintroduces essential minerals (Ca^{2+} , Mg^{2+}) for healthy, balanced drinking water.

- Media:**

Limestone (CaCO_3) or Dolomite ($\text{CaMg}(\text{CO}_3)_2$).

- Reactions:**



- Effect:**

Water becomes slightly alkaline and mineral-rich, improving taste and stability.

Pollutant Summary & Chemical Reactions

Parameter	Source	Removal Method	Reaction	Output	Example Sensor (Pakistan)
pH (H^+)	Acidic/basic imbalance	Neutralization	$\text{H}_2\text{CO}_3 + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCO}_3 \downarrow + 2\text{H}_2\text{O}$	Neutral water	DFRobot pH Sensor V2
Lead (Pb^{2+})	Pipes, effluent	Precipitation/Adsorption	$\text{Pb}^{2+} + 2\text{OH}^- \rightarrow \text{Pb}(\text{OH})_2 \downarrow$	Lead sludge	DFRobot Pb ²⁺ ISE
Mercury (Hg^{2+})	Industrial waste	Sulfide precipitation	$\text{Hg}^{2+} + \text{S}^{2-} \rightarrow \text{HgS} \downarrow$	HgS precipitate	Mercury ISE Probe
Manganese (Mn^{2+})	Groundwater, mining	Oxidation + Filtration	$3\text{Mn}^{2+} + 2\text{KMnO}_4 + 2\text{H}_2\text{O} \rightarrow 5\text{MnO}_2 \downarrow + 4\text{H}^+ + 2\text{K}^+$	MnO_2 solid	DFRobot Mn ²⁺ ISE

Parameter	Source	Removal Method	Reaction	Output	Example Sensor (Pakistan)
Magnesium (Mg^{2+})	Natural minerals	Lime softening	$Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + Mg(OH)_2 \downarrow + 2H_2O$	Mg precipitate	DFRobot Mg ²⁺ ISE

Smart Monitoring Integration

- **Microcontroller:** ESP32-S3 for IoT connectivity.
- **Features:**
 - Real-time water quality sensing (pH, Pb, Hg, Mn, Mg).
 - Automated chemical dosing via pH feedback.
 - Multi-stage purification and cloud-based monitoring.

Merits

- High accuracy with modular sensor integration.
- Effective multi-contaminant purification.
- Environmentally sustainable via remineralization.
- Scalable for R&D and municipal applications in Pakistan.

Demerits

- Periodic maintenance of filters and media required.
- Sensor calibration and cost constraints for multi-ion systems.
- Complex design increases initial setup expense.

Conclusion

This **Multi-Stage Smart Water Purification System** represents a forward-looking R&D solution for **Pakistan's water quality challenges**, merging **IoT-based real-time sensing** with **traditional purification principles** (oxidation, adsorption,

filtration, and remineralization). It ensures safe, mineral-balanced, and environmentally compliant drinking water aligned with **EPA and WHO standards**.