

Management of *P. polystachyum* has become a vicious circle in which the control activity and reappearance of new infestation of *Polygonum* are inextricably linked. Inhabitants of high-altitude villages, particularly those engaged in sheep/goat-rearing have noticed that *P. polystachyum* is expanding downward from the alpine/subalpine ecosystem to the forest ecosystem. The species was restricted to alpine meadows with very few pockets in the past three decades, but is now seen in large pockets along the timberline and the adjoining high-altitude villages. Management options are still not known for the Himalayan knotweed. The Forest Department has been trying to control the colonization of the species manually by cutting the aerial portion from the selected areas in VoFNP, while no conservative steps have been initiated in other parts of NDBR and the Western Himalayan region.

P. polystachyum, capable of forming dense populations, exerts severe effect on the plant species diversity of subal-

pine and alpine ecosystems in Western Himalaya. Long-term ecological monitoring studies are required to assess and understand the ecological impact of invasion by native invaders for effective conservation and management of alpine ecosystems or protected areas, particularly in the Himalayan region.

1. Mooney, H. A. and Cleland, E. E., *Proc. Natl. Acad. Sci. USA*, 2001, **10**(98), 5446–5451.
2. Kala, C. P., *Biodivers. Conserv.*, 2004, **13**, 985–995.
3. Misra, R., *Ecology Workshop*, Oxford and IBH, Calcutta, 1968.
4. Mueller-Dombois, D. and Ellenberg, E., *Aims and Methods of Vegetation Ecology*, John Wiley, New York, USA, 1974.
5. Shannon, C. E. and Weaver, W., *The Mathematical Theory of Communication*, University of Illinois Press, Illinois, Urbana, USA, 1963, p. 117.

ACKNOWLEDGEMENTS. We thank DST-SERB for funds (Grant no. SB/YS/LS-204/2013) to conduct this study and Task Force-3

under NMSHE funded by DST, New Delhi for partial funding to support the study. We also thank the Director, GBPNIHESD, Kosi-Katarmal, Almora, for providing the necessary facilities.

Received 23 June 2017; revised accepted 25 October 2017

VIKRAM S. NEGI^{1,*}
R. K. MAIKHURI²
AJAY MALETHA²

¹*G.B. Pant National Institute of Himalayan Environment and Sustainable Development (GBPNIHESD), Kosi-Katarmal, Almora 263 643, India*
²*GBPNIHESD, Garhwal Unit, Srinagar (Garhwal) 252 424, India*
*For correspondence.
e-mail: vikramsnegii@gmail.com

Recycling sugar effluent in hybrid flow constructed wetland and reusing for agriculture

Globally, water constraint is gaining increasing public attention as a critical environmental dilemma due to population growth, urbanization, rapid industrialization and expansion and intensification of food production that need to be addressed. Water scarcity is a reality in many areas today, and it is being exacerbated due to climate change creating critical distress in the future. According to the United Nations, the world's population is expected to grow by one-third to over 9 billion by 2050, demanding 55% more water, while the amount of freshwater will not increase. Concurrently, the world is also facing water quality crisis as a result of increasing wastewater generation and unregulated discharge of contaminated water from point and non-point sources. Over 80% of the world's wastewater is released to the water bodies without treatment¹. Accessing the contaminated water for various uses poses a threat, causing major health challenges, including costs to health care, decreasing labour productivity, and degrading ecosystem and biodiversity.

Agriculture is the highest water-consuming sector accounting for around 70% of global freshwater withdrawals, and even up to 90% in some fast-growing economies². The projected irrigation demand exceeds the available freshwater threshold. With the widening gap between freshwater demand and lagging water supply^{3–5}, wastewater reuse is a commonly suggested option^{3,6,7}. Either intentionally or accidentally, wastewater has long been used as a resource in agriculture across the world. Wherever unpolluted water is a scarce resource, particularly in arid and semi-arid regions, the water and nutrient values of wastewater are considered important drought-resistant resource by farmers. Estimated worldwide acreage of land irrigated with wastewater varies between 4.5 M ha (ref. 7) and 20 M ha (refs 8, 9), which is around 10% of irrigated land surface¹⁰. This corresponds to 200 million farmers irrigating with both treated and untreated wastewater⁸.

Among all the sources, industries are the prime sources of generating waste-

water and are the major contributors of toxic pollutants. UNESCO estimated that 5–20% of total available water is used by industries and found that 70% of its effluents in developing countries are discharged untreated¹¹. In India, according to Dey¹², total industrial wastewater generated from all major industries is estimated to be 83,048 MLD; however, the CPCB¹³ reported that about 60% of wastewater generated by industries is primary treated in conventional treatment plants. Among the industries in India, agro-food industries are fast-growing and rank sixth in the global market. As an agro-food industry, sugar industry contributes to about 12% of the world's sugar production with annual production capacity of 23 million tonnes. The sugar industry is a major water user and wastewater producer. According to Gunjal and Gunjal¹⁴, there are around 530 sugar industries in India having crushing capacity of 1.6 million tonnes per day utilizing 3.2 million m³ of water, generating 0.6 million m³ of effluent per day. Reusing primary treated sugar effluent

for irrigation without post-treatment will lead to clogging, affect plant growth, yield and soil health. Therefore, removal of pollutants from sugar effluent is essential. Yet inadequate and underdimensioned infrastructure of conventional primary treatment plants and management systems for treating the increasing/entire volume of sugar factory effluents is one of the causes for poor treatment and often not meeting the statutory requirements.

There are many physical, chemical and biological treatment methods, but most of them generate secondary pollutants, are cost and energy intensive and require high maintenance. Hence the need of the hour is a low-cost and green technology that requires no post-treatment and produces reusable effluents. One such technology is constructed wetlands, a natural treatment system that stabilizes, sequesters, accumulates, degrades, metabolizes and mineralizes the contaminants. In partnership with KCP Sugar and Industries Corporation Ltd, the M. S. Swaminathan Research Foundation has demonstrated under the Department of Biotechnology, Government of India-funded, EU-India collaborated water 4 crops project to treat 24,000 l of primary treated sugar effluent (PTSE) per day in the hybrid flow constructed wetland and reuse in an integrated aqua-agro farming system. The constructed wetland system is established in Lakshmipuram site of the KCP Sugar and Industries Corporation Ltd, Krishna district, Andhra Pradesh, India (long. 16°07'26"N and lat. 80°57'38"E).

PTSE as a source water has high levels of pH (8.50), conductivity (E_c – 1.8 mS), temperature (33.9°C), total dissolved solids (TDS – 600.1 mg/l), total suspended solids (TSS – 126.8 mg/l), chemical oxygen demand (COD – 3980.1 mg/l), biological oxygen demand (BOD – 280.2 mg/l), total hardness (366.1 mg/l), total alkalinity (533 mg/l), total nitrogen (TN – 112.27 mg/l), total phosphorus (TP – 1.7 mg/l), chloride (Cl – 258.9 mg/l), calcium (Ca – 2.3 me/l), nitrate (NO_3 – 103.34 mg/l), magnesium (Mg – 2.9 me/l), sulphate (SO_4 – 2.2 mg/l) and dissolved oxygen (DO – 2.5 mg/l). The targets for recycling and to ensure its reuse in fertiligation and aquaculture are to reduce COD, BOD, TN, TP, increase DO and neutralize pH.

A four-stage treatment process comprising filtration tank (FT), hybrid flow

constructed wetland (CWL), storage tank and fish pond (FP) accomplished the reduction targets of PTSE effectively (Figure 1). FT filled with large-sized gravel removed the suspended solids and subsequently minimized clogging of CWL. A subsurface flow (SSF) and free water surface (FWS) hybrid model CWL consisting of five chambers with vertical followed by horizontal flow alternatively was filled with different substrates, viz. large, medium and small sized gravels, mix of sand and soil, planted with emergent and floating macrophytes. The wetland was constructed with an impermeable layer to protect infiltration and seepage of wastewater, aspect ratio 2 : 1, 1% bottom slope and ~50% porosity to treat PTSE. The CWL was partly below (0.4 m) and partly above ground level (0.6 m), mainly to prevent external water from entering the system. The influent PTSE from filtration tank enters the CWL through gravity, controlled manually by adjusting a valve attached to the inlet pipe. More the contact time of PTSE with substrates and vegetation, maximum is the removal of pollutants. This was ensured by fixing appropriate hydraulic retention time (HRT) and hydraulic loading rate (HLR). The gener-

ally perceived limiting factors of CWL such as short-circuiting and clogging were addressed by ensuring flow paths, uniform distribution of water and regular harvest of biomass. However, availability of land is considered a challenge, which is a meagre investment for the industry.

Typha angustifolia, an emergent macrophyte in CWL, removes pollutants from PTSE by its rapid vegetative reproduction with steady root growth enhancing water-plant interaction. Duck weed and *Wolffia arrhiza*, floating macrophytes with indigenous filamentous algae and diatoms in the FWS of CWL contributed in the removal process. The alternative aerobic and anaerobic zones in CWL facilitated effective removal of TSS, TN, TP, COD and BOD as the organic content in PTSE is metabolized by microbes, absorbed and taken up by floating and emergent macrophytes. The facultative bacteria in anoxic condition convert nitrate to nitrogen and release it into the atmosphere in the form of NO and N_2O . Algae play an important role in nitrate uptake and mitigate the nutrient pollution¹⁵. The quantity of algae removed from the constructed wetland was 4 kg/day, which clearly substantiates that



Figure 1. Hybrid flow constructed wetland connected with 24 × 7 on-line monitoring multi-parameter analyser.

Table 1. Comparison of parameters in sugar effluent before and after treatment

Parameters	Before treatment	After treatment	CPCB standards	Irrigation standards
COD (mg/l)	3980.1	41	250	90
BOD (mg/l)	280.2	20.5	30	30
TSS (mg/l)	126.8	17.9	30	50–100
pH	8.5	7.9	8.5	6.5– 8.4
DO (mg/l)	2.5	4.6	–	–

alga is a significant contributor for TN removal from the sugar effluent. The oxygenation of wastewater is important to improve its quality. This is done by (i) the removal of chemicals and biological matter that demand oxygen, and (ii) supply of oxygen by diatoms, roots of *Typha*, and free surface flow with intermittent loading (increased air/water interface). Thus the DO content of sugar effluent was enhanced and pollutant concentrations decreased simultaneously.

Tangible outcomes are availability of water which is an adaptive measure for water-scarce situation. Using the source in an integrated manner for aquaculture and then for agriculture, where the fish in addition to growing luxuriantly enrich the water with nutrients, is a rich bio-fertilization for agriculture minimizing fertilizer usage. Thus dual productivity is gained from fish and crop with the same amount of water.

On 14 January 2016, the Ministry of Environment, Forest and Climate Change, Government of India has notified stricter environment standards in the Gazette of India for sugar industries in the country. Further, it allowed only one outlet/discharge point, to be covered according to the '24 × 7 on-line monitoring' protocol. However water quality from the ETP of KCP industry was unable to meet the regulations. Industry witnessed the performance of CWL that requires no post-treatment and produces reusable effluent suitable for aquaculture and agriculture. To overcome the challenge of '24 × 7 on-line monitoring' pro-

col, industry adopted the CWL system as the secondary treatment. As shown in Figure 1, an on-line multi-parameter analyser is fixed and connected to the FP for real-time monitoring of water quality by the government. Final discharge values observed using the on-line monitor are presented in Table 1, which meets the environmental pollution regulations and the irrigation standards.

1. The United Nations World Water Development Report, UNESCO, Paris, 2017.
2. <http://www.unwater.org/statistics/statistics-detail/en/c/211204/>
3. Comprehensive Assessment of Water Management in Agriculture, *Water for life: A Comprehensive Assessment of Water Management in Agriculture*, Earthscan, London and International Water Management Institute, Colombo, 2007.
4. United Nations Environment Programme, Nairobi, 2007; www.unep.org/geo
5. Lee, A., Giulio, B., Mike, K. and Martin, S., *Charting our Water Future: Economic Frameworks to Inform Decision-Making*, The 2030 Water Resources Group, 2009.
6. McCormick, P. G., Hijazi, A. and Sheikh, B., In *Wastewater Use in Irrigated Agriculture* (eds Scott, C. A., Faruqui, N. I. and Raschid-Sally, L.), CABI Publishing, UK, 2004.
7. Jiménez, B. and Asano, T. (eds), In *Water Reuse: an International Survey of Current Practice, Issues and Needs*, IWA Publishing, London, UK, 2008, pp. 3–26.
8. Sato, T., Qadir, M., Yamamoto, S., Endo, T. and Zahoor, A., *Agric. Water Manage.*, 2013, **130**, 1–13.

9. Hamilton, A. J., Stagnitti, F., Xiong, X., Kreidl, S. L., Benke, K. K. and Maher, P., *Vadose Zone J.*, 2007, **6**(4), 823–840.
10. Keraita, B., Jiménez, B. and Drechsel, P., *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 2008, **3**(58), 1–15.
11. The United Nations World Water Development Report 3, UNESCO, Paris, 2009.
12. Dey, P., Bhan, S. and Arora, S. (eds), *Advances in Soil and Water Resource Management for Food and Livelihood Security*, Soil Conservation Society of India, New Delhi, 2015, pp. 224–233.
13. Performance Status of Common Effluent Treatment Plants in India. Central Pollution Control Board, 2005.
14. Gunjal, B. and Gunjal, A., *Nat. Environ. Pollut. Technol.*, 2013, **12**(2), 325.
15. Cardinale, B. J., *Nature*, 2011, **472**, 86–89.

ACKNOWLEDGEMENTS. We thank the Department of Biotechnology, Government of India for financial support. We also thank the Editor, *Current Science* for valuable suggestions that helped improve the manuscript.

Received 18 May 2017; revised accepted 4 December 2017

J. D. SOPHIA*
JASTIN SAMUEL
J. HEMAMALINI

*M.S. Swaminathan Research Foundation,
III Cross Road,
Taramani Institutional Area,
Chennai 600 113, India*

**For correspondence.
e-mail: sophi_john@yahoo.com*

Quantification of rainfall during the late Miocene–early Pliocene in North East India

The monsoon rainfall contributes about 30% of the total global rainfall¹. The Asian monsoon system (ASM) is one of the largest systems and is of great significance in the global climate system. It consists of two subsystems, namely Indian summer monsoon (ISM)/southwest (SW) monsoon/South Asia summer monsoon (SASM) and East Asia monsoon (EAM). There are two monsoon seasons in India: (i) SW monsoon of the summer season (June–September/JJAS) producing 70–90% of the total annual rainfall², and (ii) northeast monsoon (October–

December/OND) accountable for 50% of the east coast annual rainfall³. Moreover, the northeastern region (NER) has a special rainfall system as it receives notable rainfall not only in the monsoon season (JJAS), but also in pre-monsoon season (March–May/MAM)⁴. Due to this, the region is affected by floods which wreak havoc⁴.

The rainfall pattern in North East (NE) India shows a large variation both spatially and temporally⁵. Due to this, severe flood occurs frequently in the region. Therefore, it is important to study the

variability of pre-monsoon and summer monsoon showers of the region in the geological past. The quantitative palaeo-monsoonal record from NE India is poor. On the basis of leaf physiognomy, Khan *et al.*⁶ suggested that the intensity of the SW monsoon has remained the same since the middle Miocene in Arunachal Pradesh.

In this communication, we deduce pre-monsoon, summer monsoon and dry seasonal (January–February) rainfall using coexistence approach (CA)^{7,8} on the fossil assemblage recovered from the late