Final Year Design Project Showcase
Batch-2022
Year 2026

Department: Computer Science & Information Technology Programme: Computer Science & Information Technology	
1	**Project Title** Soil Based Water Quality Prediction Using Machine Learning: A Case Study of Tharparkar
2	**Project Idea** This project delivers a field-validated machine learning system that predicts Tharparkar's groundwater quality from soil properties with over 92% accuracy, eliminating blind exploratory drilling that costs up to PKR 2,000,000 per failed attempt. • **The Problem:** Today, drilling for clean water in Pakistan's most water-stressed region is highly financial risk-prone, offering zero guarantee of safe water before breaking ground. • **The Solution:** By evaluating soil-water retention behavior across three depths, our system forecasts four critical indicators—TDS, electrical conductivity, pH, and turbidity—before excavation begins. • **Technical Core:** The predictive pipeline runs an ensemble of Random Forest, XGBoost, and Physics-Informed Neural Networks trained on physical soil and water datasets collected from 53 active field sites
3	**Process** We engineered a four-stage pipeline that converts simple surface soil data into complex underground hydraulic profiles, bypassing expensive lab testing to feed our multi-model AI. **Stage 1: Ground-Truth Field Sampling** Our team spent six months mapping 53 villages across the Mithi and Islamkot talukas. Using manual augers, we extracted soil samples stratified across three depths (0–50 cm, 50–100 cm, 100–150 cm). To establish baseline controls, we paired these soil layers directly with physical water samples collected from neighboring functional wellheads. **Stage 2: Physics-Informed Lab Modeling** We conducted sieve and hydrometer testing to isolate precise sand, silt, and clay distributions. Instead of relying on expensive, unavailable laboratory pressure plate equipment, we utilized mathematical pedotransfer functions. This automatically derived five core Van Genuchten hydraulic parameters, embedding unsaturated soil physics into the pipeline at zero cost. **Stage 3: Controlled AI Augmentation** To train complex machine learning models without overfitting, we implemented a controlled data augmentation strategy that safely scaled our 159 field rows into 15,105 high-fidelity records. The algorithm enforced strict mathematical guardrails: soil fractions were locked at exactly 100%, porosity was constrained between 0 and 1, and target adjustments strictly mirrored authentic desert salinity variations.

	Stage 4: Hybrid Ensemble Engineering The enriched dataset was processed using three complementary architectures: a 300-tree Random Forest to neutralize data noise, a 500-estimator sequential XGBoost to minimize errors, and a 4-layer Physics-Informed Neural Network (PINN) to enforce hydraulic laws. These models were unified into a production framework using an optimized weighted voting system.
4	**Outcome** The system achieved a 92.7% mean accuracy across all targets, delivering a field-validated prototype that successfully maps deep groundwater safety entirely from surface soil parameters. **Predictive Accuracy & Benchmarks** The optimized machine learning ensemble achieved exceptional validation scores on the held-out testing dataset. The XGBoost engine led individual model performance, capturing complex non-linear patterns to yield specific accuracy scores of 94.8% for Total Dissolved Solids (TDS), 94.8% for Electrical Conductivity (EC), and 93.8% for water turbidity. **Primary Environmental Drivers** Our feature importance analytics successfully isolated the exact physical variables driving groundwater contamination in the desert. The AI mathematically proved that soil electrical conductivity, localized well depth, and near-surface soil salinity are the three most influential predictive indicators, confirming that vadose zone chemistry directly dictates aquifer safety. **Tangible Scientific Assets** This project bypassed purely theoretical research to deliver a fully functional, validated software prototype. Furthermore, our field logging produced the first structured, depth-resolved soil-groundwater physical dataset for Tharparkar in Pakistan's history, creating an open-access scientific asset for regional water resource deployment.
5	**Evidence (Theoretical Basis)** This project shifts Tharparkar's water crisis from a blind, high-risk drilling gamble to a predictable data-driven certainty, offering a globally scalable AI solution to a 1.6-million-person humanitarian emergency. **The Crisis & Status Quo Failure** Tharparkar relies entirely on groundwater due to dangerously low annual rainfall (100–400 mm), yet only 47% of the population has access to clean drinking water. Current NGO strategies favor building Reverse Osmosis (RO) plants over drilling new wells due to extreme geological uncertainty. This fails the community: many existing village wells are dry or non-functional, forcing women and children to walk over 3 kilometers for up to 5 hours daily to fetch water. Desalination infrastructure is useless without functioning wellheads. **The Global Technical Gap** A comprehensive literature review revealed a major flaw in global research: prior studies either built accurate AI models exclusively in data-rich, non-saline temperate zones, or developed physics-based theories lacking true groundwater field validation.

	No study globally has unified multi-depth soil sampling, Soil Water Characteristic Curve (SWCC) estimation, and machine learning into a single field-validated system for high-salinity desert terrains. This project is the first to bridge that gap. **Theoretical Foundation & Global Scale** The framework is structurally anchored in Van Genuchten's equations combined with Physics-Informed Neural Network (PINN) theory. This prevents the system from making unconstrained statistical guesses, forcing the AI to strictly obey real-world subsurface fluid physics. Developed and field-tested in Pakistan, this framework is entirely geography-independent and can be deployed across any arid, groundwater-dependent region globally to eliminate blind drilling risks.
6	**Competitive Advantage or Unique Selling Proposition** This system completely eliminates a 40–60% drilling failure rate by replacing a blind PKR 2,000,000 engineering gamble with a simple, few-thousand-rupee laboratory soil test-dropping exploration costs by 70% to 85%. This project's edge is not incremental; it introduces a first-of-its-kind, physics-grounded prediction system that does not exist anywhere else in Pakistan at any price. Instead of spending millions on heavy drilling machinery only to risk hitting toxic water, operators simply test surface soil samples at a fraction of the cost. Our AI models instantly process these basic laboratory metrics to predict deep groundwater safety, turning a high-risk financial gamble into a low-cost, data-driven certainty before the ground is ever broken.
a	**Attainment of any SDG** • **SDG 6 (Clean Water & Sanitation)**: Only 47% of Tharparkar's population has reliable water access. This system identifies safe groundwater zones before drilling, securing clean water for a 1.6-million-person emergency. • **SDG 2 (Zero Hunger)**: Over 60% of regional farmland suffers from severe soil salinity, worsened by irrigating with unpredicted, toxic groundwater. Our predictive mapping protects crops and stabilizes local food security. • **SDG 5 (Gender Equality)**: Water fetching falls heavily on women and girls, who walk 3+ kilometers for 3–5 hours daily. Bringing verified, working wells into villages recovers these lost hours for education and economic work.
b	**Any Environmental Aspect** • **Saving Farming Land from Ruin**: When farmers use underground water without testing it, they often pump up highly salty water. This salty water ruins the soil over time and turns green land into a useless desert. Our system helps communities avoid these toxic water zones before they ever drill a well, protecting Tharparkar's scarce farming land and keeping the soil healthy for crops.
c	**Cost Reduction of Existing Product** **Replacing Million-Rupee Risks with Low-Cost Lab Tests:** Right now, drilling a single exploratory well in Pakistan is a complete blind gamble costing between PKR 500,000 and PKR 2,000,000. If the well hits salty or toxic water, all that money is completely wasted. **The Low-Cost Breakthrough:** Our system completely changes this. Instead of bringing in heavy drilling rigs, a farmer or NGO worker only needs to collect basic soil samples from three depths. These samples are sent to a standard lab for a basic texture test costing just a few thousand rupees. Our machine learning system takes these cheap test results,

	automatically calculates the hidden soil-water properties using physics formulas, and compares them against our massive, pre-built field dataset to predict water safety instantly. This turns a multi-million rupee gamble into a cheap, safe, and calculated decision.
d	**Process Improvement which Leads to Superior Product or Cost Reduction, Efficiency Improvement of the Whole Process** **The Current Process Issue (Reactive & High Risk)**: The current workflow is entirely backwards—operators bring heavy machinery, dig hundreds of feet into the ground at great expense, and only test the water quality *after* the well is built. If the water comes up salty, the entire process fails, wasting weeks of heavy labor and millions of rupees. **Our Suggested Improvement (The Modern Science Pipeline)**: As proven in our thesis literature review, modern hydrogeology shows that near-surface soil and deep groundwater are closely connected through the vadose zone. Our system uses this exact scientific connection to flip the old workflow: • **Test Soil First**: A farmer or NGO collects basic soil samples from 3 shallow depths. • **AI Predicts Deep Water**: Our model analyzes how this soil naturally filters and holds water, matching it against our pre-built desert dataset. • **Safe "Go/No-Go" Decision**: This gives engineering teams a clear answer *before* excavation begins. We replace weeks of blind digging and multi-million rupee gambling with a fast, scientific process that takes minutes.
e	**Expanding of Market share** **The Problem with the Current Market (Hardware Bottleneck)**: The groundwater exploration sector in Pakistan is entirely limited by physical machinery. Because drilling rigs are expensive to transport and operate, government agencies and NGOs can only test a tiny number of sites each year. They are trapped in a slow, low-volume market where every single attempt carries a 40–60% financial risk of hitting toxic water. **How Our System Expands Market Share (The Software Multiplier)**: Our AI pipeline completely removes this physical bottleneck. Instead of sending heavy machinery to inspect one site, field teams can visit dozens of villages with a simple hand auger to collect soil samples. This shifts the market from a slow, high-risk model to a rapid, high-volume operation. Water authorities can screen **10 times more land area in less time**, vastly expanding their operational market share and ensuring that development budgets are spent only on sites guaranteed to deliver clean water.
f	**Capture New Market** Beyond serving existing well-owners better, this framework opens a segment that today has zero product options at all — NGOs that have stopped drilling new wells entirely because the risk is too high, and international arid regions with no local equivalent of this system. **The niche this addresses:** NGOs running WASH (Water, Sanitation, Hygiene) programmes in Tharparkar currently avoid new-well drilling altogether, redirecting funds instead toward desalination infrastructure for existing sources — not because drilling wouldn't help, but because there's no reliable way to justify the risk to donors. This is a segment the current market doesn't serve at all: not "underserved," but effectively locked out of an entire category of intervention. A field-validated, evidence-backed prediction report gives these

	organizations exactly what they're missing — a defensible basis to fund new-well drilling again, rather than defaulting to costlier workarounds. **The geographic niche:** The same soil-water physics (Van Genuchten SWCC, ensemble ML) is not specific to Tharparkar — it applies to any arid, high-salinity, groundwater-dependent region. Balochistan, Rajasthan (India), and comparable drylands across the MENA region and Sub-Saharan Africa face the identical blind-drilling problem, with no local system currently addressing it — a genuinely unaddressed market this framework is positioned to enter first.
g	**Any Other Aspect** This project bridges a major gap in global hydrogeology by proving that a farmer's simple surface soil sample can successfully predict deep water safety. It delivers Pakistan's first Physics-Informed AI model, builds Tharparkar's first ground-truth desert soil-water dataset, and is independently validated by winning the Technical Excellence Award at the FYDP Expo 2026 **Our Contribution to Data Mining** Global resource exploration — oil, gas, mineral mining — relies on high-tech data mining of seismic and historical data to map underground "sweet spots" before drilling, avoiding costly blind exploration. This project brings that same elite strategy into the humanitarian sector: we proved that simple, near-surface soil data (0–150 cm) can be algorithmically mined using physics-based formulas to predict the safety of groundwater lying far below — bringing corporate-grade pre-drilling analytics to rural water development for the first time. **Pakistan's First Ground-Truth Desert Dataset** This isn't a theoretical model — it's a physical foundation built for Pakistan. By extracting, pairing, and mapping 159 real structural layers across 53 active field sites, this project establishes Tharparkar's first-ever structured desert soil-groundwater dataset, built entirely from real field data. **Independent, Third-Party Validated** Every technical claim in this document has been independently scrutinized, not merely self-reported. At FYDP Expo 2026 (NED University, Software Engineering Department), this project won the **Technical Excellence Award**, selected from 28 competing projects by an external evaluation panel who reviewed the field data and confirmed the 92%+ target accuracy independently.
7	**Target Market** The primary end-users are the people currently making Tharparkar's most expensive decisions blind - smallholder farming families, WASH-focused NGOs, and government water authorities with a secondary market in comparable arid regions beyond Pakistan. • **Smallholder Farmers & Rural Families:** An estimated 200,000+ farming households in Tharparkar alone, each facing the same PKR 500,000–2,000,000 gamble every time a new well is needed, with a 40–60% chance of failure and no way to check beforehand.

	• **NGOs & WASH (Water, Sanitation, Hygiene) Organizations:** Over 100 active WASH-focused NGOs operate across Sindh and Balochistan, currently redirecting funds toward desalination infrastructure rather than new-well drilling because they have no reliable way to justify the drilling risk to donors — this system gives them the evidence to fund new wells with confidence again. • **Government Water Authorities:** Institutions such as PIDA and WAPDA plan and fund large-scale water access programmes across arid districts; a predictive tool reduces the risk of budget loss on drilling programmes with a historically high failure rate. • **Researchers & Academic Institutions:** The depth-resolved Tharparkar soil-groundwater dataset itself is a resource future hydrogeology and machine learning researchers can build directly on — a target audience independent of the prediction tool's direct field use. • **Broader Arid-Region Communities (long-term):** The same underlying soil-water physics apply to any high-salinity, groundwater-dependent region — meaning comparable farming communities and NGOs in Balochistan, Rajasthan, and similar drylands globally represent a natural next audience	
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11	**Video (If any)**	N/A — supplementary materials: project poster Canva

Pictures (to be pasted below)

Figure 1: Traditional well structure / Women carrying water

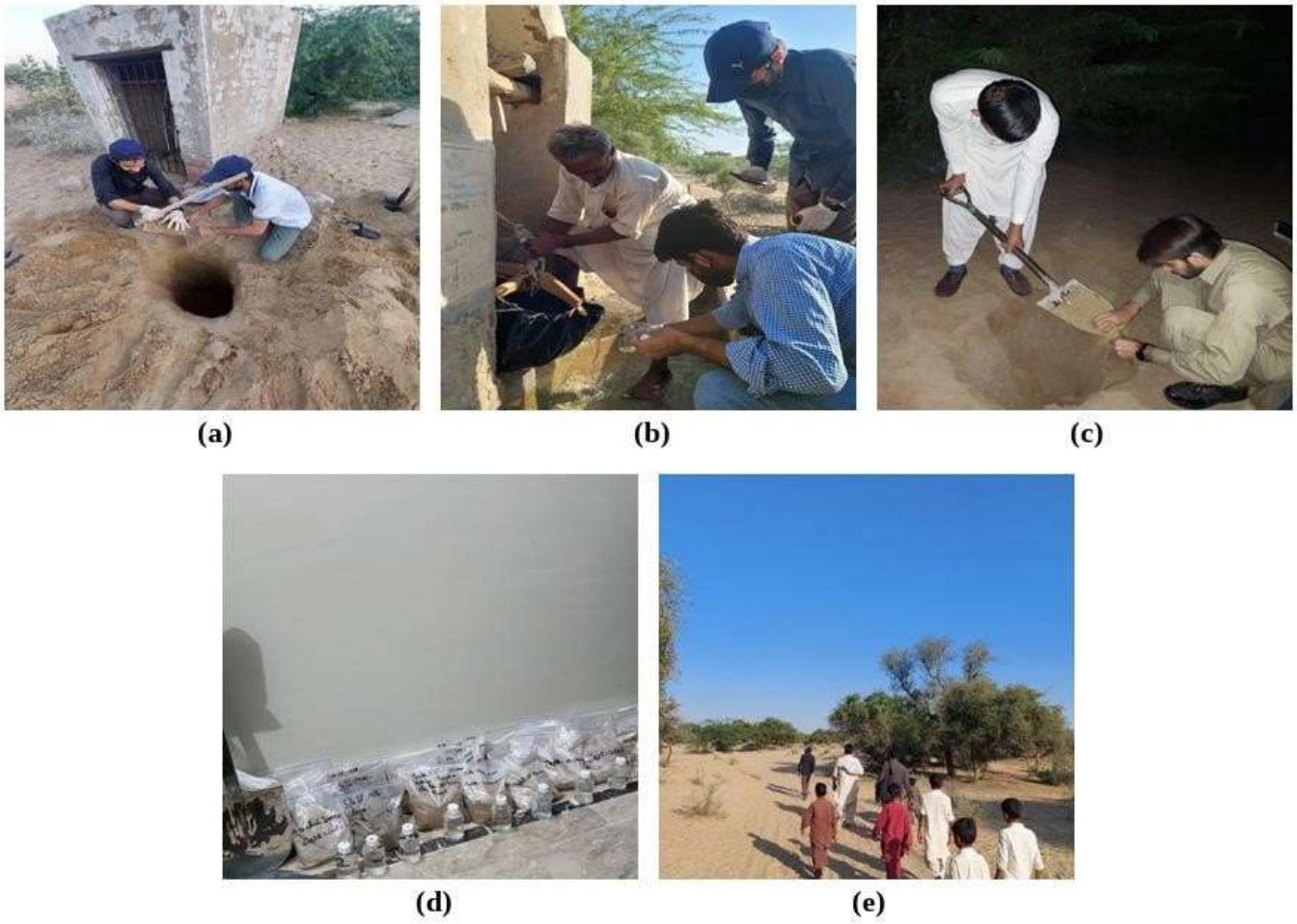

Figure 2: Field sampling activities across Mithi and Islamkot talukas — (a) daytime soil auger sampling near a borehole, (b) water collection from a community well, (c) night soil auger sampling, (d) labelled soil and water samples, (e) research team traversing desert terrain between village sites.

Figure 3: Laboratory testing procedures conducted at the TIEST Civil Engineering Laboratory — grain size distribution via sieve analysis (ASTM D422), specific gravity and porosity determination using the pycnometer method (ASTM D854), bulk density determination via the core cutter method (ASTM D2937), and soil pH/EC measurement using the 4-in-1 Soil Survey Instrument, applied across all 53 field sites and three depth intervals

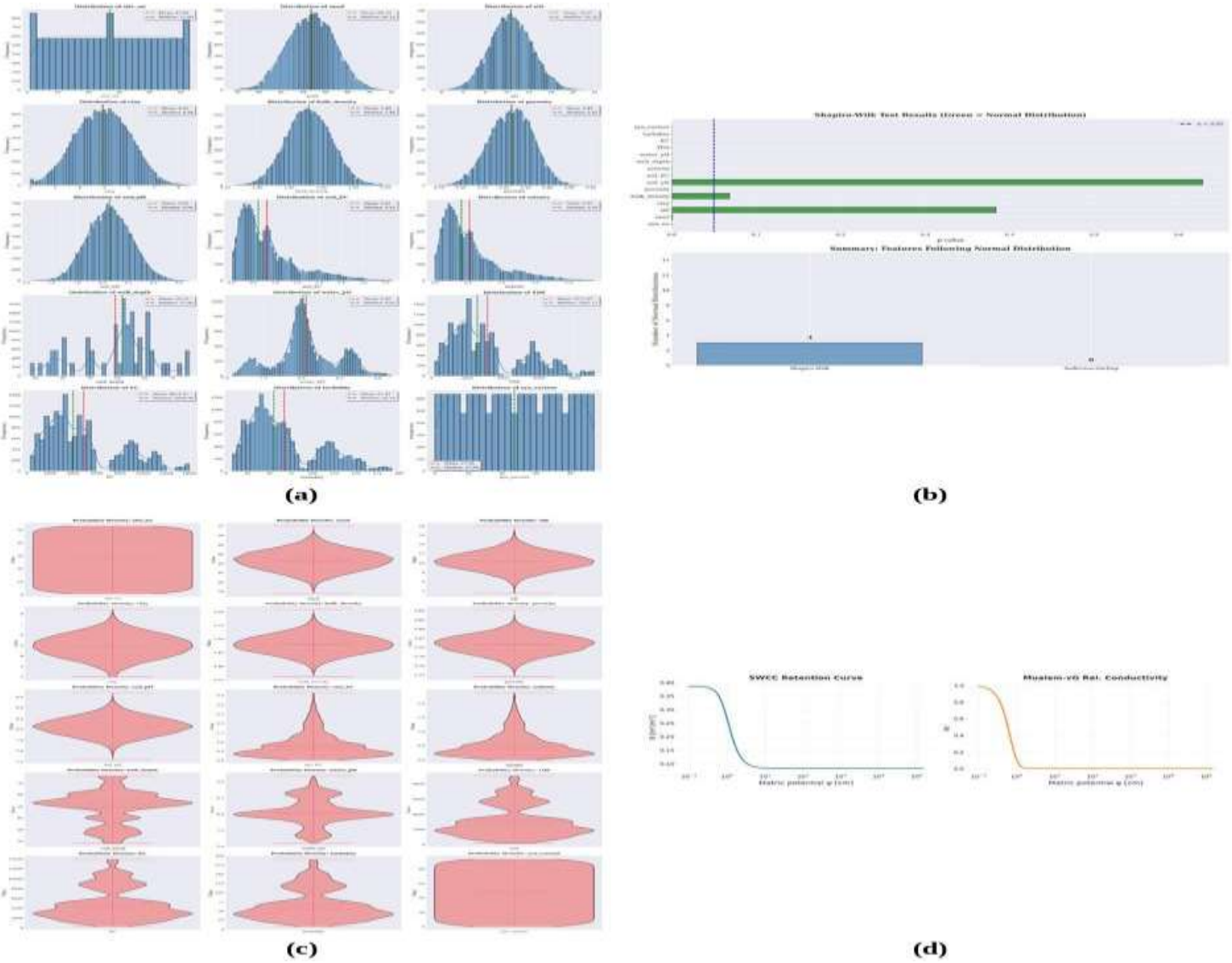

Figure 4: Statistical characterization of the augmented Tharparkar dataset — (a) frequency distributions of all parameters, showing positive skewness in EC, salinity, TDS, and turbidity typical of arid soil-water systems; (b) Shapiro-Wilk normality tests, where only 3 of 15 parameters passed the α = 0.05 threshold, justifying non-parametric ML approaches; (c) violin plots confirming the same asymmetric, multimodal distributions; (d) SWCC retention and Mualem-van Genuchten conductivity curves, automatically derived from soil properties, confirming the coarse sandy vadose zone across Mithi and Islamkot talukas.

Model	Target	RMSE	MAE	R^2	NSE	PBIAS
HydroRandom Forest	water_pH	0.246	0.186	0.634	0.634	0.054
	TDS	533.9	346.8	0.934	0.934	3.392
	EC	835.7	544.0	0.934	0.934	3.420
	Turbidity	11.50	7.849	0.925	0.925	2.972
HydroXGBoost ★ Best	water_pH	**0.193**	**0.138**	**0.775**	**0.775**	**0.002**
	TDS	**472.8**	**304.0**	**0.948**	**0.948**	**1.738**
	EC	**735.0**	**473.9**	**0.949**	**0.949**	**1.853**
	Turbidity	**10.43**	**7.127**	**0.938**	**0.938**	**1.728**
HydroEnsemble	water_pH	0.193	0.138	0.775	0.775	0.002
	TDS	473.8	304.6	0.948	0.948	1.808
	EC	736.4	474.3	0.948	0.948	1.898
	Turbidity	10.49	7.157	0.937	0.937	1.862
HydroPINN	water_pH	0.288	0.225	0.500	0.500	0.498
	TDS	559.0	368.9	0.928	0.928	2.576
	EC	872.4	575.7	0.928	0.928	2.406
	Turbidity	12.41	8.472	0.912	0.912	2.739

(a)

Target	Mean R^2	Std R^2	Mean RMSE	Std RMSE	Stability
TDS Total Dissolved Solids	0.9536	± 0.0015	0.1652	± 0.0022	95.4%
EC Electrical Conductivity	0.9533	± 0.0016	0.1659	± 0.0022	95.3%
Turbidity NTU	0.9382	± 0.0022	0.1608	± 0.0036	93.8%
water pH Geochemical complexity	0.6049	± 0.0144	0.2544	± 0.0042	60.5%

(b)

Figure 5: Final model performance results — (a) comparative performance of all four models (Random Forest, XGBoost, Ensemble, PINN) across four target parameters using RMSE, MAE, R^2, NSE, and PBIAS, with HydroXGBoost achieving the strongest individual performance (TDS R^2 = 0.948, EC R^2 = 0.949); (b) five-fold cross-validation stability results confirming consistent performance across data subsets, with TDS and EC exceeding 95% stability and water pH — the most geochemically complex target — showing comparatively lower stability at 60.5%.

Figure 6: At FYDP Expo '26 (NED University, Software Engineering Department, 07 May 2026), this project won the **Innovation Spotlight Award**, selected from 28 competing projects by an external evaluation panel who reviewed the field data and confirmed the 92%+ target accuracy independently — shown here is the award shield and certificate, along with the research team receiving it at the closing ceremony.