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AI-Based Strategies for Vetiver-Assisted Environmental Restoration

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Phytoremediation using vetiver grass (*Chrysopogon zizanioides*) is an eco-friendly and cost-effective approach for mitigating heavy metal, organic, and agricultural pollutants. However, traditional phytoremediation often suffers from unpredictable biological growth rates, environmental variable sensitivity, and time-intensive monitoring. Artificial Intelligence (AI) and Machine Learning (ML) have emerged as pivotal tools to optimize vetiver-based remediation systems. AI techniques enhance contaminant removal efficiency by accurately predicting heavy metal bioaccumulation, modelling root-zone rhizosphere dynamics, and forecasting plant biomass growth under environmental stress. Integrating AI with vetiver phytoremediation establishes a precise, scalable, and data-driven paradigm for sustainable environmental management. Vetiver is already valued for soil conservation and wastewater treatment. Artificial intelligence can add a new layer of precision: organising field data, recognising patterns, predicting stress and guiding timely action. The opportunity is especially relevant where remediation plots are large, monitoring is irregular, or skilled personnel must cover many sites.

Keywords: Vetiver Grass, Artificial Intelligence (AI), Phytoremediation, Bioaccumulation Prediction, Rhizosphere Optimization, Environmental Data Analytics

Figure 1. Vetiver above and below ground. (A) Established field clumps; (B) harvested fibrous roots. Photographs are illustrative, not from a remediation trial. Credits: (A) treesftf, Wikimedia Commons, CC BY; (B) David Monniaux, Wikimedia Commons, CC BY-SA 3.0. Images resized for this plate.

Vetiver is a useful green remediator

Vetiver (*Chrysopogon zizanioides*) is a perennial grass with dense shoots and a deep, fibrous root system. In a remediation setting, it can slow runoff, trap sediment, take up selected contaminants, stabilise polluted soil and support microbial activity around its roots. These processes are grouped under phytoremediation using plants and their associated organisms to reduce the risk by contaminated soil or water. The mechanism is not the same for every pollutant. Metals may be taken into plant tissues or immobilised near roots; nutrients can be absorbed; organic compounds may be transformed through plant–microbe interactions. Vetiver therefore functions as part of a treatment system, not as a universal sponge. Its performance depends on the contaminant, soil reaction, salinity, water regime, planting density, climate and management.

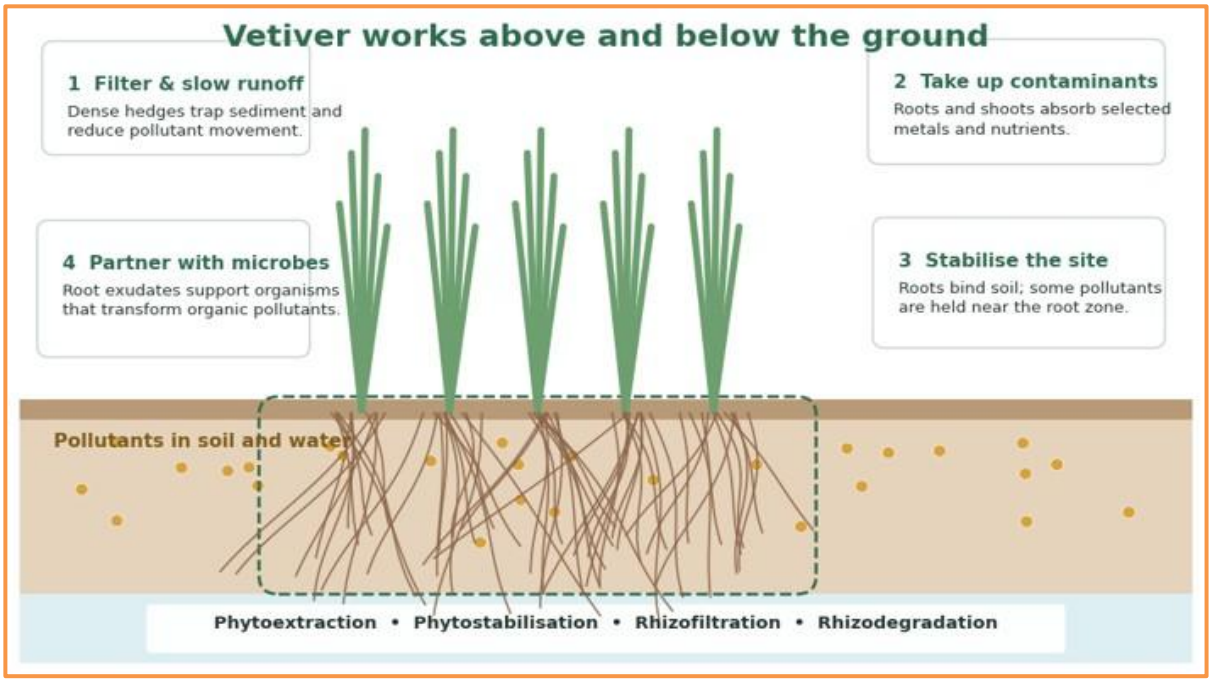

Figure 2. Conceptual pathways through which vetiver reduces pollution risk. The diagram is schematic and not to scale; the dominant pathway varies by site and contaminant.

Experimental evidence is encouraging but site-specific. In a 28-day study using artificial electroplating wastewater, vetiver removed 61.10% of chromium and 95.65% of nickel under the reported treatment conditions. Field evidence is equally important. In Nadia, West Bengal, a vetiver field trial reported reductions in soil arsenic of 24% after three months, 62% after eight months and 79% after eleven months; subsequent rice growth and grain arsenic were also assessed. These results demonstrate potential, not a fixed removal rate that can be transferred to every field.

Artificial Intelligence for Greener Environmental Restoration

AI refers to computational methods that learn patterns from data and use them to classify, predict or recommend. In vetiver remediation, the most useful AI may not be a complicated robot. It may be a phone-based image tool that detects poor canopy cover, a model that estimates biomass, or an alert that identifies an unusual change in moisture or electrical conductivity. Reviews of AI in phytoremediation highlight RGB and spectral imaging, thermal sensing and other remote measurements as promising ways to monitor plant growth and stress.

1. Mapping the problem before planting: Remediation begins with site characterisation, not with an algorithm. Historical land use, contaminant analysis, topography, drainage and soil properties can be organised in a geographic information system. Statistical or machine-learning methods can then help identify pollution hotspots and group sites with similar

conditions. AI can guide additional sampling, but a map produced from sparse or biased samples can look precise while being wrong.

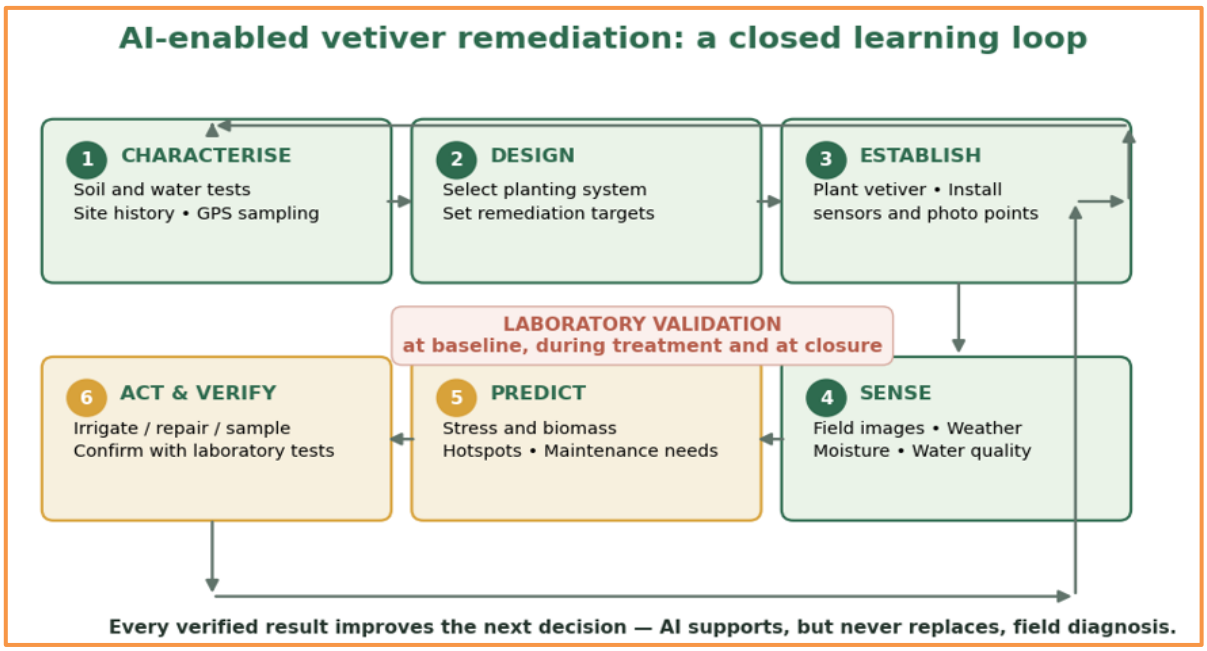

Figure 3. A closed-loop AI-enabled vetiver remediation workflow. Laboratory verification remains part of the cycle from baseline to closure.

2. Detecting plant stress early

Repeated smartphone photographs taken from fixed positions can reveal gaps, lodging, yellowing or uneven establishment. With enough labelled local images, computer vision may help distinguish healthy canopy from stressed canopy and direct attention to problem patches. Such tools detect visible symptoms; they do not, by themselves, prove metal uptake or identify the cause of stress.

3. Estimating growth and treatment progress

Plant height, tiller number, canopy cover, weather and selected sensor readings can be combined to estimate survival and biomass. Better biomass estimates support decisions on irrigation, replanting and harvesting. Models may also forecast treatment trajectories, but their predictions must be checked against new field and laboratory observations, especially when seasons or effluent quality change.

4. Making monitoring more targeted

Sensors can produce frequent readings, while soil and water analyses remain more costly and less frequent. AI can link these data streams and prioritise locations or dates for confirmatory sampling. This is adaptive monitoring: sampling becomes more informative rather than merely more frequent.

5. Supporting maintenance and record-keeping

Anomaly-detection tools can flag blocked flow, abnormal dry-down, sensor drift or sudden changes in plant condition. A simple digital dashboard can also preserve photographs, sampling locations, laboratory certificates and interventions. Good records make the remediation process auditable and help future users understand what worked.

Tamil Nadu-Specific AI-Based Vetiver Remediation and Digital Monitoring

Tamil Nadu has relevant experience on which to build. TNAU reports a vetiver grass-based remediation technology for restoring tannery effluent-contaminated soils, including reduced heavy-metal toxicity and improved soil stability.TNAU research highlights also describe a low-cost vetiver constructed-wetland system for coir-industry wastewater, with reported reductions of 44.47% in biochemical oxygen demand, 47.23% in chemical oxygen demand, 57.07% in total dissolved solids and 40% in polyphenols. An AI-supported extension of such work could begin with consistent digital monitoring rather than expensive automation. Geo-

tagged photographs, inlet–outlet measurements, maintenance logs and seasonal performance data from coir, textile, tannery or sewage-treatment pilots could form a valuable local evidence base. The aim should be a Tamil Nadu-specific decision tool trained and tested on local conditions—not a generic application with unverified recommendations.

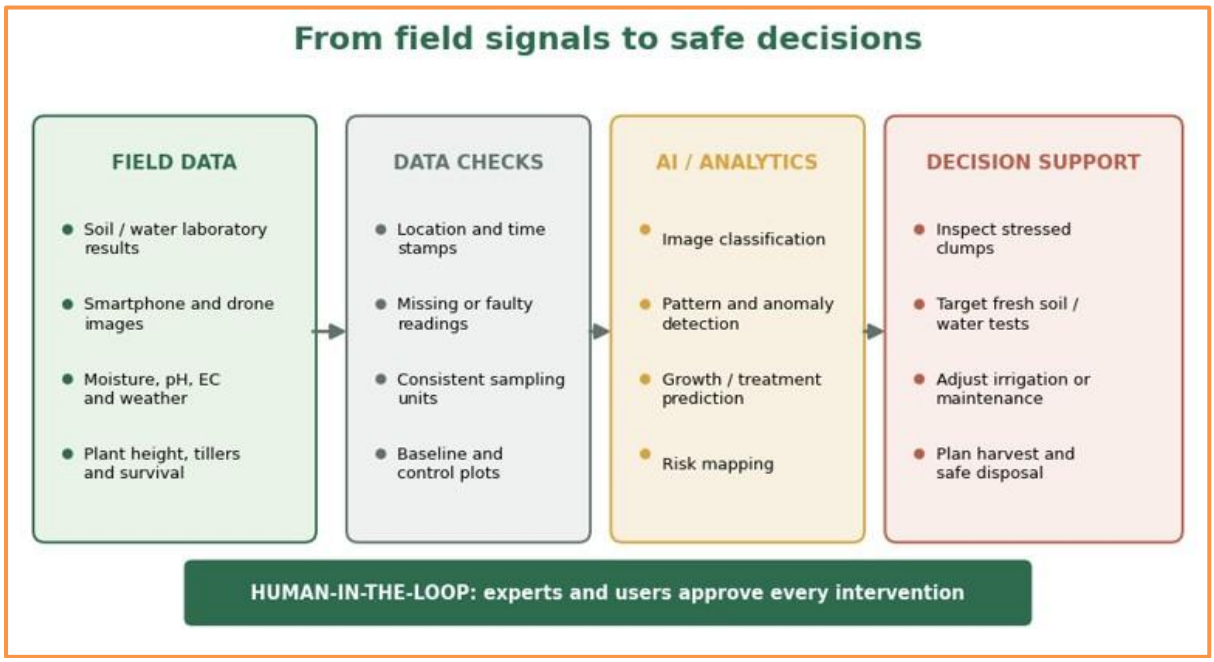

Figure 4. The data-to-decision chain. AI outputs are decision support; experts and users retain responsibility for action

Start small: a pilot that produces trustworthy evidence

A useful pilot should answer a clear question: Can the system improve plant establishment, detect failures earlier, or reduce unnecessary sampling while maintaining reliable verification? A paired design with vetiver treatment and an appropriate control provides stronger evidence than photographs from a single plot.

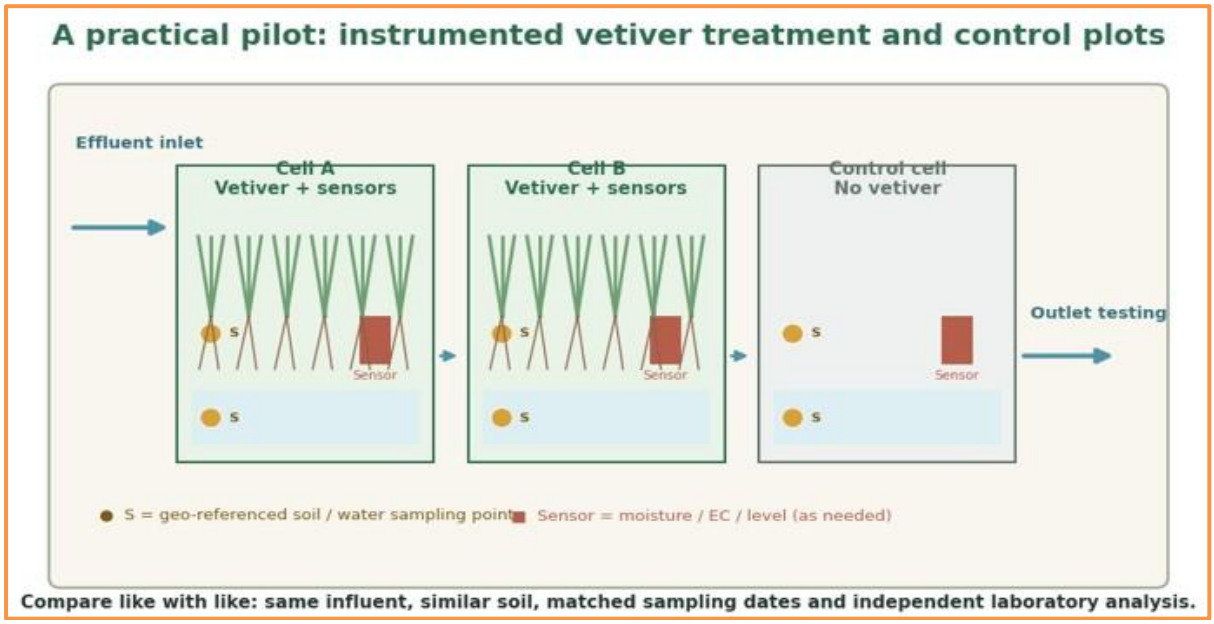

Figure 5. Conceptual layout for an instrumented pilot. Actual design, dimensions, pre-treatment, hydraulic loading and safety measures must be site-specific and approved by competent specialists

A six-step field plan

- Define the target: identify the contaminant, exposure pathway and measurable remediation objective before selecting sensors or models.

- Establish the baseline: collect geo-referenced soil, water and plant data; record site history; include control or comparison plots.
- Use fit-for-purpose measurements: fixed-point photographs and a small set of maintained sensors may be more valuable than many unreliable devices.
- Create 'ground truth': link every image or prediction with field observations and, where relevant, laboratory results from the same place and time.
- Validate across time: test performance in different seasons and on data not used to train the model; report errors and failures, not only accuracy.
- Plan closure and biomass management: define safe harvesting, transport and disposal or recovery routes before contaminated biomass is generated.

Safety and limitations must remain visible

Phytoremediation can move contaminants from one place to another. Plants containing metals or other hazardous substances must not automatically enter fodder, food, compost, handicraft or open-burning pathways. Biomass requires characterisation and an approved management route. Similarly, treated water should not be reused for irrigation or discharged simply because plants look healthy or a model predicts improvement. Data limitations also matter. A model trained on one soil, cultivar or climate may fail at another site. Yellowing can result from nutrient deficiency, salinity, pests, waterlogging or chemical stress, and similar symptoms do not share one cause. Sensors require calibration; missing data require transparent handling; and recommendations must remain explainable to the field user. Cybersecurity, privacy and equitable access deserve attention when site information is stored online.

AI can…	AI cannot…
Flag unusual plant growth or sensor readings	Identify the pollutant or certify removal from an image alone
Prioritise field inspection and confirmatory sampling	Replace baseline, periodic and closure laboratory analyses
Learn patterns from well-documented local trials	Guarantee performance at a new site without local validation
Support maintenance schedules and transparent records	Determine safe biomass disposal or water reuse by itself

The road ahead: from digital plots to living laboratories

The next step is not to make vetiver remediation appear more technological; it is to make it more measurable and dependable. Universities, industries, pollution-control agencies, farmer groups and local communities can collaborate on open, well-documented demonstration plots. Shared data dictionaries, common sampling protocols and independent laboratory checks would allow results from different locations to be compared. Future research can combine plant physiology, root-zone microbiology, hydrology and AI. Useful questions include: Which early signals predict treatment failure? Can models estimate uncertainty in a way farmers understand? How does performance change during monsoon, drought or variable effluent loading? Which low-cost sensor set gives the most useful information per rupee? Answering these questions will matter more than adding fashionable digital labels.

Conclusion

Vetiver-based phytoremediation, supported by Artificial Intelligence (AI), offers a promising, eco-friendly and cost-effective approach to polluted soil and water management. AI improves monitoring, predicts plant stress and supports timely decisions, while laboratory testing ensures reliable results. Integrating plant science, digital technology and safe waste management can strengthen sustainable remediation, particularly in Tamil Nadu. The success of this approach lies in combining the natural power of vetiver with the intelligent support of AI and scientific verification.

Glossary

Phytoremediation: use of plants and associated organisms to reduce contaminant risk.
Rhizosphere: soil and microbial zone influenced by roots.
Ground truth: reliable field or laboratory observations used to check a model.
Anomaly: a reading or pattern that differs unexpectedly from normal conditions.

References

1. Nugroho, A.P. et al. (2021). Phytoremediation of electroplating wastewater by vetiver grass (*Chrysopogon zizanoides* L.). Scientific Reports 11, 14482. https://doi.org/10.1038/s41598-021-93923-0
2. Singh, S. et al. (2024). Vetiver grass cleans up arsenic contaminated field for subsequent safe cultivation of rice with low arsenic in grains: A twoyear field study. Science of the Total Environment 923, 171491. https://doi.org/10.1016/j.scitotenv.2024.171491
3. Singh, P., Pani, A., Mujumdar, A.S. and Shirkole, S.S. (2023). New strategies on the application of artificial intelligence in the field of phytoremediation. International Journal of Phytoremediation 25, 505–523. https://doi.org/10.1080/15226514.2022.2090500
4. Tamil Nadu Agricultural University, Directorate of Natural Resource Management. Environmental Sciences—Technologies Developed: vetiver grass-based remediation technology. https://tnau.ac.in/site/nrm/environmental-sciences-technologies-developed/
5. Tamil Nadu Agricultural University (2021). Research Highlights 2020, 85th Scientific Workers' Conference: 'Recycling of Coir Industry Wastewater through Phytoremediation'. https://tnau.ac.in/site/research/wp-content/uploads/sites/60/2021/09/85th-SWC-Research-Highlights-2021-3.pdf