Utilisation Potentials of Invasive Plants in the Owabi Dam in the Ashanti Region of Ghana

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This paper provides a compendium of the utilisation potential of aquatic invasive plants found in the Owabi Dam in the Ashanti Region of Ghana. In total, seven aquatic invasive plants were identified in the Owabi Dam, which included *Ceratophyllum demersum*, *Nymphaea odorata*, *Polygonum lanigerum*, *Arthropteris orientalis*, *Typha domingensis*, *Pistia stratiotes*, and *Cyprus papyrus.* Some of the identified invasive plants were found to be highly nutritious and suitable for human consumption or use as feed for livestock, fish, and poultry. Other plants had high medicinal potential and aesthetic value. Several of the invasive plants were suitable for bio-industrial usages as feedstock to produce biofuels, insecticides, and biofertilizer, among other products. Therefore, if an effective utilization method of these currently unutilized aquatic invasive plants is established, it can provide a source of livelihood and income generation for individuals and households and contribute to controlling the impact of invasive plants on the Owabi Dam.

Keywords: Bioresources; Biofertilizer; Biofuel; Insecticides; Medicine; Aesthetic

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INTRODUCTION

The presence of invasive species in any habitat can threaten species diversity, the environment, economic development, and public health. Invasive plants include exotic species that persist in a new environment, reproduce, and spread greatly in distribution (Havel *et al.* 2015). Native species that colonize a site rapidly and eliminate the chance for plant biodiversity are also considered invasive plants (Leger and Espeland 2010). Due to their nature, invasive species have the potential to multiply rapidly and take over any bioregion into which they are introduced (Tobin 2018). Invasive plants, for instance, have been found to colonize large areas of terrestrial and aquatic ecosystems, which causes remarkable economic and ecological losses in a short period (Thomaz *et al.* 2015). In aquatic environments, the presence of invasive plants affects the quality and quantity of the water (Smith and Knapp 2011), disrupts ecological processes (Van Wilgen 2017), and increases the cost of treating water for domestic use (Turpie 2004). Invasive plants affect water quality and aquatic ecosystem health by altering the ecological stability of riverbanks and the volume and pollution levels in runoff (McCormick *et al.* 2009).

Theoretically, invasive plants are mostly dispersed into new habitats *via* natural migration, floods, storms, and other events (Eminniyaz *et al*. 2013). However, in some cases, humans may transport invasive plant species into aquatic bodies deliberately or accidentally. Indeed, anthropogenic activities have been recognized as a key pathway for the introduction of invasive plants into most water bodies (Tobin 2018). Agricultural activities and waste disposal are a remarkable anthropogenic source of invasive species in water bodies; they are an especially prevalent source in developing countries, where a large quantity of fresh untreated wastes from households and farm sources find their way into water bodies (Manfredi *et al.* 2010). In small quantities, invasive plants in water pose little threat. However, in large quantities, invasive plants become a serious nuisance, and they are injurious and problematic for users and managers of water resources.

Due to the known impacts of invasive plants in water, water resource managers are often concerned with the presence of any patch of invasive plants in their water system, and they employ various means in controlling their spread. The literature has shown that many of the conventional invasive plant control methods and techniques require immense capital and human resources with little or no noticeable success (Wong *et al.* 2017). However, recent advances in bioeconomic technology have made it possible to envision a new strategy to manage invasive plant species in water bodies by converting them into value-added products, such as compost, biochar, medicine, and biofuels, among others (Borokini and Babalola 2012). Invasive plant species have large potential for bio-resource exploitation due to their relatively high photosynthetic efficiency, fast growth, high carbohydrate content, lack of required cultivation land area, and lack of competition with food crops (Stratton and Goldstein 2001). The traditional usage of some invasive plants for cultural and aesthetic purposes has been documented, which provides an additional pathway for the removal and utilisation of aquatic invasive plants.

Despite the high resource potential of aquatic invasive plants and the prospects of their exploitation for socioeconomic benefits, such as livelihood improvement, income generation, and local economic development, limited knowledge and awareness regarding their beneficial uses are obstacles to their effective utilization. In the Owabi Dam located in the Atwima Nwabiagya District in the Ashanti Region of Ghana, different invasive plant species exist, but there is limited or no documented evidence on their benefits. However, as indiscriminate waste disposal and agrarian activities around the Owabi Dam continue, the growth and spread of invasive plants will create problems for the Ghana Water Company Limited's (GWCL) processing of the water from the dam for domestic use. This paper aims to identify and provide a comprehensive review of the utilisation potential of the available aquatic invasive plants in the Owabi Dam.

EXPERIMENTAL

Study Area (Owabi Dam)

This study was conducted at the Owabi Dam located in the Atwima Nwabiagya Northern District in the Ashanti Region of Ghana. The Owabi Dam is located at latitude 06-43 °N and longitude 01-36 °W with an altitude of 287 m. It is near the Akropong Esaase in the Atwima Mponua District of the Ashanti region of Ghana, and it was constructed in 1928 (Tetteh *et al*. 2004). The Owabi River comes together with seven tributaries to form the reservoir. The average area of the entire reservoir is 3.5 km^2 with an average depth of 6.9 m. The dam (reservoir) is a protected area under the management of the Ghana Water Company Limited (GWCL). The study focused on the dam itself and the marshland surrounding it where invasive plants are found.

Identification of invasive plants

An ecological survey was conducted throughout the Owabi Dam, and transect movement was performed to identify and take samples of different aquatic invasive plant species in the dam. All the identified aquatic invasive plants were harvested manually from the dam. The harvested plants were sorted into their respective species with the assistance of a skilled botanist. Then, they were washed to remove dust particles and packed into polythene bags. The plants were transported to the Botany Laboratory at the Department of Theoretical and Applied Biology of the Kwame Nkrumah University of Science and Technology (KNUST) (Kumasi, Ghana) for confirmatory identification. After each species was identified, the International Union for Conservation of Nature (IUCN) Global Invasive Species Database (GISD) (IUCN Invasive Species Specialist Group (ISSG) 2006) was consulted to confirm the invasive status of each species.

Bibliometric Review

Bibliometric studies of each of the different invasive plants in the Owabi Dam were conducted. The first step consisted of searching for all known beneficial and socioeconomic uses of aquatic invasive plants published in journals and available from open-access electronic databases and search engines, which included Science Direct, Emerald, Sage, and Google Scholar. Phrases such as “beneficial uses,” “economic value,” “sociocultural/socioeconomic value,” “utilization,” “exploitation,” “medicinal use,” and their synonyms were searched with the names of invasive plants across different databases. After identifying all known beneficial and socioeconomic uses of aquatic invasive plants, the benefits were grouped into three thematic areas *viz*, medicinal uses, bioeconomic uses, and cultural and aesthetic uses. A further search was then conducted using the identified invasive plants to find studies that have documented the usage of the identified aquatic invasive plants under each of the three thematic areas.

RESULTS AND DISCUSSION

Invasive Plants in the Owabi Dam

From the ecological survey at the Owabi Dam, seven aquatic invasive plant species were identified, namely *Ceratophyllum demersum*, *Nymphaea odorata*, *Polygonum lanigerum*, *Arthropteris orientalis*, *Typha domingensis*, *Pistia stratiotes*, and *Cyperus papyrus*. Brief botanical descriptions of each of the identified aquatic invasive plants are as follows:

Ceratophyllum demersum (hornwort, rigid hornwort, coontail, or coon's tail): *C. demersum* (Fig. 1) belong to the family Ceratophyllaceae and is a submerged, cosmopolitan, free-floating aquatic plant that has perennial macrophytes without any roots. It is monoecious, pollinated by water, and known to grow fast in shallow, muddy, quiescent water bodies at low light intensities. The plant is found in ponds, lakes, and rivers with temperatures of 15 °C to 30 °C and a rich nutrient status (USDA PLANTS 2011). *C. demersum* has allelopathic qualities that inhibit the growth of phytoplankton and cyanobacteria (blue-green algae). Its most notable negative consequences have occurred in New Zealand, where it has caused problems with hydroelectric power plants (NIWA 2005). *C. demersum* is native to all continents except Antarctica, it is declared a weed under the Tasmanian Weed Management Act (1999) in Tasmania, Australia, and classed as an unwanted organism in New Zealand (Ministry of Primary Industry (MPI) Biosecurity New Zealand 2012; Global Invasive Species Database 2020).

Fig. 1. *Ceratophyllum demersum*

Nymphaea odorata (water lily): *N. odorata* is an aquatic plant that belongs to the family Nymphaeaceae. The *N. odorata* plant (Fig. 2.) is rooted from a branched rhizome that gives rise to its long petioles that terminate in a smooth, floating, round leaf with a waxy, water-repellent upper coating. The flowers of *N. odorata* also float and are radially symmetric with prominent yellow stamens and many white petals. The flowers open each day, close each night, and are very fragrant.

Fig. 2. *Nymphaea odorata*

Once the flowers are pollinated, the developing fruit is pulled back underwater for maturation. It has a cosmopolitan distribution and is common in shallow lakes, ponds, and permanent slow-moving waters, and it has been declared an invasive weed (Northey 2014). *N. odorata* is featured in the databases of the Center for Aquatic and Invasive Plants of the University of Florida (2018) as an aquatic invasive plant native to Florida (Langeland *et al*. 2006). It can be found commonly throughout North America, where it ranges from Central America to northern Canada, and its presence has also been reported in Brazil and Guyana (Stevens *et al.* 2001).

Polygonum lanigerum (knotweed): *P. lanigerum* is a perennial herbaceous plant that is rarely shrubby and has many branched stems. The leaves of *P. lanigerum* (Fig. 3) are arranged alternately, and they are usually less than 2 cm (0.8 in) long with a length greater than the width. They have a membranous ochrea (a sheath around the stem nodes). The flowers are usually bisexual, rarely unisexual, and have five tepals, the outer of which is slightly different from the inner ones. There are usually four to six stamens and three styles, though there are two styles in some rare situations. *P. lanigerum* belongs to the family Polygonaceae, and the produced fruit is three-sided (Ortiz *et al*. 2008). *P. lanigerum* has a cosmopolitan distribution, particularly in the temperate regions (Maha *et al*. 2014), and it has been declared a weedy and invasive aquatic plant in the USA (Cusick and Ortt 1987).

Fig. 3. *Polygonum lanigerum*

Arthropteris orientalis (Msasa fern): *A. orientalis*, locally known as Msasa fern, belongs to a small genus of ferns in the family Tectariaceae. It is a creepy plant that has rhizomes up to 3 mm in diameter with broad scales that are ovate to circular in outline and are up to 1.5 mm long and dark brown. *A. orientalis* (Fig. 4) was thought to have originated from the East (Australia) and was therefore named accordingly. It is usually found in rocky areas in open deciduous woodland in dappled shade and seasonally wet grassland with scattered trees. *A. orientalis* is widely distributed in Australia, Europe, Asia and Africa, and they are particularly numerous in Yemen, Réunion, Madagascar, and Mauritius (Robinson 1991). The *Arthropteris orientalis* is a species of the family Tectariaceae that is an invasive weed; these plants can establish themselves well in disturbed habitats (Perrings *et al.* 2005), and they are mostly found in disturbed areas, such as farms, impoundments, and settlement areas.

Fig. 4. *Arthropteris orientalis*

Typha domingensis (Cattail): *T. domingensis* is an aquatic plant from the family Typhaceae. It is a perennial monoecious plant that grows up to 3 m (9 ft 10 in) and is pollinated by wind. It prefers wet soil and can grow in soil characterized as saline, acid, neutral, and basic. In addition, it can grow in water. *T. domingensis* requires a rich wet soil to do well. It can grow in sun or partial shade and is highly invasive, spreading freely at the roots when in contact with a suitable medium. *T. domingensis* aggressively invades and forms nearly pure stands in brackish to fresh marshes and pools common in North America, where it is believed to have originated (Fig. 5). *T. domingensis* is widespread in the tropics, subtropics, and warm temperate regions. It has been found in some African countries, including Ghana, Ethiopia, Guinea, and Zambia. In addition, it has been found in Central America, North America, South America, Asia, and Australia.

Fig. 5. *Typha domingensis*

Pistia stratiotes (water lettuce, water cabbage, Nile cabbage, or shellflower): *P. stratiotes* is a floating, stoloniferous herbaceous plant that grows in ponds and streams. It has green, odourless, and bitter leaves. The leaves (Fig. 6) are approximately 13 cm long and 17 cm wide, they are fan-shaped and have parallel venation, blunt apex, and have entire margin (*i.e.* margin without serrations). It belongs to the family Araceae with an uncertain native distribution, but it is probably pantropical, as it was first discovered from the Nile near Lake Victoria in Africa. Through human introduction, *P. stratiotes* is now appearing in nearly all fresh waterways in the tropics and sub-tropics. It is a productive freshwater aquatic plant and is considered an invasive species (Muniappan *et al.* 2009). In waters with high nutrient content, especially those particularly contaminated with sewage or fertilizers from human activities, water lettuce can often exhibit weedy overgrowth behavior; therefore, it is a common weedy plant in hydrologically altered systems, such as canals and reservoirs (Kasulo 2000).

Fig. 6. *Pistia stratiotes*

Cyprus papyrus (Papyrus sedge, Nile grass): *C. papyrus* is a species of aquatic flowering plant that belongs to the sedge family (Cyperaceae). It is a tender herbaceous perennial native to Africa, and it forms tall stands of reed-like swamp vegetation in shallow water.

Fig. 7. *Cyperus papyrus*

As an aquatic plant, *C. papyrus* is robust, leafless, and can grow 4 m to 5 m high. It usually forms grass-like clumps of triangular green stems that rise from its thick, woody rhizomes. Each stem of *C. papyrus* (Fig. 7) is topped by a dense cluster of thin, bright green, thread-like stems of 10 cm to 30 cm in length. *C. papyrus* is a fast-growing perennial sedge native to central Africa and the Nile Valley, and has been introduced, often as an ornamental species, to other warm parts of the world.

According to the Centre for Agriculture and Bioscience International (CABI) (2004), *C. papyrus* is an invasive plant that is a serious threat to ecosystems and impedes the flow of waterways. *C. papyrus* is highly invasive within and outside its native range, highly mobile locally, fast growing, and highly reproductive. In Ghana, *C. papyrus* is reported as an introduced species (CABI, 2004; Ernest 2015) and has been found in places such as Kpong Headpond, Silicon Hotel, Kumasi, and Accra.

Potentially Beneficial Values of Aquatic Invasive Plants in the Owabi Dam

From a review of literature on the identified aquatic invasive plants in the Owabi Dam, their utilisation potentials were identified and outlined under three themes: medicinal potency, bioeconomic usage, and cultural and aesthetic usage.

Medicinal Potency

Historically, invasive plants are known to have medicinal properties and hence have been used for the treatment of various ailments. The suitability of invasive plants for medicinal use is supported by their phytochemical constituents and biologically active chemical or natural products, such as alkaloids, glycosides, flavonoids, terpenoids, tannins, and steroids (Rashmi and Rajkumar 2011). From the review presented in Table 1, almost all the identified invasive plants (*i.e.*, *C. demersum*, *N. odorata*, *P. lanigerum*, *A. orientalis*, *T. domingensis*, and *P. stratiotes*) have reported analgesic and antimicrobial uses. Many invasive plants have a noticeable amount of aspirin, morphine, codeine, and thebaine (paramorphine), which gives them high analgesic potency and curative uses. Some of the aquatic invasive plants, especially *C. demersum*, have allelopathic compounds to defend against feeding (NIWA 2005). Many of the allelopathic compounds produced by invasive plants tend to be effective in the treatment of infections and ailments, thereby improving the medicinal uses and curative potential of invasive plants.

Aside from the analgesic uses of invasive plants, the results in Table 1 show that invasive plants are also used as antimicrobials (Kakarla *et al.* 2014), anti-inflammatory medicine (Karale *et al.* 2013; Syed *et al.* 2018), diuretics (Bansal *et al.* 2019), tonics (Jain 2017), antimalarial drugs (Oladimeji *et al.* 2008; Ma *et al.* 2019), and antidermatophytic medication (Premkumar and Shyamsundar 2005), among others. Before the scientific exploitation of invasive plants for their phytochemical constituents as medicine, local knowledge was available on the usage of some invasive plants for medicinal purposes. Abu (2015), Karataş *et al.* (2014), and Taranhalli *et al.* (2011) all presented evidence of local uses of invasive plants, such as *C. demersum* for the treatment of wounds, fever, burning sensation, and piles, among others. The leaves of *T. domingensis* have also been used as a diuretic in Chinese medicine (Duke and Ayensu 1985), and nose bleeds, hematemesis, hematuria, uterine bleeding, dysmenorrhea, and postpartum abdominal pain were also treated with the pollen of *T. domingensis* (Yeung 1995). Seeds and rootstock of the *T. domingensis* have also been used in treating haemostatic conditions in human (Duke and Ayensu 1985) and as a diuretic (Chopra *et al*. 1986).

In addition, *Pistia stratiotes* is used as "Tridosha," which is a treatment for fever and diseases of the blood. The leaves of *P. stratiotes* have been used for curing kidney afflictions, hematuria, dysentery, and anemia, among other issues (Tripathi *et al.* 2010). *C. demersum* also has local medicinal uses in Chinese medicine for cooling, antiperiodic, treatment of biliousness, and scorpion stings (Yeung 1995). It emerged from the study that curative/medicinal uses of invasive plants are most common in China, India, Bangladesh, Australia, and many North American countries, whereas they are still obscure in Africa. The disparity in medicinal usage of invasive plants globally is due to disproportionate knowledge and awareness of the curative properties and the techniques for converting invasive plants into finished products for use as medicines.

Table 1. Medicinal Uses of Invasive Plants Identified in the Owabi Dam

Invasive Plants	Medicinal Uses	References
Ceratophyllum demersum	Analgesic	Karale *et al*. (2013); Malathy and Stanley (2015); Syed *et al.* (2018)
	Antimicrobial	Fareed *et al.* (2008)
	Anti-inflammatory	Karale *et al*. (2013); Syed *et al.* (2018)
	Cooling agent	Khare (2004)
	Diuretic	Zhang *et al.* (2013)
	Wound healing, fever, pills	Taranhalli *et al.* (2011); Karataş *et al.* (2014)
	Tonic (cardio-tonics)	Syed *et al.* (2018)
Nymphaea odorata	Analgesic	Selvakumari et al. (2016)
	Antimicrobial	Oladimeji *et al*. (2008)
	Antimalarial	Oladimeji *et al*. (2008)
	Tonic	Singh and Jain (2017)
	Narcotics	Emboden (1981)
	Diuretic	Selvakumari *et al*. (2016)
	Aphrodisiac	Selvakumari *et al*. (2016)
Polygonum lanigerum	Analgesic	Saha *et al*. (2005)
	Anti-inflammatory	Saha *et al*. (2005)
	Diuretic	Saha *et al*. (2005)
Arthropteris orientalis	Analgesic	Syed *et al.* (2018)
Typha domingensis	Analgesic	Islam *et al*. (2015)
	Nose bleeds, dysmenorrhoea	Yeung (1995)
	Haemostatic conditions (bleeding)	Duke and Ayensu (1985)
	Diuretic	Bansal *et al*. (2019)
Pistia stratiotes	Analgesic	Kumar *et al*. (2011)
	Antimalarial (larvacides)	Ma *et al*. (2019)
	Antidermatophytic	Premkumar and Shyamsundar (2005)
	Treating ulcer, leprosy, and eczema	Khan *et al*. (2014)
Cyperus papyrus	Antimicrobial uses	Kakarla *et al*. (2014)

In Africa, few cases of aquatic invasive plants used for medicinal purposes have been reported. In Southern Africa, Maema *et al*. (2016) reported the use of some invasive plants, such as *Schinus molle* (L.) and *Catharanthus roseus* (L.), by communities to treat various ailments in humans. The use of the identified invasive plants in the Owabi Dam (*C. demersum*, *N. odorata*, *P. lanigerum*, *A. orientalis*, *T. domingensis*, *P. stratiotes*, and *C. papyrus*) for medicinal purposes is not common, despite their abundance. Among the invasive plants identified, only those of the family Cyperaceae (*C. papyrus*) have known medicinal uses in Ghana (Boadu and Asase 2017). As such, the many other invasive plants with potent medicinal properties have not yet been discovered in Ghana.

Bioeconomic Usage

Many invasive plants have demonstrable potential as feedstocks to produce value-added biobased items, materials, and services. Chemical, mechanical, and biological transformation of the biomass of invasive plants into various useful products of economic importance have been reported. The identified bioeconomic uses of invasive plants as summarized in Table 2 show that invasive plants have been used in biogas, biodiesel, and bioethanol production (Pastare *et al.* 2015; Kaur *et al.* 2018; Kusolsongtawee *et al*. 2018). In addition, they have been used in the production of botanical insecticides (Dogan *et al*. 2017; Koranteng *et al*. 2018), biofertilizer, compost, and potash (Aboohanah and Yeaser 2018). Further, invasive plants have been used to produce paper and related products (Leach and Tait 2000), among others. The various bioeconomic uses identified indicate that invasive plant valorization is a potential source of income. A study by Tardivel (2018) observed that, in the Pacific Island Countries and Territories, valorization of several invasive species has provided much economic opportunity for households and communities.

Table 2 also shows the usage of invasive plants for phytoremediation and heavy metal removal (Essuman 2013), biological life support (Voeste *et al.* 2003), and wastewater purification (Foroughi *et al*. 2010; Mburu *et al.* 2015; Rusnam 2016). These studies, among others, have demonstrated the enormous potential of the bioeconomic usage of the identified invasive plants globally. According to Tardivel (2018), market incentives for invasive plant control is currently gaining attention globally as a result of the realization of the enormous potential of invasive plants as feedstock for biobased product development. Many invasive plants that were considered nuisances are now recognized as valuable bioresources (Van Meerbeek *et al*. 2015).

Several industrial and agro-industrial applications of invasive plants have been reported, which demonstrate their high bioeconomic value. Invasive plants have been utilized as a feedstock to produce compost (Kanwal *et al*. 2011), biochar (Liu *et al*. 2019), potash/manure (Polthanee *et al.* 2015), and other bio-based products that have high agrarian and industrial relevance. Two of the aquatic invasive plants identified in the Owabi Dam (*P. stratiotes* and *C. demersum*) have been previously used as feedstocks for compost production (Kanwal *et al.* 2011; Aboohanah and Yeaser 2018), and nearly all have demonstrable success as feed for livestock, poultry, and fish production (Huxley and Griffiths 1992; Atala 2012; Ekunseitan *et al*. 2013; Essuman 2013; Mohammed *et al.* 2015).

Many invasive plants have high nutrient content, which includes crude fibre, lipids, protein, and carbohydrates; therefore, they are suitable for human consumption, use as feed, and use as a feedstock for conversion into valuable bio-based products (Stephen *et al*. 2017). The seeds of *T. domingensis*, for instance, contain high linoleic acid and are therefore used to feed cattle and chickens (Reed and Marsh 1955). Three of the aquatic invasive plants found in the Owabi Dam (*N. odorata*, *P. lanigerum*, and *T. domingensis*) are reportedly used for human consumption in Turkey and other places (Lim 2016; Stephen *et al.* 2017; Kayabaş *et al.* 2018). These observations demonstrate that invasive plants can be used both as feed for animals and human consumption. According to Huth *et al.* (2018), the consumptive potential of many invasive species is high, and they are more market competitive due to their “environmentally friendly” nature.

Table 2. Bioeconomic Usage of Invasive Plants Identified in the Owabi Dam

Invasive Plants	Bioeconomic Uses	References
Ceratophyllum demersum	Remediation of dumpsites	Stilinovic and Hrenovic (2000)
	Biological life support	Voeste *et al.* (2003)
	Heavy metal adsorption	Keskinkan *et al*. (2004)
	Bioethanol production	Kusolsongtawee *et al*. (2018)
	Water/sewage purification	Foroughi *et al*. (2010)
	Biomethane/biogas/bioenergy	Pastare *et al*. (2015); Kaur *et al.* (2018)
	Biofertilizer (liquid fertilizer)	Aboohanah and Yeaser (2018)
	Pesticide and botanical insecticides	Koranteng *et al*. (2018)
	Biochar production	Liu *et al*. (2019)
	Bioindicator for heavy metals	Polechońska *et al*. (2018)
Nymphaea odorata	Wastewater purification	Rusnam (2016)
	Bio-indicator of water quality	Polechońska *et al*. (2018)
	Food crop (young leaf)	Stephen *et al*. (2017)
	Fish feed	Mohammed *et al*. (2015)
Polygonum lanigerum	Eaten in parts of central Turkey	Łuczaj (2008); Kayabaş *et al.* (2018)
	Used as anti-feedant and insecticide	Quesada-Romero *et al*. (2017)
	Fodder/animal feed	Ekunseitan *et al*. (2013)
Arthropteris orientalis	Phytoremediation of heavy metals	Essuman (2013)
	Animal feed/fodder	Essuman (2013)
Typha domingensis	Bioethanol production	Grosshans (2014)
	Edible to humans	Lim (2016)
	Paper production	Colbers *et al.* (2017)
	Diapers, baby powder, and cradleboards	Jahan *et al.* (2007); Bidin *et al*. (2015)
Pistia stratiotes	Biogas production	Nipaney and Panholzer (1987)
	Eaten in soup preparation	Ruffo *et al*. (2002)
	Used as insecticides	Ito *et al*. (2015)
	Cover for spawning fish in fish farming	Huxley and Griffiths (1992)
	Manure (potash)	Polthanee *et al*. (2015)
	Feedstock for compost	Kanwal *et al*. (2011)
Cyperus papyrus	Production of bioethanol	Lim (2016)
	Biomass briquette production (biofuel)	Morrison *et al*. (2014); Jones *et al*. (2018)
	Wastewater purification	Mburu *et al*. (2015)
	Phytoremediation of heavy metals	Jomjun *et al*. (2010); Mburu *et al*. (2015)
	Usage in the production of paper	Leach and Tait (2000)
	Food and feed/fodder for animal	Atala (2012)

Although valorization of invasive plants is not entirely new, the recent appeal and interest in circular economy approaches and sustainable production in line with the United Nations Sustainable development goals (SDGs) (UN General Assembly 2015) have resulted in the increasing emergence of technologies and strategies that promote bio-based product development from invasive plants and other materials. Tardivel (2018) noted that native or endemic species are increasingly threatened by human economic activities, and as such, invasive alien species with similar potentials are now exploited for their bioeconomic and market potential. In addition, there is interest in scientific discovery of the suitability and potential of various invasive plants for bioeconomic exploitation. For instance, *T. domingensis* is a well-known bioenergy crop used as a source of starch to produce ethanol (Dubbe *et al.* 1988). Moerman (2010) also reported the use of *T. domingensis* as an alternative to cotton and linen in the clothing industry. Based on these findings, it can be inferred that the invasive plants found in the Owabi Dam have high bioeconomic resource potential, although reports on local usage is still obscure, and quantification of the potential is still lacking.

Cultural and Aesthetic Usage

Beyond the medicinal and bioeconomic usage of invasive plants, there is abundant evidence indicating their cultural and aesthetic values. As presented in Table 3, this includes usage as cultural symbols, ornamental pot plants, architectural motifs, and decorations.

Table 3. Cultural and Aesthetic Usage of Aquatic Invasive Plants Identified in the Owabi Dam

Invasive Plants	Cultural and Aesthetic Uses	References
Ceratophyllum demersum	Aquarium plants	Syed *et al*. 2018
Nymphaea odorata	Ornamentals plants	Stephen *et al*. (2017)
	Symbols of fertility gods/goddess (ancient Egypt)	Tresidder (1997)
	National flower of Sri Lanka and Bangladesh	Jayasuriya (2011)
	Architectural motifs and decorations	Tresidder (1997)
	Decorative container storage containers	Comedis *et al*. (2017)
Polygonum lanigerum	-	-
Arthropteris orientalis	Ornamental plants	Aboohanah and Yeaser (2018); Addo-Fordjour *et al.* (2007)
Typha domingensis	Thermal insulation in buildings	Colbers *et al.* (2017)
	Tinder for starting fires	Moerman (2010)
	Stuffing material for pillows, mattresses, and toys	McPherson and McPherson (1977)
Pistia stratiotes	Ornamental plants in water gardens	Chapman *et al*. (2017)
Cyperus papyrus	Ornamental or pot plants	Atala (2012)
	Making mats, fences, hats, and botanical beads	Atala (2012)

Tresidder (1997) reported that in ancient Egypt, *N. odorata* was used as a lotus motif and to symbolize fertility gods and goddesses. The flower of *N. odorata* is also the national flower of Sri Lanka and Bangladesh (Jayasuriya 2011). Thus, in these countries, *N. odorata* is a plant of cultural importance.

In some communities, invasive plants, such as *C. papyrus*, are used in handcraftsmanship for making mats, fences, hats, and botanical beads (Atala 2012). According to Dos Santos *et al*. (2014), invasive plants within the semi-arid area of northeastern Brazil are culturally important, as they are used in local craftsmanship for constructing houses, hats, and beds, among other things. For local native tribes around Lake Titicaca in Peru and Bolivia, *T. domingensis* is a valuable plant for cultural activities, which include its use for the thermal insulation of local buildings (Colbers *et al.* 2017) and making storage containers (Comedis *et al*. 2017), mats, fences, hats, and botanical beads (Atala 2012). The aesthetic and cultural value of invasive plants constitute additional competitive beneficial uses.

Management Issues

While the findings show that the identified invasive plants have various utilisation potentials, a number of management issues need to be addressed to ensure efficient harnessing of them for the various benefits. To prevent a situation whereby local indigene may propagate the invasive plants elsewhere due to their economic benefits, public education on the negative impacts of the invasive plants on water resources and farmlands should be carried out. The local district assembly together with local authorities can also be persuaded to enact byelaws that prohibit deliberate propagation of invasive plants in the district. To address occupational health risk that may be associated with harvesting of the invasive plants by the local inhabitants also, only the trained "water workers" at the Owabi dam should be allowed to undertake harvesting for anyone that intent to utilize any invasive plant in the dam. For any reason if local inhabitants should engage in harvesting of the invasive plants in the Owabi dam, this should be proceeded by effective and use of the necessary personal protection equipment (PPE).

CONCLUSIONS

1. The environmental, economic, and health impacts of aquatic invasive plants have been widely reported in many studies.
2. Competitive beneficial uses of various invasive plants species based on local knowledge and emerging bio-based technology have also been found.
3. The findings make clear that the invasive plants have medicinal uses, bioeconomic potential, and cultural and aesthetic values.
4. If appropriately harnessed, invasive plants could contribute to the development of the local economy, provide employment, and reduce poverty in several locations.
5. Given that the dam is a protected area, harvesting activities should be regulated such that reintroduction of aquatic invasive plants (AIPS) or their cultivation anywhere else due to their economic benefits is prohibited.
6. Also only professionally trained "water workers" of the Ghana Water Company Limited (GWCL) should handle the harvesting of the invasive plants for users to prevent occupational injuries.
7. Further studies should focus on the quantification of the bioresource potential and analysis of implementation strategies for utilizing the invasive plant species.

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