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| Commentary |
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# Commentary:

# Invader or Indicator? Water Lettuce (*Pistia stratiotes*) and the Eutrophication Paradox in the Vaal River

Anthropogenic activities, such as the discharge of raw/partially treated sewage from dysfunctional wastewater treatment works (WWTW), agricultural (i.e., runoff and wastewater containing elevated nutrient concentrations), mining (e.g. acid mine drainage), and industrial (e.g. textile dyes) effluent into watercourses increase the susceptibility of water bodies to biological invasions by alien invasive species and cyanobacteria (commonly referred to as blue-green algae) (Willby, 2007; du Plessis, 2017).

**Photo: Thomas du Toit**

According to the Green Drop Watch Report 2023 (DWS, 2023), approximately 60% of WWTW within municipalities located in the Vaal River catchment are in a critical state - some of which discharge raw/partially treated sewage directly or indirectly (e.g., via tributaries such as the Rietspruit River) into the Vaal River. The Vaal River is the third largest river in South Africa (RSA) and supplies water to key sectors such as mining, power generators, agriculture (e.g., irrigation), various industrial activities, and urban development (Tempelhoff *et al*., 2007). This highlights the need to protect the Vaal River and its tributary.

The discharge of sewage and agricultural runoff, containing high levels of bioavailable forms of nitrogen (ammonium, nitrates, and nitrites), phosphorous (phosphates), and trace elements, as well as dissolved and suspended organic matter results in eutrophication and change in biological and hydrogeochemical characteristics of the Vaal River (Carey and Migliaccio, 2009). Eutrophication is a process whereby elevated nutrient levels promote the proliferation of algae, cyanobacteria (which may produce and release harmful toxins called cyanotoxins, such as microcystins, into the water and air), and alien invasive plant species (AIPS) such as *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) (Ballot *et al.,* 2013; Matthews and Bernard, 2015).

**Photo: Thomas du Toit**

The reported presence of *Pistia stratiotes* in the Vaal River system has raised concern due to the negative environmental and socioeconomic impacts associated with the aquatic plant. Water Lettuce is an alien invasive, free-floating aquatic plant with an adventitious root system that has two reproductive strategies, namely vegetatively (via plant fragments) and sexually (dispersal of seeds by wind and water) – contributing to its effective invasion dynamics. *Pistia stratiotes* can reach plant densities of approximately 1000 plants/m2 and 1kg/m2 dry mass (Dewald and Lounibous, 1990; Reddy and De Busk, 1984) – typically observed as dense *P. stratiotes* mats that cover the surface of the water body, reducing the penetration of sunlight to submerged aquatic organisms, as well as reducing the pH level and dissolved oxygen content (Das *et al.,* 2014; Hill *et al.,* 2020; Kumar *et al.,* 2019). Such changes trigger a shift in the composition of the fauna and flora communities, which can have cascading effects on other trophic levels and lead to ecosystem collapse. Although *P. stratiotes* has a limited ability to overwinter (i.e., dies back during colder seasons), seeds have a high viability and germination potential under warmer conditions (Hussner *et al.,* 2014). This must be considered in the management of the species whereby the absence of the plant does not indicate its complete eradication from a water body.

Although *P.* stratiotes is an invasive plant species, numerous studies have demonstrated the plant’s elevated phytoremediation potential, relative to a range of contaminants such as cadmium, copper, mercury, iron, and nutrients (improving the quality of eutrophic water) present in sewage and agricultural runoff (Das *et al.,* 2014). Although the plant has an elevated phytoextraction potential (accumulating high concentrations of these contaminants within its biomass), plant dieback results in the reintroduction of accumulated nutrients into the water body through plant senescence and death – contributing to the biogeochemical cycling of nutrients within the Vaal River system (Mader *et al.,* 2022). This contributes to the complex invasion dynamics of the species and ultimately, the *P. stratiotes* - eutrophication paradox. Although a legacy of wastewater discharge has resulted in the eutrophication of certain parts of the Vaal River (Mararakanye *et al.,* 2022), the sudden exponential growth and spread of *P. stratiotes* raises various questions regarding the source of eutrophication. A key question raised is: what acute pollution event(s) created conditions favorable to the proliferation of *P. stratiotes*, differing from the legacy of point (PS) and non-point sources (NPS) of pollution over the past decades?

The occurrence of critical source areas (CSA), areas contributing disproportionate amounts of NPS pollution resulting from complex interactions between factors associated with the source and fate and transport of contaminants within the receiving water body (Wang *et al.,* 2020), need to be identified to design and implement effective water management and AIPS control programs (Lintern *et al.,* 2018). For example, the low water quality in the lower Vaal River Catchment is attributed to anthropogenic activities (such as agricultural activities), a key NPS pollution in the region (Mararakanye *et al.,* 2022). The identification of these CSAs enables the implementation of mitigation measures to reduce/ prevent the release of harmful contaminants into the environment.

In November - December 2023, the South African Weather Service issued yellow Level 2 warnings for intense rainfall, severe thunderstorms, and hail storms in various provinces including the North West province. Hydroclimatological conditions mediate the introduction, fate, and transport of nutrients within receiving water bodies – attributed to intense rainfall events influencing maximum discharge, time to peak, and runoff rations (Bauwe *et al.,* 2015; Xie *et al.,* 2019). This highlights a potential acute NPS pollution event(s) whereby the observed proliferation of *P. stratiotes* may be attributed to the increased release of nutrients into the Vaal River and its tributaries via anthropogenic activities. These activities may have included increased runoff from recently fertilized cultivated areas, erosion of fertilizer and tailing storage facility stockpiles, overflow and subsequent discharge of additional raw/partially treated sewage from dysfunctional WWTWs, and increased volume of wastewater discharge from mining and other industrial processes during intense rainfall events. In further support of this potential contamination pathway, the currently reported proliferation of *P. stratiotes* is significant due to the absence of any previous *P. stratiotes* blooms in the Vaal River system despite decades of PS and NPS pollution events. Identifying the source and physicochemical characteristics of pollution provides valuable insight into the type of control required (biological, physical, and/or chemical) as well as timeframes whereby implemented control measures must be completed.

Based on the invasion biology of *P.* *stratiotes*, this AIPS has been designated a Category 1b invasive species (NEMBA) – indicating that the species poses a threat to aquatic ecosystems and species supported by such ecosystems. Various measures have been implemented to control the spread of *P. stratiotes*, namely the use of biocontrol agents (e.g., *Neohydronomus affinis* - Water lettuce weevil), physical removal (e.g. mechanical harvesting), and chemical (e.g., application of herbicides such as glyphosate). Since 1985, *Neohydronomus affinis* has been released in RSA in watercourses such as Sunset Dam, Letaba, Crocodile, and Sabie Rivers, located within the Kruger National Park (Cilliers, 1991).

 A study conducted by Coetzee *et al.,* (2020) demonstrated that *N. affinis* is an effective biological control agent, resulting in the reduction of *P. stratiotes* percentage cover while significantly increasing dissolved oxygen content and promoting the recovery of benthic macroinvertebrate community*.* Additionally, biocontrol measures can be supported by physical control measures, namely the mechanical removal of plants (e.g., plant harvesters) (Mugido *et al.,* 2014). To increase the efficacy of physical control measures, temporal and spatial factors must be considered – such as the flowering season of *P. stratiotes* and the percentage cover (Galal *et al.,* 2019). Furthermore, *P. stratiotes* can be controlled through the application of herbicides such as (but not limited to) glyphosate (Datta and Mahapatra, 2015) and bispyribac-sodium (Mudge and Netherland, 2015). However, the application of herbicides may have various ecotoxicological risks and may persist in the environment once introduced.

Based on the potential acute NPS pollution event, the application of a combination of mechanical harvesting and biocontrol measures would be effective, along with the creation of physical barriers (which are currently being deployed throughout the Vaal River system) to prevent *P. stratiotes* entering key strategic areas. Moreover, increased mechanical removal of *P. stratiotes* (currently at approximately 220 tons/hr – personal communication) is required to reduce the establishment of a *P. stratiotes* seed bank prior to the plant’s winter dieback. The simultaneous application of *N. affinis* would also reduce the plant’s vegetative and sexual reproductive strategies due to the weevil’s mechanism of biocontrol action (Moore and Hill, 2012). Although *P. stratiotes* has various environmental (e.g., elevated phytoremediation potential) and socioeconomic (harvesting of plant for medicinal uses – e.g. Tripathi *et al.,* (2010)) benefits, the magnitude of the negative impact related to retaining these plants in vital watercourses has not been evaluated. These data could be obtained through undertaking an ecosystem services assessment – an assessment addressing the provisioning, regulating, supporting, and cultural services offered by the Vaal River with and without the presence of *P. stratiotes*. These data could then be used to support calls for physical and financial investment to control *P. stratiotes* along with identifying CSAs.

In alignment with our Sustainable Legacies strategy, AECOM RSA is committed to creating sustainable solutions to complex challenges and enhancing the provision of vital ecosystem services. The Small and Medium Enterprises (SMEs), forming part of AECOM’s Enterprise Capacities (EC) Sustainability as well as Environmental portfolios, provide various nature-based solutions (NbS) to address complex environmental and socioeconomic challenges. A key service offered by the EC SMEs is the design and implementation of constructed wetlands (CWs) - engineered biological and hydrogeochemical systems with controllable functional (integrating phyto- and bioremediation technologies) and operational (e.g., hydrological regime) parameters to optimize the remediation of a range of inorganic (*viz.* metals, salts, nutrients, and radionuclides) (Liang *et al.,* 2019; Overall and Parry, 2004), and organic (e.g., per- and polyfluoroalkyl substances (PFAS) (Arslan and El-Din, 2021) contaminants present within wastewater produced by anthropogenic activities. For example, hybrid and novel CWs can be designed to address and mitigate PS and NPS pollution events, reducing the release of contaminants required for the proliferation of *P. stratiotes* and cyanobacteria. Simultaneously, this approach enhances the provision of ecosystem services, amid climate change – promoting sustainable development. Additional EC SME components include (but are not limited to) wetland and riparian zone rehabilitation, ecosystem services assessments, regenerative ecology, flood management, and carbon sequestration - incorporating sustainability frameworks (such as Envision) into the design and effective delivery of sustainable, resilient, and equitable NbS.

In conclusion, the presence of *P. stratiotes* is indicative of an underlying problem, namely the acute and chronic discharge of contaminants into the Vaal River and its tributaries from PS and NPS pollution events. Controlling the symptom (*P. stratiotes*) does not address the source of pollution - ultimately maintaining the *P.* stratiotes – eutrophication paradox. The presence of *P. stratiotes* highlights our need to shift our perspective on how we address environmental challenges, focusing on identifying and addressing CSAs and not the symptoms. Based on the latest scientific literature and best practice guidelines, the EC SMEs at AECOM offer holistic and sustainable NbS, ultimately contributing to your organization’s Sustainable Legacy.

**References**

Adebayo, A.A., Briski, E., Briski, E., Kalaci, O., Hernandez, M., Ghabooli, S., Beric, B., Chan, F.T., Zhan, A., Fifield, E. and Leadley, T., 2011. Water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) in the Great Lakes: playing with fire?. *Aquatic Invasions*, 6(1), p.91.

Araújo, R.G., Rodríguez-Hernandéz, J.A., González-González, R.B., Macias-Garbett, R., Martínez-Ruiz, M., Reyes-Pardo, H., Hernández Martínez, S.A., Parra-Arroyo, L., Melchor-Martínez, E.M., Sosa-Hernández, J.E. and Coronado-Apodaca, K.G., 2022. Detection and tertiary treatment technologies of poly-and perfluoroalkyl substances in wastewater treatment plants. *Frontiers in Environmental Science*, 10, p.864894.

Arslan, M. and El-Din, M.G., 2021. Removal of per-and poly-fluoroalkyl substances (PFASs) by wetlands: Prospects on plants, microbes and the interplay. *Science of the Total Environment*, 800, p.149570.

Ballot, A., Sandvik, M., Rundberget, T., Botha, C.J. and Miles, C.O., 2013. Diversity of cyanobacteria and cyanotoxins in Hartbeespoort Dam, South Africa. *Marine and Freshwater Research*, 65(2), pp.175-189.

Bauwe, A., Tiemeyer, B., Kahle, P. and Lennartz, B., 2015. Classifying hydrological events to quantify their impact on nitrate leaching across three spatial scales. *Journal of Hydrology*, 531, pp.589-601.

Carey, R.O. and Migliaccio, K.W., 2009. Contribution of wastewater treatment plant effluents to nutrient dynamics in aquatic systems: a review. *Environmental management*, 44, pp.205-217.

Cilliers, C.J., Zeller, D. and Strydom, G., 1996. Short-and long-term control of water lettuce (*Pistia stratiotes*) on seasonal water bodies and on a river system in the Kruger National Park, South Africa. In Management and Ecology of Freshwater Plants: Proceedings of the 9th International Symposium on Aquatic Weeds, European Weed Research Society (pp. 173-179). Springer Netherlands.

Coetzee, J.A., Bownes, A., Martin, G.D., Miller, B.E., Smith, R., Weyl, P.S.R. and Hill, M.P., 2021. A review of the biocontrol programmes against aquatic weeds in South Africa. *African Entomology*, 29: 935-964.

Das, S., Goswami, S. and Talukdar, A.D., 2014. A study on cadmium phytoremediation potential of water lettuce, *Pistia stratiotes* L. *Bulletin of environmental contamination and toxicology*, 92, pp.169-174.

Datta, S. and Mahapatra, B.K., 2015. Effect of Glyphosate and Three Phenoxyacetic Acid Herbicides against *Eichhornia crassipes* (Mart) and *Pistia stratiotes* L. *Pesticide Research Journal*, 27(1), pp.75-83.

Department of Water and Sanitation (DWS): Green Drop Watch Report, 2023. <https://ws.dws.gov.za/iris/releases/GDWR.pdf>

Dewald, L.B. and Lounibos, L.P., 1990. Seasonal growth of *Pistia stratiotes* L. in south Florida. *Aquatic botany.* 36: 263-275.

du Plessis, A, 2017. Primary water quality challenges for South Africa and the Upper Vaal WMA. Freshwater Challenges of South Africa and its Upper Vaal River: Current State and Outlook, pp.99-118.

Galal, T.M., Dakhil, M.A., Hassan, L.M. and Eid, E.M., 2019. Population dynamics of Pistia stratiotes L. Rendiconti Lincei. *Scienze Fisiche e Naturali*. 30: 367-378.

Hill, M.P., Coetzee, J.A., Martin, G.D., Smith, R. and Strange, E.F., 2020. Invasive alien aquatic plants in South African freshwater ecosystems. In *Biological Invasions in South Africa* (pp. 97-114). Cham: Springer International Publishing.

Hussner, A., Heidbuechel, P. and Heiligtag, S., 2014. Vegetative overwintering and viable seed production explain the establishment of invasive *Pistia stratiotes* in the thermally abnormal Erft River (North Rhine-Westphalia, Germany). *Aquatic botany*, 119, pp.28-32.

Kumar, V., Singh, J., Saini, A. and Kumar, P., 2019. Phytoremediation of copper, iron and mercury from aqueous solution by water lettuce (*Pistia stratiotes* L.). *Environmental Sustainability*, 2, pp.55-65.

Liang, Y., Zhu, H., Bañuelos, G., Xu, Y., Yan, B. and Cheng, X., 2019. Preliminary study on the dynamics of heavy metals in saline wastewater treated in constructed wetland mesocosms or microcosms filled with porous slag. *Environmental Science and Pollution Research*, 26, pp.33804-33815.

Lintern, A., Webb, J.A., Ryu, D., Liu, S., Bende‐Michl, U., Waters, D., Leahy, P., Wilson, P. and Western, A.W., 2018. Key factors influencing differences in stream water quality across space. Wiley Interdisciplinary Reviews: *Water*, 5(1), p.e1260.

Mader, A.E., Holtman, G.A. and Welz, P.J., 2022. Treatment wetlands and phyto-technologies for remediation of winery effluent: Challenges and opportunities. *Science of the Total Environment*, 807, p.150544.

Mararakanye, N., Le Roux, J.J. and Franke, A.C., 2022. Long-term water quality assessments under changing land use in a large semi-arid catchment in South Africa. *Science of The Total Environment*, 818, p.151670.

Matthews, M.W. and Bernard, S., 2015. Eutrophication and cyanobacteria in South Africa's standing water bodies: A view from space. *South African journal of science*, 111(5), pp.1-8.

Moore, G.R. and Hill, M.P., 2012. A quantitative post-release evaluation of biological control of water lettuce, *Pistia stratiotes* L.(Araceae) by the weevil *Neohydronomus affinis* Hustache (Coleoptera: Curculionidae) at Cape Recife Nature Reserve, Eastern Cape Province, South Africa. *African Entomology*, 20(2), pp.380-385.

Mudge, C.R. and Netherland, M.D., 2014. Response of giant bulrush, water hyacinth, and water lettuce to foliar herbicide applications. *Journal of Aquatic Plant Management*. 52: 75-80.

Mugido, W., Blignaut, J., Joubert, M., De Wet, J., Knipe, A., Joubert, S., Cobbing, B., Jansen, J., Le Maitre, D. and Van der Vyfer, M., 2014. Determining the feasibility of harvesting invasive alien plant species for energy. *South African Journal of Science*. 110: 1 - 6.

Overall, R.A. and Parry, D.L., 2004. The uptake of uranium by *Eleocharis dulcis* (Chinese water chestnut) in the Ranger Uranium Mine constructed wetland filter. *Environmental Pollution*, 132(2), pp.307-320.

Petrie, B., Barden, R. and Kasprzyk-Hordern, B., 2015. A review on emerging contaminants in wastewaters and the environment: current knowledge, understudied areas and recommendations for future monitoring. *Water research*, 72, pp.3-27.

Reddy, K.R. and DeBusk, W.F., 1984. Growth characteristics of aquatic macrophytes cultured in nutrient-enriched water: I. Water hyacinth, water lettuce, and pennywort. *Economic Botany*, 38(2), pp.229-239.

Tempelhoff, J., Munnik, V. and Viljoen, M., 2007. The Vaal River Barrage, South Africa's hardest working water way: an historical contemplation. TD: *The Journal for Transdisciplinary Research in Southern Africa*, 3: 107-133.

Tripathi, P., Kumar, R., Sharma, A.K., Mishra, A. and Gupta, R., 2010. *Pistia stratiotes* (Jalkumbhi). *Pharmacognosy Reviews*. 4: 153.

Wang, S., Wang, Y., Wang, Y. and Wang, Z., 2022. Assessment of influencing factors on non-point source pollution critical source areas in an agricultural watershed. *Ecological Indicators*, 141, p.109084.

Willby NJ (2007) Managing invasive aquatic plants: problems and prospects. *Aquatic Conservation: Marine and Freshwater Ecosystems* 17, 659–665.

Xie, H., Dong, J., Shen, Z., Chen, L., Lai, X., Qiu, J., Wei, G., Peng, Y. and Chen, X., 2019. Intra-and inter-event characteristics and controlling factors of agricultural nonpoint source pollution under different types of rainfall-runoff events. *Catena*, 182, p.104105.