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REVIEW PAPER

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Tropical Asian mega-delta ponds: Important and threatened socio-ecological systems

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Abstract

This paper uses multimedia to showcase the narratives and lived experiences of those who live and work in tropical Asian mega-deltas, and as such is the first journal article of its kind in the field of Regional Geography. Using videos, photography and audio this paper describes the characteristics of ponds and their place in the intrinsically connected human-environmental fabric of these delta regions. The aim is to bring to life descriptive inventories and provide greater weight in support of our conclusion that tropical Asian mega-delta ponds are important and threatened systems. River deltas comprise just 1% of land cover worldwide but support the livelihoods of more than 500 million people. Delta research has historically focused on the major river channels and the socio-ecological role of ponds has been overlooked despite their large number and surface area. Ponds are intrinsically linked to daily life (potable water, sanitation, bathing, washing), industry (aquaculture, agriculture) and the natural-cultural heritage (religion,

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folklore) of deltas. In contrast to the larger river channels, ponds are likely to be significant stores and processors of nutrients, including carbon, and pollutants at annual to decadal scales, on account of their heavy anthropogenic use and smaller individual sizes. Consequently, they are severely polluted water sources and pose significant public health risks. In this review, we use case studies from three Asian mega-deltas (the Red River Delta and the Mekong River Delta, Vietnam, and the Ganges-Brahmaputra-Meghna Delta, India and Bangladesh) to highlight the importance of Asian mega-delta ponds as important socio-ecological systems in their own right. We discuss future environmental challenges, knowledge gaps on the ecological function and biodiversity of these habitats, management and policy practices, and the capacity of ponds to achieve the UN Sustainable Development Goals.

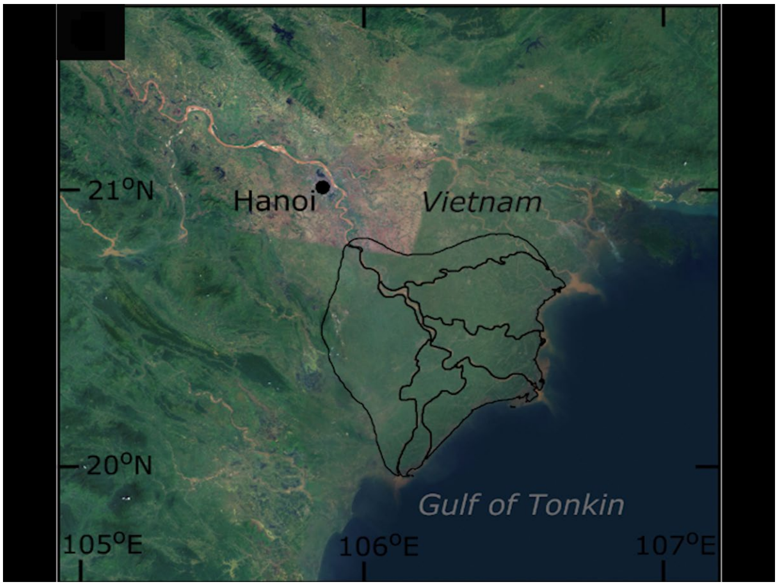
1 | INTRODUCTION

This review article is one of the first in Regional Geography to use multimedia as a tool for a deeper sensory exploration of our topic of interest: tropical Asian mega-delta ponds. River deltas are important socio-ecological ecosystems, a term that acknowledges the complex link between human and natural systems, whose governance and regulation are influenced by external social and economic institutions, as well as environmental pressures (Berkes & Folke, 1998; Colding & Barthel, 2019). By using audio and visual stimuli, namely multiple delta voices and imagery, we hope to connect the reader more strongly and simplify the complexity of the multiple social and environmental landscape settings and the multi-functionality of deltas and delta ponds. The use of different narratives and sensory tools allows us to do this more effectively than text alone, thus subverting the tendency.

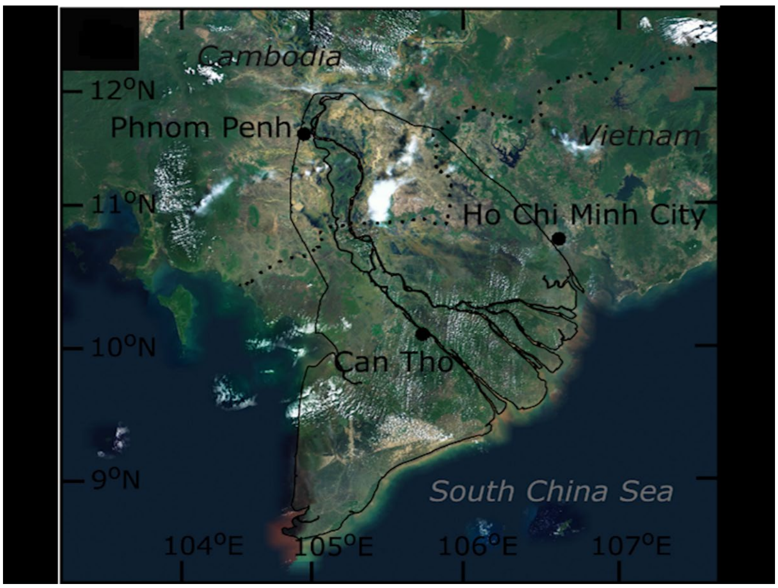
Deltas typically possess vast and dense networks of waterways and the close connectivity between the terrestrial and aquatic components of deltas makes them some of the most agriculturally productive and biologically diverse ecosystems, attracting human settlement on delta plains for millennia (Stark, 2006). River deltas comprise 0.56% of global land cover yet contain 4.1% of the world's population, with more than 250 million people living in the nine Asian mega-deltas (Edmonds et al., 2017; Woodroffe et al., 2006). Asian mega-deltas are consequently one of the most densely populated and rapidly urbanising environments in the world. We will focus on examples from three densely populated and environmentally vulnerable mega-deltas of South and Southeast Asia: the Red River Delta, Vietnam (Video 1a), the Mekong River Delta, Vietnam (Video 1b), and the Ganges-Brahmaputra-Meghna (GBM) Delta, India and Bangladesh (Video 1c).

Deltas offer a range of ecosystem services to global, national, regional and local societies, for example the Vietnamese Mekong and Red Rivers are the second-largest global exporters of rice. However, these ecosystems are increasingly at risk from the intensification of human activity, population growth, sea-level rise, and climatic variability. Most research on anthropogenic pressures in Asian mega-deltas has focused on the major river channels and canal drainage networks (e.g., Anthony et al., 2015; Best, 2019; Bowes et al., 2020; Chan et al., 2012; Kondolf et al., 2018; Pokhrel et al., 2018; Wilbers et al., 2014). This is due to the provision of services (e.g., fisheries, transport, energy, industry, and irrigation), water quality concerns (e.g., faecal pollution and eutrophication) and their spiritual importance (e.g., religious bathing ceremonies such as the annual *"Gangasagar Mela"*) (Bowes et al., 2020). However, there has been less research focus on Asian mega-delta ponds despite their widespread coverage and integral role in daily delta life as introduced in Video 2. The narrator describes a typical homestead pond in GBM India used for bathing, washing and pisciculture but other pond uses can include potable water supply, sanitation, aquaculture, irrigation, fertiliser, and water storage.

As the narrator in Video 2 explains, ponds are multifunctional landscapes, used by different people in different ways at different times of the year. To capture that multiplicity, we have adopted a multimedia approach. Combining video and audio narration of still photography not only enabled us to provide a richer and more evocative account of delta landscapes and the role of delta ponds in local livelihoods, it also provided a way to give voice, quite literally in some cases, to the local knowledge of our international collaborators involved in the UKRI GCRF Living Deltas Hub. The Living Deltas



VIDEO 1A Video introducing the Red River, Vietnam. Narrated by Bui Van Anh, Ministry of Labour, Invalids and Social Affairs (MOLISA) (2021). Map created using QGIS and data from http://www.globaldeltarisk.net/data.html. Photographs courtesy of S. McGowan, taken on fieldwork as part of NERC-NAFOSTED Research Partnerships NE/P014577/1: Assessing human impacts on the Red River system, Vietnam, to enable sustainable management. Video produced by H. Moorhouse. Running time 02:24s.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103



VIDEO 1B Video introducing the Mekong River Delta, Vietnam. Narrated by P. Nguyen Tanh (2021). Map created using QGIS and data from http://www.globaldeltarisk.net/data.html. Photographs courtesy of A. Large, A. Henderson, V. Panizzo, taken on the Living Deltas Hub Scoping Visit 2019. Video produced by H. Moorhouse. Running time 02:03s.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

Hub is a collective of over 100 international researchers who live and/or work in the Vietnamese Mekong and Red River Deltas and the Indian and Bangladesh GBM delta. Methodologically our paper combines non-systematic methods of desk-based literature review with materials collated from past field trips. An initial draft was produced during the early months of lockdown from the COVID-19 pandemic. Then as the manuscript developed and restrictions were lifted, we were able to solicit additional video footage and voice over materials from our delta Hub colleagues to bring to life details of local landscapes and livelihoods. It is hoped this process brought more authenticity to the narratives we relate, but we

VIDEO 1C Video introducing the Ganges-Brahmaputra Meghna Delta, India and Bangladesh. Narrated by M. F. Rahman (2021). Map created using QGIS and data from http://www.globaldeltarisk.net/data.html. Photographs courtesy of A. Henderson, A. Majumdar, H. Moorhouse, taken during Living Deltas Hub Scoping Visits 2019. Video produced by H. Moorhouse. Running time 02:58s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

VIDEO 2 Video introducing the uses, owners and quality of a water storage pond, in Satjelia Island, Indian Sundarbans. Narrated by T. Ghosh (2020). Photograph provided by T. Ghosh. Video produced by H. Moorhouse. Running time 00:38s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

acknowledge its biases too. While the multiplicity of views and voices included herein helps, at least in part, to subvert our singular authority as western scientists (Clifford, 1983), it is nevertheless selected and choreographed by two white British-born and educated early career researchers working as part of a large international project in a somewhat privileged position. It is also important to recognise that the range of views and voices included in our multimedia clips were all provided by in-country academic collaborators and researchers, rather than from those actually living in the coastal deltas themselves.

2 | ASIAN MEGA-DELTA PONDS

Unlike other delta socio-ecological systems, ponds are accessed by most delta community members, possess a high economic value (in respect to aquaculture), and are multi-functional sites for different tiers of society (Fu et al., 2018). The heavy societal reliance on ponds and close proximity to anthropogenic activities, alongside the ubiquitous socio-environmental risks of deltas as a whole, has resulted in delta ponds being "hotspots" of serious human and biodiversity health risks, including environmental degradation, disease, and entrenching gender inequality and poverty.

Currently, no classification of ponds in tropical Asian mega-deltas exists. For the purposes of this review, we adapt the Ramsar definition of ponds and describe delta ponds as standing permanent/ephemeral, fresh/brackish/saline waterbodies, which are predominantly artificial in origin and often below 8 ha (Ramsar Convention Secretariat, 2010). Most delta ponds facilitate the capture of rainwater during the monsoon (Dubey et al., 2017), acting as a vital source and replenishment of freshwater as highlighted by the increased water levels in the seasonal imagery and timelapses of Figure 1 and Video 3.

Groundwater (Kale, 2017) or tidal exchange (Johnston et al., 2002) are also used as primary water sources depending on intended pond use. We use the term ephemeral to account for seasonally dependent monsoon-fed ponds, which typically form most homestead and community delta ponds. Regardless of primary water source, monsoonal inputs drive changes in pond water levels and volume, thus influencing the concentrations of natural and anthropogenic materials in these systems.

With this definition, delta ponds cover a large land area; in the 1980s tidal aquaculture ponds alone accounted for 1.3 million ha in Southeast Asia (Macintosh, 1983) and several initiatives since 2000, including resolution 09/2000/NQ-CP, a Vietnamese government initiative to convert saline, low productivity rice fields into shrimp farms (Binh et al., 2005; Central committee of the Communist Party Vietnam, 2000; Vuong & Lin, 2001), have significantly increased the number of ponds over the past 40 years in Vietnam. Bangladesh alone has nearly 2.5 million ponds of different sizes, constituting a total surface area of approximately 0.3 million ha (Dey et al., 2008). In Europe, large concentrations of ponds, termed pondscapes, are biodiversity "hotspots" that contribute more to catchment-wide aquatic biodiversity than lakes, streams, and rivers individually (Davies et al., 2008; EPCN, 2008). Whilst evidence supports the existence of tropical Asian delta pondscapes on account of their number and land area, their contribution to biodiversity and role in supporting ecosystem

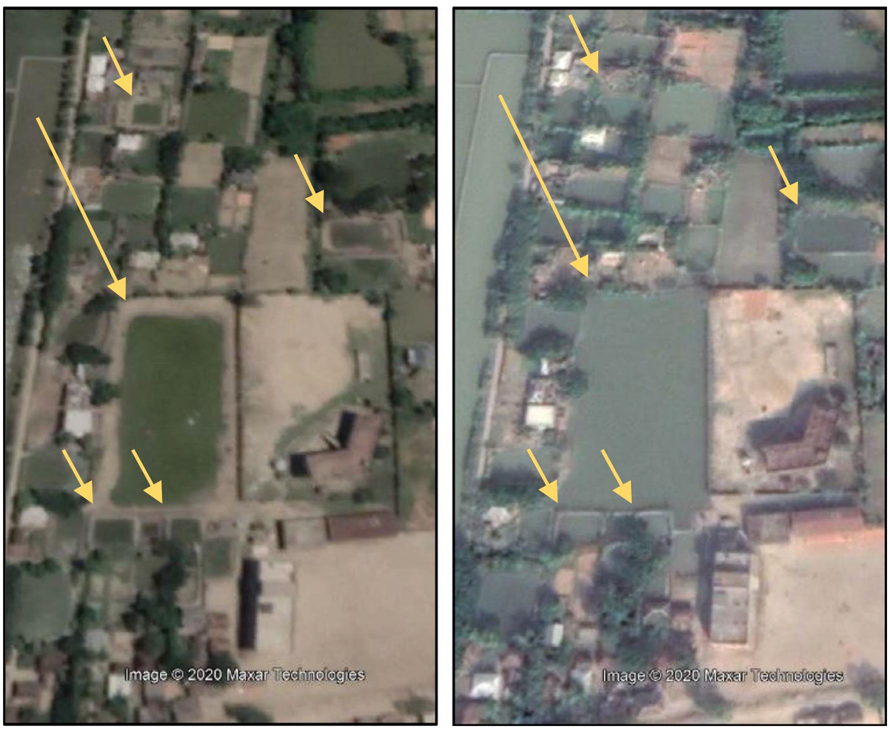
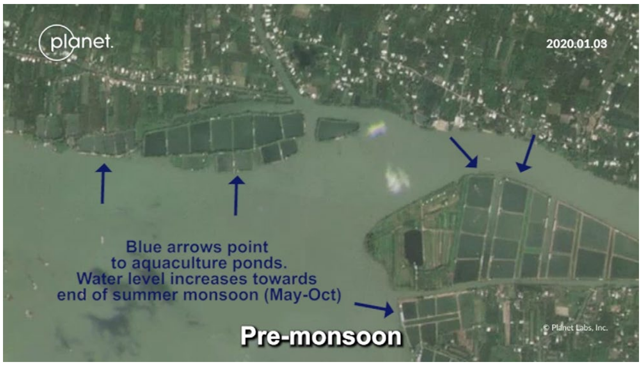


FIGURE 1 Google Earth © images showing ponds (shown by yellow arrow) in Dakshin Bedkasi, Khulna district, Bangladesh pre- (07/06/2018) and post-monsoon (22/12/2018) highlighting the importance of monsoon delivered freshwater to these water systems. Image locations: 22°12'43.65" N, 89°19'05.98"E, and elevation: 3m. Eye altitude: 356m

VIDEO 3A Time-lapse of aquaculture ponds created using PlanetScope Imagery, courtesy of Planet Labs, Planet Team (2018). Planet application program interface: In space for life on Earth. Planet Labs, San Francisco, CA. https://api.planet.com. Videos produced by C. Hackney and H. Moorhouse. (a)Time-lapse of aquaculture ponds from Moth Bari, Khulna District, Ganges Brahmaputra Meghna Delta, Bangladesh (22°23’16.16”N, 89°19’32.57”E) from 25/01/2020 - 07/12/2020. The ponds are the square structures found in a vertical strip (in centre of frame) below the Koyra River. Increased water level visible during summer monsoon season (June to September) shown in images taken 06/06/2020 and 03/09/2020. Running time 00:10s.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103



VIDEO 3B Time-lapse of aquaculture ponds created using PlanetScope Imagery, courtesy of Planet Labs, Planet Team (2018). Planet application program interface: In space for life on Earth. Planet Labs, San Francisco, CA. https://api.planet.com. Videos produced by C. Hackney and H. Moorhouse. (b) Time-lapse of aquaculture ponds in the Chợ Lách District, Ben Tre province, Mekong Delta, Vietnam (10°15’49.60”N, 106°02’27.37”E) from 03/01/2020 – 28/11/2020. The ponds are the square structures on the top and bottom of the small peninsulas in the Cổ Chiên river channel. Increased water level in the ponds is most notable on the image taken on 28/11/2020, following the summer monsoon (May to October). Running time 00:09s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

services (e.g., species and habitat diversity) remains unclear. Further, ponds are increasingly recognised as important global greenhouse gas sources due to the biogeochemical processing of elements such as carbon in these systems. Their small size, close proximity to human land use, and nutrient inputs for aquaculture and high biological productivity means ponds both store and release carbon through photosynthesis, decomposition, and respiration. As such, it is estimated that small waterbodies (<0.1 ha) account for 15% of CO_2 and 40% of diffusive CH_4 emissions, despite accounting for only around 9% of the lentic freshwater total area (Holgerson & Raymond, 2016). Although not currently quantified, the vast pondscapes of Asian deltas could therefore be significant in global carbon budgets.

Ponds provide provisional and cultural services and are typical features of rural delta waterscapes as well as urban settlements, including megacities such as Kolkata, India, and Dhaka, Bangladesh (Adhikari et al., 2009; Mukhopadhyay & Dewanj, 2005; Roy & Nandi, 2010). Traditionally, ponds or “*pukur*” in Bangla were created for domestic use (Nhan et al., 2007; Van Liere, 1980) with large numbers of households in rural India (Manoj & Padhy, 2015), Bangladesh (Huda et al., 2010; Kränzlin, 2000; Little et al., 2007), and Vietnam (Ngoc & Demaine, 1996) either owning or using ponds close to their household. For example, an estimated 4.27 million households in Bangladesh operate a homestead pond (Belton & Azad, 2012). In Video 4, Indian pond owner B. Bhowmik introduces the uses of his household pond.

VIDEO 4 Video of pond owner B. Bhowmik, introducing the uses of the household pond. Indian Sundarban, Ganges-Brahmaputra-Meghna delta. Media courtesy of S. Das and B. Bhowmik. Video produced by I. Garrett. Running time 00:41s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

Ponds in both rural and urban areas offer provisions for a wide range of activities, including bathing, washing, fish farming, community gatherings, spiritual practices, tourism, and recreational activities (Suchana et al., 2020). More often, they are multi-functional units and can be found in an array of public and private localities from the homestead to parks and tourist resorts, where ponds are used for sanitation, irrigation, and aesthetics, as the narrator in Video 5 explains.

More recently, a period of intense growth and intensification of the commercial aquaculture industry, known as the "blue revolution," has increased the economic value of ponds and industrial aquaculture in Southeast Asia (Ahmed, 2013). Deltas have seen the creation of ponds for commercial aquaculture at the expense of other land uses (Bush & Kosy, 2007; Pucher et al., 2015), moving away from traditional domestic uses of ponds. This is more prevalent in the Vietnamese deltas where ponds are very rarely used as drinking sources or as integral domestic entities compared with India and Bangladesh GBM, where these practices remain common. In the Red River Delta, for example, ponds are commonly found as part of the VAC integrated farming system. Where VAC is the acronym for a garden (Vuon), a fish pond (Ao Ca), and a cattle shed (Chuong), with waste recycled between the three components, as the narrator in Video 6 explains. The role and value of the delta pond has, therefore, seen shifts alongside social, economic, and cultural trends in Southeast Asia.

In this review, we highlight the importance of delta ponds as important socio-ecological systems in their own right. We review their traditional and cultural role, the current and future environmental concerns, and the current management practices and policy. We evaluate what is known of their role as habitats for fresh and brackish water biodiversity and the extent to which delta ponds could become sentinel resources in the achievement of the UN Sustainable Development Goals (SDGs) (e.g., Hambrey, 2017).

3 | THE SOCIAL CONTEXT OF TROPICAL ASIAN MEGA-DELTA PONDS

3.1 | Ponds as spiritual sites

Water remains an important symbol of life and re-birth in many delta cultures, though ponds are often overlooked by the more substantial river channels. For instance, constitutional amendments in India and Bangladesh have granted rivers "rights to life," meaning harm or damage to a river is akin to harming a "living entity," with ponds not possessing the

VIDEO 5 Video introducing the uses and quality of a tourist resort pond, in Satjelia Island, Indian Sundarbans. Narrated by T. Ghosh (2020). Photograph provided by T. Ghosh. Video produced by H. Moorhouse. Running time 00:37s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

same reverence. Historically, however, ponds were important stages for rural folklore and the exploration of traditional values and cultural identity within it. For example, Video 7 details the folklore behind Ba Om pond in the Vietnamese Mekong Delta, an important site for the Khmer people.

Ponds have been built close to important Asian Buddhist, Hindu, and Muslim sites for centuries, with water regarded as a precious life-giving resource (Kränzlin, 2000). In Hindu culture, water is the symbol of life and pervades rituals and myths surrounding ponds as treasure keepers, sacrificial sites and links between the underworld, spirits, and human beings (Kränzlin, 2000). In Islamic culture, water is an element of purification, with the Muslim period in Bengal heralding the digging of ponds to allow free water for the whole community (Kränzlin, 2000). In Bangladesh and West Bengal, spirituality remains associated with larger ponds or lakes (called "*dighi*"), where myths surround ponds as good fortune for local communities, a sacrifice is made before holding pond water (Lun, 2011), and pond water is used in spiritual healing practice (Haque et al., 2018).

3.2 | Ponds as community entities

Ponds have become important spaces for domestic and community cultivation purposes, highlighting an important shift in the societal perception of ponds as sites of capital. For example, in the GBM under British colonial rule, ponds were the responsibility of the "*zamindars*"; local landlords and tax collectors, who often owned the largest pond and determined which ponds the communities could use for different activities, i.e. aquaculture, bathing, drinking water for cattle

VIDEO 6 Video introducing VAC ponds in the Red River Delta, with photographs showing duck rearing on fish ponds. Narrated by N. Do Thu (2020). Photographs provided by N. Do Thu. Video produced by H. Moorhouse. Running time 02:06s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

VIDEO 7 Video introducing Ba Om pond in the Mekong Delta, Vietnam, an important cultural site for the Khmer people. Narrated by P. Nguyen Thanh (2020). Photograph provided by P. Nguyen Thanh. Video produced by H. Moorhouse. Running time 01:31s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

(Kränzlin, 2000). Pond development was encouraged and rent reduced if land was converted for irrigation purposes and fish stocking (McLane, 1993). Since India's independence in 1947 and the collapse of the "*zamindar*" system, many ponds became derelict. However, in rural Bangladesh, ponds continued to be used for drinking and cooking, with a particular pond dedicated to these purposes whilst others are used for bathing and washing clothes as in the "*zamindar*" system

VIDEO 8 Video introducing the quality of a crab culture pond in Hamilton Abad, Satjelia Island, Indian Sundarbans. Narrated by T. Ghosh (2020). Photograph provided by T. Ghosh. Video produced by H. Moorhouse. Running time 00:44s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

(Kränzlin, 2000). Historically, and in some cases today, pond water was purified for drinking and domestic purposes using camphor (a natural extract of the camphor tree), boiling the water, and/or filtering it. Owing to a massive campaign by the Bangladesh government and international communities in the 1970s and 1980s, tubewells became the preferred water source to access safe water and limit waterborne disease. Nonetheless, since 1983, the Department of Public Health Engineering (DPHE), Bangladesh and UNICEF have incentivised the use of ponds as primary drinking water sources through the establishment of Pond Sand Filters (PSFs), a low cost technology for purifying pond water (DPHE & UNICEF, 1989; Harun & Kabir, 2013). PSFs have been utilised in small rural coastal communities, such as villages in the Satkhira coastal district of the Bangladesh Sundarbans, whose groundwater water sources have been impacted by arsenic and saline intrusion (Rabbani et al., 2018).

The "blue revolution" in recent decades increased the economic value of ponds again and encouraged a decrease in community and domestic use in replacement of intensified livestock cultivation (Ahmed, 2013; Bush & Kosy, 2007; Pucher et al., 2015). For example, mud crab aquaculture, common in the Indian and Bangladesh Sundarbans, yields profits of US $22,812.5 ha^{-1} $year^{-1}$ for culturing young crabs until they reach a desirable size and US $30,820.8 ha^{-1} $year^{-1}$ for fattening, where soft-shelled crabs are reared until their exoskeleton is hardened (Sathiadhas & Najmudeen, 2004). Video 8 shows one such crab-fattening pond common throughout the Indian Sundarbans.

In Bangladesh, freshwater prawn and brackish water shrimp are termed "white gold" for their commercial export value (Ahmed, 2013). Whereas in the Mekong Delta, Vietnam, the freshwater *Pangasius* spp. (catfish) farming industry expanded, on average, 30% a year between 2004 and 2008 because of demand from the EU, Australia, and Canada (Bush & Duijf, 2011). To boost production and maintain productivity of ponds, 99% of farmers in the Mekong Delta excavate ponds twice annually, with pond digging the largest employment sector for non-landowners (Christensen et al., 2008). Most shrimp ponds are typically excavated annually too. The demand on ponds to generate profit continues to occur alongside their need to provide local subsistence of food, water, and sanitation.

3.3 | Pond owner and user identity

There are distinct hierarchal social structures between delta pond owners and users. For instance, in rural GBM districts, private pond ownership is common, with pond owners often more financially stable than their non-pond-owning counterparts (Belton & Azad, 2012; Belton et al., 2012). The urban poor, residing in cities such as Kolkata, who rely on ponds for subsistence or market sales of aquatic livestock, have no rights to governance much like rural non-pond owners. They must accept degraded pond water quality from wastewater directed to these systems and the consequent risks to human, aquatic, and livestock health (Bunting et al., 2010). Video 9 introduces one such polluted pond in Kolkata, with mats of aquatic vegetation and plastic pollution masking the pond water surface.

Nearly a third of medium-sized and small-sized pond owners in the GBM delta live below the poverty line. Unexpected events (e.g., cyclones, ill-health, salinisation) increase financial vulnerability further through the loss of production and essential income (Belton & Azad, 2012; Belton et al., 2012). A similar experience is found with *Pangasius* fish farmers in the Mekong Delta, Vietnam, where wealthier households have access to financial capital to enable their larger scale aquaculture operations, and banks are less willing to lend to smaller-scale operators (Belton & Little, 2011). In addition, smaller-scale operations tend to be fully invested in the industry so are more susceptible to market or environmental “shocks,” whereas medium and larger farms tend to be multi-operational with rice paddies or orchards, and so, are able to buffer against any unforeseen circumstances (Belton & Little, 2011). Thus, pond ownership has been found to entrench social class structure rather than deconstruct or enable class mobility (Belton & Little, 2011).

3.4 | Ponds, displacement and loss of livelihoods – the case of aquaculture

The expansion of export-orientated aquaculture in tropical Asian mega-deltas has resulted in land use changes from virgin mangrove forest and/or agricultural land to ponds (cf., Hamilton, 2013). Government incentives and policies, which aim to increase conversion of common land such as mangrove forest to aquaculture ponds with minimal rent, were enacted in order to alleviate rural poverty (Ahmed, 1999). As such, tidal shrimp pond creation in the 1980s was the primary cause of more than 4.5×10^5 ha of mangroves being deforested throughout Asia. In Minh Hai province (today Ca Mau and Bac Lieu provinces) of the Mekong Delta, Vietnam, 66,253 ha of mangroves were cleared to create shrimp ponds between 1980 and 1995 (Buu & Phuong, 1999). In the Mekong Delta, the expansion of freshwater *Pangasius* fish farming led to market surplus production in the early 2000s, leaving many farmers suffering heavy financial losses (Belton & Little, 2011). Land-use planning and government targets were then put in place in an attempt to control the spontaneous and uncontrolled *Pangasius* pond expansion in the early 2000s, however these

VIDEO 9 Video describing an urban pond in the Maidan, an area of parkland in the city of Kolkata, India. Narrated by H. Moorhouse (2020). Photograph provided by H. Moorhouse. Video produced by H. Moorhouse. Running time 00:52s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

VIDEO 10 Video introducing a crab fattening pond in the Indian Sundarbans. Solar panels are managed and utilised by the village community. Narrated by H. Moorhouse (2020). Photograph provided by H. Moorhouse. Video produced by H. Moorhouse. Running time 01:25s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

were later surpassed and expansion continued (Bush et al., 2009). In Bangladesh, urbanisation and industrialisation has reduced land availability and increased land prices, and alongside corrupt and ineffective administration has increased land scarcity and decreased sustainable land management (Mookherjee et al., 2020). The displacement of traditional agricultural landscapes in lieu of aquaculture and urbanisation has led to a surplus of agricultural workers who have had to seek employment in other sectors often away from their home regions, sometimes in exploitative industries (e.g., in Brick Fields, see University of Nottingham Rights Lab, 2018), and alongside an extensive young population demographic, explains in part the large migrant workforce in many Asian deltas (Haque & Saifuzzaman, 2003).

Aquaculture expansion has also resulted in further marginalisation of poorer communities who are reliant on subsistence and harvest of forestry-based products, by reduction of the mangrove forest (Ahmed & Lorica, 2002; Luttrell, 2006). In the Sundarbans, rural individuals who do not own ponds are typically involved in forest-based crab and prawn seed collection to supply aquaculture and have much lower incomes than those employed by the aquaculture industry directly, as their income responds to local market economics compared with international markets (Belton & Azad, 2012; Chand et al., 2012). Furthermore, demand for aquaculture wild seed has promoted over-fishing and led to illegal fishing activity, rooted from loss of traditional livelihoods and basic income, with the economic profits from selling wild stock to aquaculture overriding occasional financial penalties from illegal forest collection (Ghosh, 2015). Though local government initiatives to provide alternate income and household supplies do exist, as shown in this crab aquaculture pond surrounded by solar panels in the Sundarbans (Video 10).

3.5 | Ponds and the female experience

Women are important pond users as they are typically responsible for managing household chores, especially the provision of food and water. Yet in delta regions, they often lack the economic or land-use rights afforded to men, so have limited ability to respond to deteriorating water quality. Coupled with the different needs of female physiology and reproductive health, greater pond exposure makes them more susceptible to health issues from poor pond water quality (Benneyworth et al., 2016; Upadhyay, 2005). Increased consumption of saline pond water, which is more prevalent in the dry season, has been linked to elevated blood pressure and preeclampsia in pregnant women in Bangladesh (Khan et al., 2011), as well as dermatological issues, dysentery, and more acute health risks from regular everyday exposure (Abedin et al., 2014). Further, women are more vulnerable to the negative environmental, social, economic, and health impacts of extreme events (Cannon, 2002). This is because women make up a disproportionate share of the poorest in society and are more reliant on economic activity related to domesticity. Extreme events such as cyclones, floods, and storm surges reduce aquatic livestock harvests, the quality and access to drinking water, and complicate women's ability to fetch water, ultimately inhibiting female domestic duties and resulting in them experiencing greater risk of financial, domestic abuse, and health difficulties (Cannon, 2002).

Ponds can be unsafe and uncomfortable spaces for women, who are at greater risk of sexual harassment and physical and/or verbal abuse when bathing in communal ponds (Crow & Sultana, 2002; Joshi et al., 2011). Menstruation remains taboo in many delta communities, which can result in women avoiding bathing or suffering persecution when on their period, leading to physical and mental health implications (Crow & Sultana, 2002; Joshi et al., 2011).

Aquaculture reinforces the gender inequality in Asian mega-deltas. Traditional rice paddy agriculture typically employs more men and women, and the loss of this industry in lieu of aquaculture has led to a surplus of individuals seeking employment. If women get the opportunity to pursue employment in this industry, they will typically earn less than their male counterparts and are often restricted to the insecure, low paid, labour-intensive occupations of aquaculture such as harvesting and packing (Gammage et al., 2006). Male farmers will also migrate to urban areas, increasing the household burden on women to provide food for the family. However, women rarely have the capacity or access to economic and land-use rights, meaning that even in female-headed households they face barriers to pond management and so control over aquaculture production (Hambrey, 2017).

4 | ENVIRONMENTAL CHALLENGES

The intensification of human activity and heavy reliance on deltas and delta ponds are occurring alongside global sea-level rise, climatic variability, and the increasing frequency and magnitude of extreme events, placing these already deteriorated aquatic ecosystems and vulnerable communities under increasing stress and in the worst cases leading to water resource conflict (Oppenheimer et al., 2019; Rudra, 2018). Here, we discuss some of the most pervasive environmental concerns for pond users, including saline intrusion (e.g., Kam et al., 2012; Dubey et al., 2016), and the input of anthropogenic pollutants such as nutrients, pesticides, and antibiotics etc. (e.g., Islam et al., 2000; Tho et al., 2014). These environmental concerns consequently increase disease outbreaks of both livestock and human populations (e.g., Dubey et al., 2016; Mukherjee et al., 2011; Nam et al., 2000), which, coupled with global climate change, positions ponds as indicators of public health and environmental risk.

4.1 | Saline water inundation

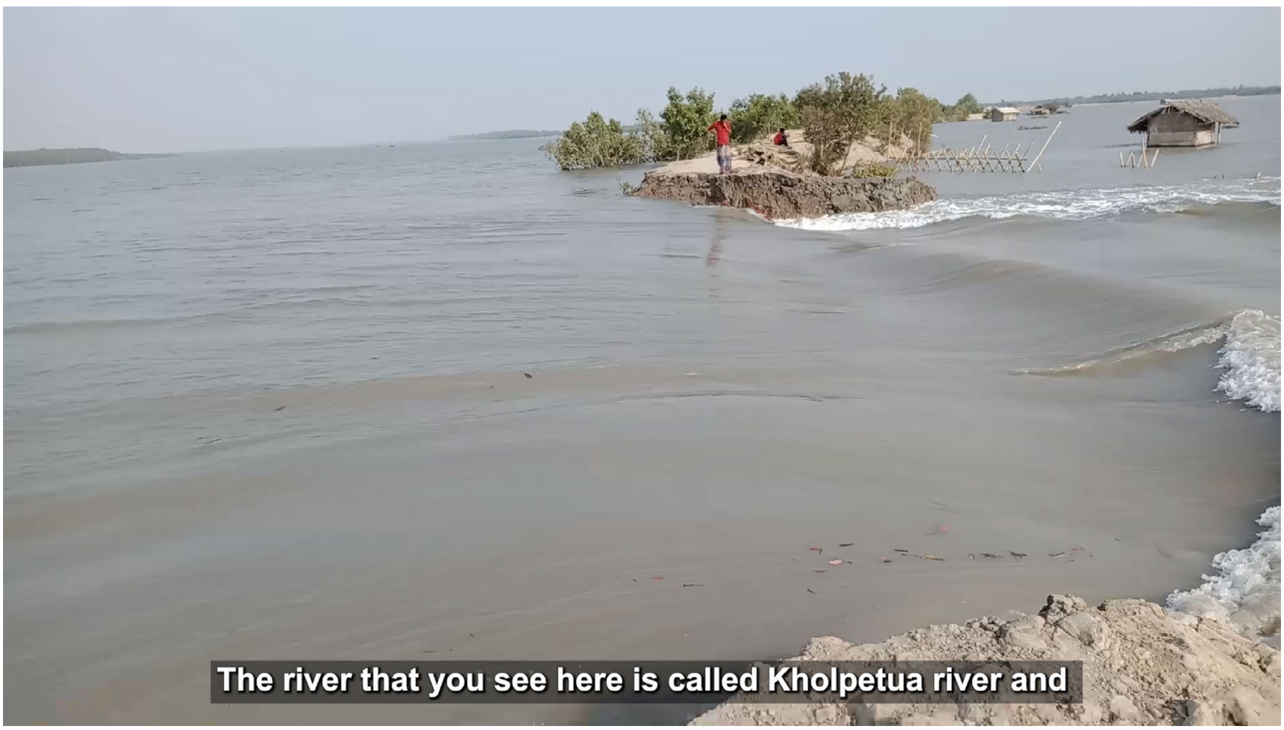
Accelerated sea-level rise, increased frequency and intensity of storm surges, and the upstream withdrawal of freshwater are major concerns for coastal wetlands worldwide (Oppenheimer et al., 2019). Rising salinity is often exacerbated during the dry season due to low river discharge allowing saltwater intrusion further inland (Chand et al., 2012). In the Bangladesh GBM, saltwater penetrates 100 km inland (Allison et al., 2003), while in the Mekong Delta saltwater intrusion affects 1.7 million ha accounting for about 45% of the delta area (Wassmann et al., 2004). In the Bangladesh Sundarbans, increasing pond salinity has resulted in ponds being unusable for irrigation, drinking water, bathing, and freshwater fish cultivation (Miah et al., 2003). Consumption of saline water can lead to increased blood pressure, delirium, nausea, and in worst cases, comas, organ failure, and mortality (e.g., Miah et al., 2003).

Storm surges caused by Cyclone Sidr, Cyclone Aila, and Cyclone Amphan, which hit the Indian and Bangladesh Sundarbans in November 2007, May 2009, and May 2020 respectively, led to the inundation of freshwater ponds and tubewells with saline water in many coastal villages. For six months following Cyclone Sidr, and the inundation of around 6000 freshwater ponds, residents depended on aid or walking long distances for safe drinking water (Government of Bangladesh, 2017; Rabbani et al., 2013). Similarly, Cyclone Aila damaged 163 PSFs and inundated 3,032 freshwater ponds in the Khulna and Satkhira districts of Bangladesh (Action Aid, 2009). More recent flooding from Cyclone Amphan has again resulted in the contamination of ponds, scarcity of drinking water, and the loss of freshwater aquaculture species from saline intrusion. Consequent embankment breaches during high tides, for example seen in April 2021 in the Shyamnagar subdistrict, Satkhira district, south-western Bangladesh (Video 11a,b), continue to delay recovery further and threaten the livelihoods of these coastal communities. Even with draining, liming, and the addition of potassium persulphate, ponds that have been inundated with brackish water, as shown in Video 11c, have been found to take years to return to completely fresh conditions (Amin, 2020; Thakur, 2020).

Adaptation to salinity has included the expansion of brackish shrimp farming, for example in the Satkhira, Khulna, and Bagerhat districts of Bangladesh, since the late 1980s, where saline water has been actively channelled into shrimp ponds, known locally as "*ghers*" (Rahman et al., 2013; Salehin et al., 2018). Video 12 introduces and details the typical nature of shrimp ponds in the Bangladesh GBM.

However, proliferation of brackish shrimp culture ("*Bagda*") has increased conflict between monsoon paddy ("*Aman*") and brackish shrimp producers, as the harvesting period of the former and the growing season of the latter overlaps, and monsoon rainfall does not always flush out salts required for *Aman* production (Salehin et al., 2018). The following footage in Video 13 captures the pondscapes of Bangladesh GBM during the monsoon, where freshwater rice paddy, community, and homestead ponds co-exist next to their saline shrimp counterparts. All these systems are heavily reliant on monsoonal rainfall to maintain their requisite conditions.

In some cases, saline intrusion has driven farmers to shift from aquaculture to agriculture. For example, in the Red River Delta, between 2008 and 2011 due to severe inundation from saltwater and the consequent disease of farmed soft shell turtles, many aquaculture farms filled in ponds and began to farm the Japanese pagoda tree *Styphnolobium japonicum* (L.) Schott, and Ming aralia *Polyscias fruticosa*, both used for ornament, traditional medicine, construction, and the latter also used as a spice (Nguyen et al., 2019). The loss of these ponds has important consequences for wider delta biodiversity, such as birds and pollinators, which utilise them for food and habitat (e.g., Lewis-Phillips et al., 2019, 2020; Stewart et al., 2017).



VIDEO 11A Videos showing the effects of the breach of a tidal embankment at Burigoalini Union, Satkhira district, Bangladesh and flooding of shrimp ponds in early April, 2021. Footage and commentary provided by Vaskar Mondal. Subtitles provided by M. F. Rahman. Videos produced by H. Moorhouse (a) Running time 00:55s.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

VIDEO 11B Videos showing the effects of the breach of a tidal embankment at Burigoalini Union, Satkhira district, Bangladesh and flooding of shrimp ponds in early April, 2021. Footage and commentary provided by Vaskar Mondal. Subtitles provided by M. F. Rahman. Videos produced by H. Moorhouse (b) Running time 00:54s.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

4.2 | Eutrophication

Livestock and human waste, chemical fertilisers, rice by-products, and molluscs and crustaceans from rice fields are typically added to aquaculture ponds to fertilise and promote phytoplankton growth used to feed aquatic livestock (Nhan et al., 2005, 2007). Tropical delta ponds, particularly in Vietnam, are typically nutrient-rich, with phytoplankton productivity often light-limited due to high suspended solid loads (Alongi et al., 1999; Furnas, 1992). Eutrophic brackish water aquaculture ponds in China have been shown to be CH_4 emission "hotspots" and across the estuarine regions of China, shrimp aquaculture ponds have an estimated CO_2 emission of 63.68Tg CO_2-eq during the culture period (Yang et al., 2018). Collectively, tropical Asian delta ponds may be considerable contributors to climate forcing on account of their heavy nutrient and organic matter inputs and anaerobic processing (Gorsky et al., 2019).

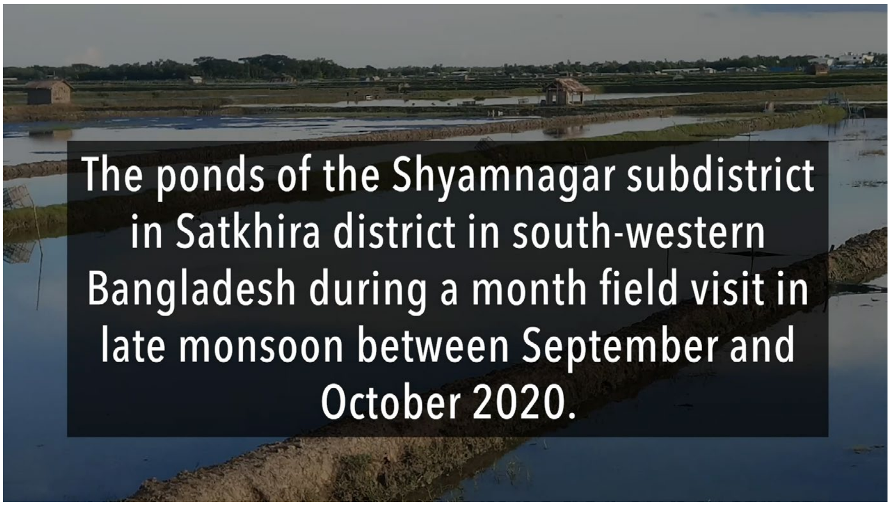
In the Mekong and Red River Deltas, it has been suggested that domestic, agricultural, and industrial discharges are the most significant sources of nutrients to surrounding rivers and canals (Do et al., 2019; Luu et al., 2020; Tho et al., 2014). Farmers typically apply more fertiliser during the wet season when run-off nutrient losses are greater, thus resulting in greater transport and elevated ammonia and total nitrogen in water bodies adjacent and downstream from rice fields in the Mekong and Red River Deltas (Do & Nishida, 2014; Luu et al., 2020; Wilbers et al., 2014). This highlights the

VIDEO 11C Videos showing the effects of the breach of a tidal embankment at Burigoalini Union, Satkhira district, Bangladesh and flooding of shrimp ponds in early April, 2021. Footage and commentary provided by Vaskar Mondal. Subtitles provided by M. F. Rahman. Videos produced by H. Moorhouse (c) Footage showing the flood damage to the village of Porakatla community ponds and homesteads following the embankment breach. Running time 01:06s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

importance of aquatic connectivity in pollutant pathways, with isolated ponds less likely to be pollutant sources to the wider waterscape than tidally connected ponds.

Delta ponds receive excess nutrients from a variety of anthropogenic sources, including household and municipal waste (e.g., livestock and human faecal waste), drainage, and surface runoff. As a result of excess nutrients and high temperatures, toxin-producing harmful algal blooms (HABs) are common during certain seasons, causing declines in aquatic biodiversity, fish kills, livestock, and wildlife health concerns as well as human health concerns such as skin irritations and headaches (Jahan et al., 2010). Ponds in Bangladesh have an average concentration of microcystin toxins (from cyanobacteria) higher (>10 μg/L) than the World Health Organization (WHO) guideline concentrations of 1 μg/L (Welker et al., 2005). Cyanobacteria may also act as a substrate for *Vibrio cholerae*, the bacterium that causes cholera in humans (Islam et al., 2004), with almost all cholera outbreaks reported following HAB blooms (Mukherjee et al., 2011). Activities identified as increasing the risk of cholera included washing utensils in ponds, bathing in and drinking pond water, mouth washing, and cooking with pond water (Mukherjee et al., 2011). Increasing salinity and nutrient levels of ponds, in turn, increase the longevity of *V. cholerae* (Mukherjee et al., 2011), which may result in a greater number of future cholera outbreaks.

VIDEO 12 Video introducing industrial-scale shrimp ponds, Shayamnagar, Satkhira, Bangladesh. Narrated by M. F. Rahman (2020). Photograph provided by M. F. Rahman. Video produced by H. Moorhouse. Running time 01:50s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103



VIDEO 13 Video documenting community and shrimp aquaculture ponds of the Shyamnagar sub-district, Satkhira district, south-western Bangladesh, Ganges-Brahmaputra-Meghna delta, during the late monsoon period. Footage and subtitles courtesy of M. F. Rahman. Video produced by I. Garrett. Running time 01:52s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

4.3 | Public Health implications of pond exposure

Open defecation, poor sanitation, and lack of wastewater treatment within delta regions have resulted in the significant contamination of surface waterbodies with faecal coliform and pathogenic bacteria (UN, 2019). Since delta ponds form an essential component of daily domestic and agricultural life and given there may be minimal water exchange with other surface waters, faecal pollution is concentrated and often exceeds WHO guidelines (Islam et al., 2000, 2011). For instance, in India, ponds have the highest counts of human and animal faecal indicators (87% Faecal Coliforms) compared with improved groundwater drinking sources (49% Faecal Coliforms; Schriewer et al., 2015). In Bangladesh, 100%

of pond samples failed bathing water standards for *Escherichia coli* and enterococci, with heavy rainfall events increasing faecal delivery and contamination of ponds (Islam et al., 2017). Bathing is often prohibited at ponds reserved for irrigation or aquaculture, meaning bathing takes place in ponds where water quality is not managed, with consequent risk to human health (Kränzlin, 2000). Bathing pond overuse is therefore common in communities where aquaculture has expanded and there becomes limited access to ponds for bathing. This results in ponds being major transmitters of diarrhoeal and waterborne diseases (Islam et al., 2000). Additionally, in the rural Mekong Delta, fish pond toilets with direct delivery of human excreta to ponds for fish fodder remain common (Herbst et al., 2009). Since diarrhoea is a leading cause of child mortality and impaired development across Southeast Asia, ponds are a significant concern for human health (Johnson et al., 2010).

Tropical delta ponds are also hotspots for infectious and parasitic diseases, principally by providing suitable habitat and transmission pathways for disease vectors. A study on the highly pathogenic avian influenza H5N1 in the Red River Delta found increased pond density, waterfowl production density, and proximity to villages were important risk factors in disease transmission (Desvaux et al., 2011). Tropical ponds themselves provide habitats for endemic mosquito vectors of viral dengue fever and parasitic malaria (less so in Vietnamese deltas), both serious tropical diseases. Furthermore, host-vector-pathogen interactions reduce host nutritional or reproductive health and alter pond food web structure, function, and stability (Selakovic et al., 2014). However, through improved understanding of pond-mosquito ecology (Ohba et al., 2011, 2015), and the use of pond zooplankton and fish as bio-controls (Nam et al., 2000), the pond may be an important agent in addressing disease vector populations.

The importance of bio-controls for disease outbreaks may also be important in addressing Southeast Asia as a “hotspot” for antimicrobial resistance due to excessive and arbitrary use of antibiotics in agriculture and aquaculture (Dang et al., 2011; Kim et al., 2013). Antimicrobial resistance is linked to the increased frequency and duration of bacterial infections, ineffective treatment, and increased human and livestock mortality risk. This is further exacerbated in regions with dense human populations, high incidents of poverty, and poor access to health care, all of which are typical in deltas (Aly & Albutti, 2014; Jasovský et al., 2016).

The combination of intensified aquaculture and agriculture alongside traditional practices have also given way to increased infections of fishborne zoonotic trematodes such as liver or intestinal flukes. Fishborne zoonotic trematodes are considered a neglected, serious public health risk, infecting an estimated 750 million individuals globally, but are particularly widespread across Asia (Keiser & Utzinger, 2009). Liver flukes can lead to bile duct cancer, and alongside other flukes can damage major organs in infected humans (Keiser & Utzinger, 2009). Fishborne zoonotic trematodes are transmitted to fish via intermediate mollusc hosts and infect humans that subsequently consume raw fish. In Vietnam, difficulties in changing behaviours around consuming traditional raw fish dishes account for the high prevalence of fishborne zoonotic trematode infected humans in the Red River Delta and Mekong Delta (Phan et al., 2010; Thien et al., 2015). The nature of the pond can influence fishborne zoonotic trematode risk, with deeper ponds increasing the density of intermediate snail hosts, thus increasing the risk of fishborne zoonotic trematode transmission (Thien et al., 2015). Further, fishborne zoonotic trematode transmission can be greater in VAC pond systems, where gardens (Vuon), fish ponds (Ao Ca), and livestock sheds (Chuong) recycle waste between one another. Here, poultry can become infected through the consumption of snails and raw fish waste, and transmit the parasite to cultivated fish through their waste used as aquaculture feed or fertiliser (Anh et al., 2010).

4.4 | Uncertain water supply

Due to the changing behaviour of rainfall in tropical Asia, drought has become a common phenomenon (Kale, 2017; Martin et al., 2013; Wassmann et al., 2009) and is of concern to those who rely on monsoon rainfall to replenish pond water levels as detailed in Video 14.

This reliance on rainfall replenishment makes them vulnerable to climate instability. For instance, in the southern part of Cau Mau province, Mekong Delta, rainfall during the wet season is stored to ensure sufficient water supply for aquaculture during the dry season (Nhung et al., 2019). In some circumstances, groundwater is abstracted for drinking water and to fill up ponds (Kale, 2017). Conversely, where groundwater is contaminated with arsenic and saline water, increased reliance on rainwater ponds as drinking water sources occur, as seen in coastal districts of southwest Bangladesh (Harun & Kabir, 2013). Interestingly, ponds may further exacerbate groundwater contamination, specifically with regard to arsenic. For instance, in the Bangladeshi GBM and the Red River Delta Vietnam, ponds are an important source of shallow aquifer recharge and transport arsenic to aquifers following anoxic events (cf., Kuroda et al., 2013; Neumann

VIDEO 14 Video introducing a rice paddy irrigation pond from Satjelia Island, Indian Sundarbans. Narrated by T. Ghosh (2020). Photograph provided by T. Ghosh. Video produced by H. Moorhouse. Running time 00:35s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

et al., 2010). Lining ponds with plastic is common (Kale, 2017) to prevent seepage and can therefore limit the recharge of groundwater with potentially contaminated surface water. However, it also inhibits the establishment of aquatic vegetation, which plays an important role in maintaining clear water and promoting high diversity of aquatic macroinvertebrates and therefore good pond health (Roy & Nandi, 2010). Whilst these issues are specific to the pond geographical locations, villages with large numbers of ponds can also cause water supply issues further downstream. For instance, the abstraction of large volumes of groundwater from aquifers lowers the water table and, in some cases, limits the base flow of streams and drains that rely on groundwater sources during dry periods. This has been the case in the northwest region of Bangladesh, where depletion of the groundwater table because of irrigation abstraction has led to the drying up of many surface waterbodies including ponds (Dey et al., 2011). Furthermore, large numbers of ponds collect surface run-off, limiting the volume that reaches the main river channels (Kale, 2017). Limiting the flow in river channels and streams can have important consequences for the availability of water downstream.

4.5 | The input of anthropogenic pollutants

Many industries in the delta regions (e.g., plastic manufacturing and leather tanneries) release heavy metals into wastewater channels or directly into the river network, which are used to fill ponds and/or exchange water with ponds during high flow events (Bunting et al., 2010). In the Mekong Delta, concentrations of several heavy metals, including arsenic

(As), cadmium (Cd), and lead (Pb), in the canals receiving water from aquaculture ponds exceeded the WHO guidelines for drinking water (Inoue & Asano, 2013). In aquaculture ponds of the Sundarbans shrimp accumulate zinc (Zn) at higher concentrations than fish (Ghosal et al., 1997), exceeding the provisional maximum tolerable daily intake (PMTDI) of toxic metals (Guhathakurta & Kaviraj, 2004), and leading to several health concerns such as diarrhoea, vomiting, skin irritation, and in severe cases cancer (Dayan & Paine, 2001; Järup, 2003).

One of the main sources of copper (Cu) in the GBM is algaecides used for aquaculture ponds (Mitra & Ghosh, 2014). Runoff of pesticides and insecticides from the surrounding landscapes also pose a risk to pond water quality. In Bangladesh, crop-producing areas are regularly treated with carbamates and organophosphates (Chowdhury et al., 2012). The pesticides contain concentrations of chlorpyrifos, carbofuran, and carbaryl, which are found in ponds for drinking water and are readily bio-accumulated in fish in aquaculture ponds (Rahman, 2000). Exposure to these chemicals even in small doses can cause neurological disorders, reproductive issues, nausea, respiratory illnesses, and cancers (EPA, 1999; Goad et al., 2004; Rauh et al., 2006). Although embankments around ponds limit run-off from surrounding areas and result in lakes and rivers being more contaminated than ponds, the dilution and flushing potential in ponds is much more limited due to their size (Chowdhury et al., 2012). The use of insecticide in brackish water shrimp aquaculture has also been linked to the loss of bird abundance and diversity due to a lack of freshwater and reduced numbers of insects (Ahmed & Diana, 2015; Miah et al., 2003).

5 | BIODIVERSITY

The majority of documented aquatic biodiversity of delta ponds stems from those species related to the aquaculture industry and from the negative impacts of the industry on wider delta biodiversity (Affan et al., 2005; Rahman et al., 2010; Thai et al., 2017). Well documented negative factors of aquaculture include (1) the loss of freshwater habitat, either due to brackish water pond creation or to monoculture (Tho et al., 2006); (2) light-limitation to primary production from high suspended particle loads (Alongi et al., 1999); (3) the depletion of wild stocks (Ottinger et al., 2016); and (4) providing optimum conditions for vector disease transmission (Merritt et al., 2005; Weterings et al., 2018). Due to their role in monitoring water quality and acting as a food source for fish, pond phytoplankton communities have been one of the most extensively studied aquatic groups (e.g., Affan et al., 2005). Affan et al. (2005) detail the annual succession and abundance of communities in ponds in Bangladesh, with highest abundance in spring and early autumn, characterised by the abundance of cyanobacterial (toxic protists) *Microcystis* spp., *Anabaena* spp., and *Planktolymbya* spp. During the rainy season ponds are dominated by the chlorophyte (green) algae *Chlorella vulgaris*, *Pediastrum* spp., and *Scenedesmus denticulatus*, with siliceous diatoms *Navicula angusta* and *Cyclotella meneghiniana* dominating during the dry season. Temperature, alkalinity, and nutrient loads to the ponds are the dominant controls on phytoplankton abundance and diversity (Affan et al., 2005; Hossain et al., 2007). However, substantial successional differences exist between ponds and over different temporal scales due to the large variability in physico-chemical parameters experienced by these systems (Alongi et al., 1999). Typically, tropical ponds have high phytoplankton abundances on account of their eutrophic conditions (Casé et al., 2008); in fishponds in Bangladesh mean abundance of phytoplankton is significantly higher than zooplankton abundance (Hossain et al., 2007). The low zooplankton values in this area are likely attributed to higher occurrences of zooplanktivorous fish and, therefore, low grazing of phytoplankton, and to high alkalinity and nutrient availability providing conditions for phytoplankton to thrive (Hossain et al., 2007).

Studies of meiobenthos (benthic organisms between 45 μm and 1 mm) in shrimp ponds in Vietnam suggest that Nematoda, Copepoda, and Rotifera are the most abundant, with overall densities higher than in mangrove forests in the Americas, Africa, Australia, and other parts of Asia (Thai et al., 2017). Of the macrobenthos (benthic organisms larger than 1 mm) Oligochaeta, Crustacea, Gastropoda, and Bivalvia are present with the gastropod *Sermyla tornatella* (a common Asian brackish water snail) being the most abundant throughout the year (Thai & Quang, 2018). Non-native fauna have also been documented in aquaculture ponds, such as the Caribbean false mussel *Mytilopsis sallei* (Récluz, 1849) (Dreissenidae), which aggressively populates areas and causes severe fouling of brackish-aquaculture equipment (Lutaenko et al., 2019). Whilst this species has spread throughout Asia in recent decades, only recently has it been documented in the Vietnamese Mekong Delta (Lutaenko et al., 2019).

The literature on the aquatic biodiversity of non-aquaculture ponds is limited. In the Indian Sundarbans, the filamentous "blanket weed" algae *Spirogyra jaoensis*, *S. hymera*, and *S. punctulata* are common alongside *C. vulgaris* (Satpati et al., 2013). A study of macrobenthos in urban ponds of Kolkata suggests high total diversity with 37 species of Polychaeta (three species), Oligochaeta (five species), Hirudinea (one species), Crustacea (three species), Insecta (seven species), Gastropoda (14 species), and Bivalvia (four species) (Roy & Nandi, 2010). Low canopy cover and emergent aquatic plant presence support high diversity, while Polychaete species dominated in polluted sewage-fed sites.

Despite the important role of aquatic vegetation for maintaining high biodiversity (Roy & Nandi, 2010), evidence suggests that in delta ponds plant diversity may have declined in recent decades due to deteriorated pond water quality and the introduction of non-natives. Some ponds are dominated by a single genus such as the free-floating Duckweed (*Lemna* spp.), which grows on the surfaces of stagnant, nutrient-rich ponds, and is more resistant to disease and pests compared with other aquatic plants (Men et al., 1995). However, duckweed is used as a feed supplement for not only the 30 million ducks raised annually in Vietnam for meat and eggs, 65% of which are raised in the Mekong Delta (Men et al., 1995), but other livestock too, promoting continued duckweed monoculture.

The introduction of invasive non-natives in delta ponds such as *Eichhornia crassipes* (Water hyacinth; e.g., Attermeyer et al., 2016) and *Alternanthera philoxeroides* (alligator weed; e.g., Chatterjee & Dewanji, 2014) have also reduced aquatic plant biodiversity through the formation of dense mats on the surface of ponds, limiting light through the water column, preventing phytoplankton growth, and rendering the fish ponds unusable (Kumar, 2011). Conversely, evidence from Kolkata City in India has found that the dominance of floating macrophytes such as water hyacinth in ponds actually reduce CO_2 and CH_4 emissions via disruption to pond carbon metabolism compared with those without (Attermeyer et al., 2016). Considering water hyacinth occupy an estimated 2000 km^2 of waterbodies and 10%–15% of the total area covered by aquatic vegetation in India, this indicates a substantial process in regional carbon budgets (Attermeyer et al., 2016; Panigrahy et al., 2012; Venugopal, 1998). To our knowledge, there exists no inventories on aquatic vegetation abundance and diversity in Asian delta ponds which would further assess and improve knowledge on the ecological and biogeochemical impacts of water quality changes and the spread and ecology of non-natives.

The majority of biological surveys in the Asian mega-deltas do not record species level and the abundance and diversity of groups is not reported alongside limnological parameters, limiting valuable information. For example, Thai and Quang (2018) employed the Azti Marine Biotic Index (AMBI) to calculate the ecological quality of shrimp ponds in Ca Mau, Mekong Delta, Vietnam, showing that all ponds had "undisturbed" or "slightly undisturbed" conditions with better ecological quality during the rainy season; presumably linked to environmental conditions, but these were not recorded. The application of this biological index is, however, problematic. The AMBI and other similar pond ecological metrics available, including the Biological Monitoring Working Party (BMWP) Index and the Predictive SYstem for Multimetrics (PSYM), are designed for use in Europe and therefore need calibrating for use in tropical environments. For example, only seven of the 28 species (39%) found in shrimp ponds in Vietnam were in the original AMBI database (Thai & Quang, 2018). Since water quality monitoring tools using macroinvertebrates are not readily available, the research collecting and recording macroinvertebrates is limited compared with Europe. More importantly there are limited tools to allow fast, reliable, and easily understood metrics for water quality, which have become common community engagement strategies across Europe, and consequently increased public awareness of water quality issues. Thus, the implementation of simple water quality assessment tools could allow communities to manage poor water quality and disease outbreaks more effectively, whilst simultaneously improving biodiversity education and restoration.

Reviews of delta-wide biodiversity do, however, exist for some deltas (e.g., Habib et al., 2017 for the Bangladesh Sundarbans), but they are not habitat specific, that is, standing and flowing waters (lakes, ponds, and rivers) and fresh, brackish, and marine biodiversity are not differentiated. Species occurrence in each of these habitats substantially differ depending upon habitat provision and, in some areas, morphological and sedimentary characteristics (e.g., the Sundarbans; Habib et al., 2017). The extent to which these areas operate as highly biodiverse pondscapes, or support forest spillover in locations close to mangrove habitats, is therefore largely unknown. Though it may be assumed natural pond-like wetlands known in Bengali as "*jheels,*" "*beels,*" "*haors,*" and "*boars*" will support greater biodiversity than their artificial pond counterparts. Furthermore, the higher anthropogenic demands, consequent environmental degradation, and the paucity of biomonitoring, threatens the ability for delta ponds to deliver the same biodiversity services as they have been shown to provide in Europe and North America (Fu et al., 2018; Thai et al., 2017).

6 | MANAGEMENT PRACTICES

6.1 | Local level management of ponds

Aquaculture is the main use of ponds in Vietnam, thus management practices here are well established. In the Red River Delta, many aquaculture farms follow the traditional integrated VAC (garden "Vuon," fish pond "Ao," livestock

"Chuong") system (Video 15). To prevent the build-up and exchange of excess nutrients, the VAC system encourages the recycling of nutrients by using livestock manure to fertilise ponds, fish remains to feed livestock, and pond sediment to fertilise crops (Nhan et al., 2005).

Whilst these practices have been found to increase fishborne zoonotic trematode transmission, the removal of nutrient-rich sediments and fish remains from the ponds prevents the build-up of chemicals, nutrients, and other diseases (e.g., Inglis, 2000; Warne, 2012), allowing the intensification of production without adverse environmental impacts (Little & Muir, 1987; Prein, 2002). Although not promoted by the government, the use of pond sediments as fertilisers has also been encouraged in Bangladesh (e.g., Haque et al., 2016). Dredging can cause an immediate decline in aquatic biodiversity, but where the seedbank remains intact, long-term water quality can improve, increasing the abundance of macroinvertebrates and consequently bird diversity and abundance due to increased emergent invertebrate food sources (e.g., Schummer et al., 2012).

In the Indian Sundarbans the most common pond water quality management strategies are (1) liming (87% of farmers); (2) dewatering before restocking (53%); (3) addition of livestock waste (29%); (4) dredging (21%); and (5) removal of aquatic plants (18%) (Dubey et al., 2017). Liming is a commonly used management strategy for both domestic and industrial ponds to improve water quality via the following mechanisms: stabilising pH, increasing available phosphorus, and/or accelerating the decomposition of organic matter (Chand et al., 2012) (Video 16). This results in increased photosynthetic activity and reducing pond CO_2 emissions (Chanda et al., 2019).

Dubey et al. (2017), however, argue that many farmers in India incorrectly and/or excessively use fertilisers and chemical treatments, which adversely affect water quality, primary producers, and fish. Furthermore, the variability of water quality conditions among ponds even within close proximity can result in management practices that result in high yields in some ponds but prove unsatisfactory in others. This may be in part due to some farmers being unfamiliar with the need to monitor conditions; for instance, only 61% monitor salinity and 42% monitor pH (Dubey et al., 2016). Some methods are primarily undertaken following a disease outbreak, with few farmers employing management techniques specifically for disease prevention. For example, 37% of farmers practiced liming and 4% exchange water only after a disease outbreak. Some farmers use potassium permanganate, copper sulphate, alum and methylene blue, despite little evidence that the application of these chemicals aids the recovery from disease (Dubey et al., 2016). However, techniques employed in Bangladesh to manage water quality such as dewatering and drying out of pond sediment, semi-regular dredging, and liming during pond creation indirectly result in low fish disease outbreaks (Dubey et al., 2016).

VIDEO 15 A short video tour of a VAC pond in the Red River delta, Vietnam. Footage and subtitles by N. Do Thu. Video produced by I. Garrett. Running time 00:41s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

VIDEO 16 Video introducing a pond that has been treated with lime in the Indian Sundarbans. Narrated by S. Das (2020). Photograph provided by S. Das. Video produced by H. Moorhouse. Running time 00:49s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

Pond management to protect from extreme climate events is primarily centred around improving pond embankments, with 37% improving and heightening embankments after storms, with the main aim to prevent livestock escaping (Dubey et al., 2017). The improvement of embankments also serves to prevent the exchange of polluted waters to and from the surrounding environment. In India, 17% of farmers strengthened embankments with fruit trees, improving wider biodiversity of the area; proximity of trees for nesting and/or food sources have been shown to significantly increase bird abundance and biodiversity at a number of managed agricultural pond sites (e.g., Lewis-Phillips et al., 2019). Conversely, in Bangladesh, riverbanks are being de-pouldered under a scheme called tidal river management (TRM), allowing rivers to flood and deposit sediment into beels (tidal basins). The aim of TRM is to constrain saltwater inundation to beels only and not increase saltwater inundation to other surface waters such as ponds. However, this is a government-led initiative, with compensation schemes often not paying out to those whose land becomes unviable for agriculture/aquaculture due to rising salinity as part of the TRM. On the individual level, many pond owners are not financially stable, and lack the financial capability to prepare and adapt to any climatic events (Belton & Azad, 2012; Belton et al., 2012; Dubey et al., 2017). There is little assistance from governments for individual pond owners and community ponds which often face greater neglect due to lack of clarity in responsibility for management and maintenance (Video 17).

6.2 | National pond management and conservation policies

Whilst some global legislation for the protection of wetlands, including ponds (e.g., Ramsar convention), and reviews of pond policy exist (e.g., Hill et al., 2018), there is little national level policy for the management and conservation of ponds in Asian mega-delta countries. In India, there is almost no legislation covering the conservation of ponds. The National Water Policy 2012 encourages (1) increasing water storage capacity including the use of ponds; (2) the use of small local level irrigation including field ponds; (3) the protection of ponds from environmental pollutants and water diversion; and (4) the restoration and maintenance of ponds. However, no routine monitoring of ponds or incentives to protect ponds and achieve the above exists. A 2010–2011 report of the Central Pollution Control Board (CPCB) showed that there are only 60 CPCB pond water quality monitoring stations in the country, none of which were located in West Bengal in the GBM delta (Manoj & Padhy, 2015).

VIDEO 17 Video introducing a village pond from Annpur, Satjelia Island, Indian Sundarbans, with evidence of heavy organic matter input and consequent poor water quality. Narrated by T. Ghosh (2020). Photograph provided by T. Ghosh. Video produced by H. Moorhouse. Running time 00:24s
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/geo2.103

The most recent water-related policy in Bangladesh, the Bangladesh Water Act 2013, supersedes all previous water-related policies. However, there are multiple concerns with the policy that are relevant to the conservation of ponds. Primarily there are no guidelines relating to non-point pollution sources like fertiliser and pesticides. Secondly, the previous *Jalmahal* Management Policy allowed the leasing of *Jalmahals* (ponds) for aquaculture and included a set of environmental guidelines. But the new legislation does not include any information for the protection and enhancement of *Jalmahals* and their surrounding environment. Similar to India, there are few provisions for the monitoring of waters, with the Ministry of Water Resources, who are responsible for the monitoring of waters, not involved in the administration of the Bangladesh Water Act 2013, which is regulated by the Executive Committee of the National Water Resources Council.

In Vietnam, despite the encouragement of VAC, none of the major government Ministries deal specifically with pond management. The Ministry of Natural Resources and Environment are responsible for river channel water monitoring and the Ministry of Agriculture and Rural Development and the Ministry of Health are responsible for rural water supply and sanitation programmes, respectively. Cooperation among the different sectors for domestic water use (e.g., ponds) is therefore difficult and often problematic. Furthermore, the complexity of governance means that in some cases provincial policy is not aligned to national legislation. For example, in Minh Hai province (later becoming Ca Mau and Bac Lieu provinces; Mekong Delta) 66,253 ha of mangrove forests were converted into shrimp ponds between 1980 and 1995 as part of their benefit-sharing policy. This decision increased the forest-to-pond ratio 10–20% above the national regulation (Ha et al., 2012). Thus, more cohesive national to local policy is needed.

A lack of coordinated effort is a common story across tropical Asian delta regions with entrepreneurial ponds managed jointly by irrigation departments, fisheries departments, and district councils. However, there is huge potential for community-driven and community-led monitoring, management, and restoration of pond ecosystems. Furthermore, conserving and protecting the biodiversity of ponds is missing from all policy. With the correct management and conservation of ponds, it is possible to increase ecosystem wide biodiversity and help to manage hydrological regimes, facilitating management of ecosystem services and wildlife habitats.

7 | PONDS AND THE UN SUSTAINABLE DEVELOPMENT GOALS (SDGS)

The UN SDGs are universal goals aimed to build a sustainable and resilient global ecosystem and human community. With correct management, the sustainable use of ponds could play key roles for addressing many of the UN SDG objectives and associated targets, particularly those focused on provisional services (e.g., SDG 2 [zero hunger] and SDG 6 [clean water and sanitation]). For example, ponds are cited as important suppliers of nutrition in deltas, whilst improving the welfare and economic capacity of low-income, resource-poor and asset-poor households, thus satisfying the demands of SDG 2 (zero hunger) and SDG 1 (no poverty) (Ahmed & Lorica, 2002; Kale, 2017). Indeed there is argument that the aquaculture industry has been cited as having capacity to satisfy each of the 12 SDGs, but more so the core SDGs which focus on improvements to nutrition, poverty alleviation, and job provision (SDGs 1, 2, and 8 [decent work and economic growth]) (Hambrey, 2017). However, as discussed throughout this paper, economic growth (SDG 8) has occurred to the benefit of only a few, further reducing social mobility (counter to SDGs 5 [gender equality] and 10 [reduced inequalities]), and promoted intensive and extractive practices which have led to environmental degradation and risk to human health and exploitation of vulnerable communities (counteracting SDGs 12 [responsible consumption and production], 13 [climate action], 14 [life below water], and 15 [life on land]) (Hambrey, 2017). Thus, presently, ponds are not successfully reaching the targets set out by the SDGs, with higher human populations, climate instability, and economic deprivation in tropical mega-deltas, shifting societal priority away from biodiversity conservation and environmental health (i.e., SDGs 12, 13, 14, and 15) toward economic profit (Szabo et al., 2016).

When considering SDG 2 (food security), Asian mega-deltas themselves have been important "food baskets" for centuries because of the dynamic interplay of fresh and saline water, and delivery of fertile sediment during flood inundation, resulting in highly productive aquatic and terrestrial environments (Renaud et al., 2013). The easy access to wild seed and suitable bio-physical conditions in these systems are what has promoted extensive aquaculture development (Ahmed, 2013). Asian mega-delta ponds are globally important producers of aquaculture foods: Asia produced 90% of global aquaculture output in 2013 (FAO, 2015), and recent observations suggest 94% of the global aquaculture pond area is found here (Boyd et al., 2010), with India, Vietnam, and Bangladesh the second, fourth, and fifth largest Asian producers, respectively (FAO, 2014). To note, this overlooks smaller-scale operations which are important to local and regional food supply chains, and so, these statistics are likely underestimated (Allison, 2011). The sustainability of this current food production is questionable, threatened by socio-ecological challenges detailed in sections 2 and 3.

When considering SDG 6 (water security), delta ponds are often the only supply of "sweet" or fresh water for communities surrounded by brackish estuarine channels and/or who have saline or arsenic-polluted groundwater, and thus are vital systems to help satisfy most of the SDG 6 targets. However, given their current water quality problems and lack of management (see sections 4 and 5), evidence suggests that delta ponds presently are not fit enough to achieve this developmental target. Incentivised by SDG 6, the Bangladesh government has not only increased the number of public water points and piped water distribution, but developed a scheme named "Excavation and Re-excavation of Ponds for ensuring Safe Drinking Water" as part of its High Level Planning on Water activity (GED, 2018). Under this scheme, one pond per mauza (lowest administrative unit) would be protected from contamination, providing drinking water and water for other domestic uses which need minimal treatment (GED, 2018). To take the sanitation aspect of SDG 6, delta ponds currently do not provide safe and accessible sanitation. For example, the World Bank estimates that, as an example, 6.4% of India's GDP is lost due to the adverse economic impacts and costs of inadequate sanitation from poor public health (UN SDG, 2019), which means funds are spent tackling the symptoms not the root causes. Recent sanitation programmes often overlook different gendered, ethical, caste, technical, and financial needs and discrepancies resulting in limited success (Joshi et al., 2011). Altering traditional human behaviours will require multiple level governance and extensive financial input if delta ponds are to provide clean water and satisfy SDG 6.

This review has highlighted the complex nexus between environmental degradation and societal vulnerability, which surround Asian mega-delta ponds. However, the exploitation of delta environments and peoples has ultimately been driven by the distribution and inequity of large-scale global power and wealth distribution. For instance, capitalism has driven expansion and technological development which has led to the extraction of fossil fuels driving anthropogenic climate change (Clark & York, 2005). In addition, historical colonial expansion and displacement of peoples continues to explain re-settlement, conflict, and vulnerability to exploitative and environmentally degrading industries in post-colonial states (Jackson et al., 2020; Suhrke & Hazarika, 1993). Thus, in order to achieve real change and achievement of the SDGs it could be argued that these root causes need to be addressed. We hope that through highlighting the localised socio-ecological challenges that face delta ponds, this will bring reflection on the need to address the dominant neoliberal economic model; in other words, the structural causes of poverty and environmental degradation in the global South (McCloskey, 2015). This may range from reflecting on patterns of consumption to questioning global governments and institutions (Bello, 2015).

8 | FUTURE CHALLENGES

Deltas and their ponds will continue to face significant social and environmental challenges in the future. Delta human populations continue to expand and predicted increases in temperatures, flooding, intensity, and frequency of extreme events threaten the already degraded condition and ability of delta socio-ecological systems such as ponds to provide food and water security for future delta civilians (Figure 2) (Sivakumar & Stefanski, 2010). In addition, deltas, particularly the Mekong, are sinking and shrinking from land subsidence, over-abstraction of groundwater, and reduced sediment delivery (Anthony et al., 2015; Dunn et al., 2019; Minderhoud et al., 2020). This is resulting in the loss of large coastal areas inland and upstream via increased flooding and saline inundation (Boretti, 2020; Eslami et al., 2019). Furthermore, large-scale riverbed sand mining in upstream rivers of the Mekong Delta has reduced sediment accretion (Hackney et al., 2020), and is now recognised as a significant cause of subsidence and saltwater inundation (Anthony et al., 2015). Sand extraction and continued urbanisation has promoted increased industrial activity around construction materials such as brick kilns, widespread across Southern Asia. Additionally, continued environmental destruction from urbanisation, aquaculture expansion, and climate-mediated impacts result in those originally employed in traditional agricultural/forest livelihoods into industries with exploitation and modern slavery such as brick kilns or fish-processing camps as found in the Bangladesh Sundarbans (Jackson et al., 2020). Modern slavery can further exacerbate environmental degradation, leading to a positive feedback of vulnerable communities at risk of exploitation (Brown et al., 2019). For example, brick kilns have been found to cause degraded water quality of local ponds and surface waters, from increased turbidity and fluctuating pH via polluted run-off with high minerogenic content, and increased temperatures from heat emitted from the kilns (Dey & Dey, 2015). In fish-processing camps earthen ponds are created for both additional revenue from

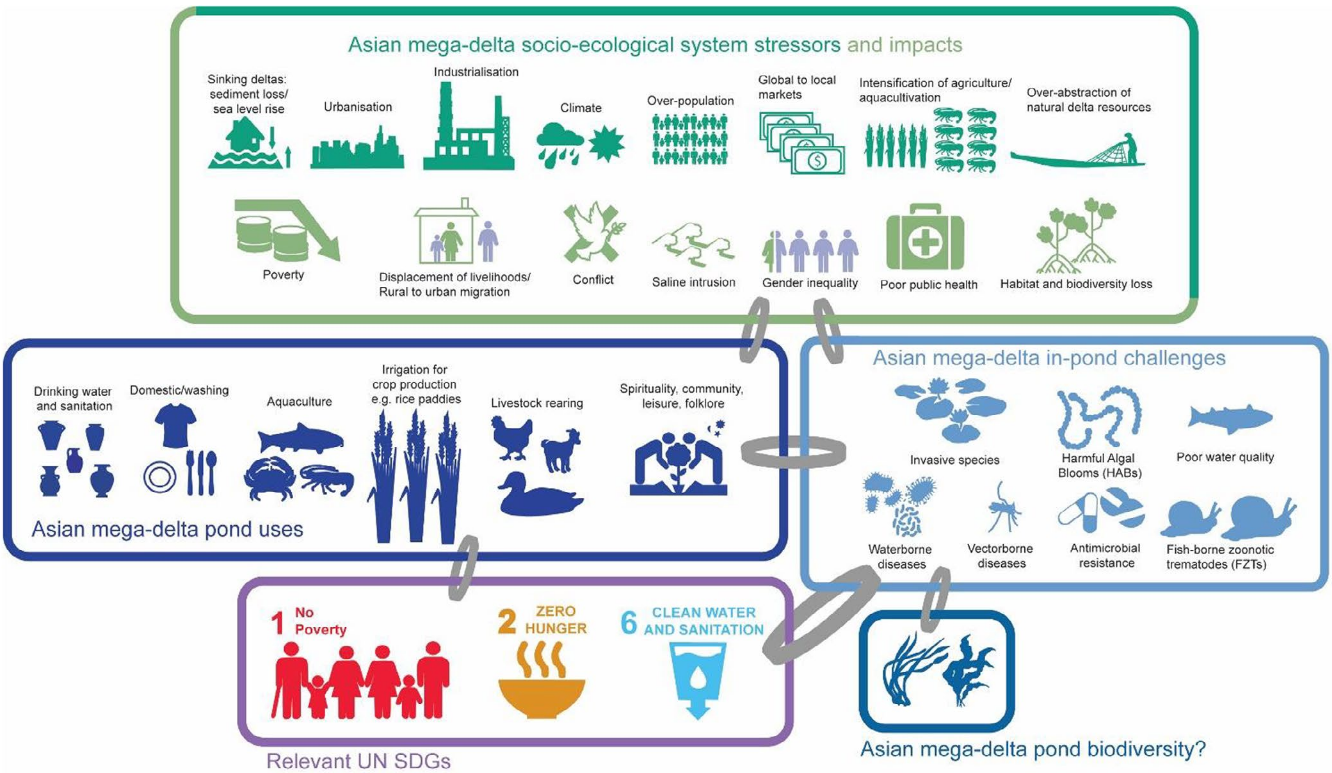


FIGURE 2 Summary diagram of the major Asian mega-delta socio-ecological stressors and impacts, Asian mega-delta pond uses and challenges, and the UN SDGs whose targets they attempt to address. Finally, the unknown entity of the biodiversity of Asian mega-delta pond ecosystems. This review paper attempts to document how these factors are linked

aquaculture and for drinking water, and as these camps expand so too does pond development leading to deforestation (Jackson et al., 2020). These practices exacerbate pollution, over-abstraction of natural resources, and water insecurity which then results in more vulnerable agricultural/forestry workers into debt bondage within these industries (Brickell et al., 2018; Brown et al., 2019). Ponds occupy a useful focal point to assess these social and environmental challenges which threaten the health of the wider delta ecosystem.

Predicted increases in extreme climatic events (Oppenheimer et al., 2019) threaten delta pond sustainability. As an example, extreme events could result in significant losses to aquaculture through increased prevalence of disease, modified salinity levels, and in the case of flooding, enabling livestock to escape (Christoplos et al., 2017). Following cyclones, aquaculture farmers reported significant alteration to the physio-chemical condition of ponds with increased storm debris (e.g., terrestrial organic matter; Video 17), death of aquatic organisms, and an increase in toxic pollutants (Ahmed & Diana, 2015). The decomposition of organisms and plant matter results in the lowering of pH, increased heterotrophic respiration, and so, the removal of oxygen for higher trophic species and emission of CO_2 and CH_4 from anaerobic processes (Alongi et al., 1999). Higher temperatures predicted in delta regions will also reduce the oxygen content of pond water, as warmer water has a lower dissolved oxygen saturation point, thus threatening farmed and other biological species that are not tolerant to low dissolved oxygen waters (Kam et al., 2012).

The COVID-19 pandemic of 2020–2021 has and will continue to alter how delta ponds are used and managed in the future. The pandemic has resulted in trade restrictions of foods, including aquaculture products, resulting in substantial economic losses, and a likely continued long-term decline in the market, threatening the livelihoods of those employed in the industry (FAO, 2020). For example, Bangladesh Sundarban crab and eel farmers have already suffered huge financial losses following the imposed import ban to China in late January 2020 (Roy, 2020). For crab farmers, China accounts for 85% of crabs exported and losses of US$46.90 million were already recorded by early April 2020 (Roy, 2020). This could result in any, or all, of the following in the near future: significant pond abandonment, return to intensive production where financial capacity allows, or conversion from intensive to more extensive local market production. Additionally, disruption to food supply chains and restrictions to food market access (FAO, 2020) may have amplified the reliance and significance of local homestead ponds in food provision; this was seen on Mousani Island, Indian Sundarbans during the Covid-19 pandemic, where ponds were used to support community sustenance following barriers to commercial markets (Chakraborty, 2020). Notwithstanding, this could intensify motivation from the household, community, and broader political actors to improve pond water quality. On the other hand, loss of income from access to work, particularly those already vulnerable to poverty such as rural to urban migrants common in deltas (Szabo et al., 2018), will reduce financial capacity to improve pond water quality. In addition, ponds of the GBM regions impacted by Cyclone Amphan, which hit late May 2020, will be even more at risk of collapse following the social and environmental disturbance of both compounding events.

9 | CONCLUSIONS

This review paper is one of the first to use multimedia to capture the sounds and sights of the natural-cultural identity of tropical Asian Mega-delta ponds. By recording the stories and voices of those who live and work in the deltas, a richer experience and depth of knowledge into the multi-functionality, daily life, and pondscapes of the Asian deltas will be attained, thus enriching the understanding of these complex socio-ecological systems. As tropical Asian mega-deltas and their ponds continue to face increasing environmental and societal pressures, there are several considerations that we recommend for the future sustainability of Asian mega-delta ponds: (1) the implementation of simple water quality assessment tools for ponds allowing communities to manage poor water quality and disease outbreaks more effectively; (2) the protection of ponds under national policy with financial assistance to prevent and respond to the negative consequences of extreme events (e.g., cyclones); (3) a more thorough understanding of the impacts of exchanges between pond water and surrounding waters; and (4) a comprehensive assessment of pond quality versus biodiversity, to improve their conservation and/or restoration.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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REFERENCES

Abedin, M.A., Habiba, U., & Shaw, R. (2014) Community perception and adaptation to safe drinking water scarcity: Salinity, arsenic, and drought risks in coastal Bangladesh. *International Journal of Disaster Risk Science*, 5(2), 110–124. https://link.springer.com/content/pdf/10.1007/s13753-014-0021-6.pdf

Action Aid. (2009) In-depth Recovery Needs Assessment of Cyclone Aila Affected Areas. Aila Response Programme Funded by ECHO, 25–31.

Adhikari, S., Ghosh, L., Rai, S., & Ayyappan, S. (2009) Metal concentrations in water, sediment, and fish from sewage-fed aquaculture ponds of Kolkata, India. *Environmental Monitoring and Assessment*, 159(1–4), 217. Available from: https://doi.org/10.1007/s10661-008-0624-8

Affan, A., Jewel, A.S., Haque, M., Khan, S., & Lee, J.B. (2005) Seasonal cycle of phytoplankton in aquaculture ponds in Bangladesh. *Algae*, 20, 43–52. https://doi.org/10.4490/ALGAE.2005.20.1.043

Ahmed, M. (1999) Policy issues deriving from the scope, determinants of growth, and changing structure of supply of fish and fishery products in developing countries. ICLARM Conference Proceedings (Philippines).

Ahmed, M., & Lorica, M.H. (2002) Improving developing country food security through aquaculture development—Lessons from Asia. *Food Policy*, 27(2), 125–141. Available from: https://doi.org/10.1016/S0306-9192(02)00007-6

Ahmed, N. (2013) Linking prawn and shrimp farming towards a green economy in Bangladesh: confronting climate change. *Ocean and Coastal Management*, 75, 33–42. Available from: https://doi.org/10.1016/j.ocecoaman.2013.01.002

Ahmed, N., & Diana, J.S. (2015) Threatening 'white gold': impacts of climate change on shrimp farming in coastal Bangladesh. *Ocean and Coastal Management*, 114, 42–52. Available from: https://doi.org/10.1016/j.ocecoaman.2015.06.008

Allison, E.H. (2011) Aquaculture, fisheries, poverty and food security. WorldFish Center Working Paper. Vol 65, pp 60. http://hdl.handle.net/1834/24445

Allison, M.A., Khan, S.R., Goodbred, S.L., & Kuehl, S.A. (2003) Stratigraphic evolution of the late Holocene Ganges-Brahmaputra lower delta plain. *Sedimentary Geology*, 155, 317–342. Available from: https://doi.org/10.1016/S0037-0738(02)00185-9

Alongi, D.M., Dixon, P., Johnston, D.J., Van Tien, D., & Xuan, T.T. (1999) Pelagic processes in extensive shrimp ponds of the Mekong delta, Vietnam. *Aquaculture*, 175, 121–141. Available from: https://doi.org/10.1016/S0044-8486(99)00078-2

Aly, S.M., & Albutti, A. (2014) Antimicrobials use in aquaculture and their public health impact. *Journal of Aquaculture Research and Development*, 5(4), 1. Available from: https://doi.org/10.4172/2155-9546.1000247

Amin, M.A. (2020) Cyclone Amphan salinates fresh water ponds in Sundarbans. Dhaka Tribune. Available at: https://www.dhakatribune.com/bangladesh/nation/2020/05/21/cyclone-amphan-salinates-fresh-water-ponds-in-sundarbans [Accessed 1st July, 2020]

Anh, N.T.L., Madsen, H., Dalsgaard, A., Phuong, N.T., Thanh, D.T.H., & Murrell, K.D. (2010) Poultry as reservoir hosts for fishborne zoonotic trematodes in Vietnamese fish farms. *Veterinary Parasitology*, 169(3–4), 391–394. Available from: https://doi.org/10.1016/j.vetpar.2010.01.010

Anthony, E.J., Brunier, G., Besset, M., Goichot, M., Dussouillez, P., & Nguyen, V.L. (2015) Linking rapid erosion of the Mekong River delta to human activities. *Scientific Reports*, 5(1), 1–12. Available from: https://doi.org/10.1038/srep14745

Attermeyer, K., Flury, S., Jayakumar, R., Fiener, P., Steger, K., Arya, V. et al. (2016) Invasive floating macrophytes reduce greenhouse gas emissions from a small tropical lake. *Scientific Reports*, 6, 20424. Available from: https://doi.org/10.1038/srep20424

Bello, W. (2015) Post-2015 development assessment: proposed goals and indicators. In G. McCann, & S. McCloskey (Eds.) *From the local to the global: key issues in development studies*, 3rd ed. London and New York: Pluto Press.

Belton, B., & Azad, A. (2012) The characteristics and status of pond aquaculture in Bangladesh. *Aquaculture*, 358–359, 196–204. Available from: https://doi.org/10.1016/j.aquaculture.2012.07.002

Belton, B., Haque, M.M., & Little, D.C. (2012) Does size matter? Reassessing the relationship between aquaculture and poverty in Bangladesh. *Journal of Development Studies*, 48(7), 904–922. Available from: https://doi.org/10.1080/00220388.2011.638049

Belton, B., Little, D.C., & Sinh, L.X. (2011) The social relations of catfish production in Vietnam. *Geoforum*, 42(5), 567–577. Available from: https://doi.org/10.1016/j.geoforum.2011.02.008

Benneyworth, L., Gilligan, J., Ayers, J.C., Goodbred, S., George, G., Carrico, A. et al. (2016) Drinking water insecurity: Water quality and access in coastal south-western Bangladesh. *International Journal of Environmental Health Research*, 26(5–6), 508–524. Available from: https://doi.org/10.1080/09603123.2016.1194383

Berkes, F., & Folke, C. (1998) Linking social and ecological systems for resilience and sustainability. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*, 1(4), 4. http://hdl.handle.net/10535/4352

Best, J. (2019) Anthropogenic stresses on the world's big rivers. *Nature Geoscience*, 12(1), 7–21. Available from: https://doi.org/10.1038/s41561-018-0262-x

Binh, T.N.K.D., Vromant, N., Hung, N.T., Hens, L., & Boon, E.K. (2005) Land cover changes between 1968 and 2003 In Cai Nuoc, Ca Mau Peninsula. *Vietnam. Environment, Development and Sustainability*, 7, 519–536. Available from: https://doi.org/10.1007/s10668-004-6001-z

Boretti, A. (2020) Implications on food production of the changing water cycle in the Vietnamese Mekong Delta. *Global Ecology and Conservation*, 22, e00989. Available from: https://doi.org/10.1016/j.gecco.2020.e00989

Bowes, M.J., Read, D.S., Joshi, H., Sinha, R., Ansari, A., Hazra, M. et al. (2020) Nutrient and microbial water quality of the upper Ganga River, India: identification of pollution sources. *Environmental Monitoring and Assessment*, 192(8), 533. Available from: https://doi.org/10.1007/s10661-020-08456-2

Boyd, C.E., Wood, C.W., Chaney, P.L., & Queiroz, J.F. (2010) Role of aquaculture pond sediments in sequestration of annual global carbon emissions. *Environmental Pollution*, 158(8), 2537–2540. Available from: https://doi.org/10.1016/j.envpol.2010.04.025

Brickell, K., Parsons, L., Natarajan, N., & Chann, S. (2018) *Blood bricks: untold stories of modern slavery and climate change from Cambodia*. London: Royal Holloway University of London. https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/15985

Brown, D., Boyd, D.S., Brickell, K., Ives, C.D., Natarajan, N., & Parsons, L. (2019) Modern slavery, environmental degradation and climate change: fisheries, field, forests and factories. *ENE: Nature and Space*, 4(2), 191–207. Available from: https://doi.org/10.1177/2514848619887156

Bunting, S.W., Pretty, J., & Edwards, P. (2010) Wastewater-fed aquaculture in the East Kolkata Wetlands, India: anachronism or archetype for resilient ecocultures? *Reviews in Aquaculture*, 2(3), 138–153. Available from: https://doi.org/10.1111/j.1753-5131.2010.01031.x

Bush, S.R., & Duijf, M. (2011) Searching for (un) sustainabilty in pangasius aquaculture: a political economy of quality in European retail. *Geoforum*, 42(2), 185–196. Available from: https://doi.org/10.1016/j.geoforum.2010.12.007

Bush, S.R., Khiem, N.T., & Sinh, L.X. (2009) Governing the environmental and social dimensions of pangasius production in vietnam: a review. *Aquaculture Economics and Management*, 13(4), 271–293. Available from: https://doi.org/10.1080/13657300903351594

Bush, S.R., & Kosy, S. (2007) Geographical distribution of investment in small-scale rural fish ponds. *Aquaculture Economics & Management*, 11, 285–311. Available from: https://doi.org/10.1080/13657300701530308

Buu, D.C., & Phuong, D. (1999) Selection of suitable mangrove species to rehabilitate the forests on high beds and embankments of shrimps ponds in Ca Mau. Presented at the Proceeding of the Scientific Workshop on Management and Sustainable Use of Natural Resources and Environment in Coastal Wetlands, Hanoi, pp. 1–3.

Cannon, T. (2002) Gender and climate hazards in Bangladesh. *Gender and Development*, 10(2), 45–50. Available from: https://doi.org/10.1080/13552070215906

Casé, M., Eskinazi Leça, E., Neumann Leitão, S., Eskinazi Sant, E., Schwamborn, R., de Moraes, T. et al. (2008) Plankton community as an indicator of water quality in tropical shrimp culture ponds. *Marine Pollution Bulletin*, 56(7), 1343–1352. Available from: https://doi.org/10.1016/j.marpolbul.2008.02.008

Central committee of the Communist Party, Vietnam (2020). Available at: http://vbpl.vn/TW/Pages/vbpq-toanvan.aspx?ItemID=6341 [Accessed 1st February, 2021]

Chakraborty, A. (2020) Sundarbans: Mousani eats better in lockdown. People's Archive of Rural India. Available at: https://ruralindiaonline.org/articles/sundarbans-mousani-eats-better-in-lockdown/ [Accessed 1st July, 2020].

Chan, F.K.S., Mitchell, G., Adekola, O., & McDonald, A. (2012) Flood risk in Asia's urban mega-deltas: drivers, impacts and response. *Environment and Urbanization ASIA*, 3(1), 41–61. Available at: https://doi.org/10.1177/097542531200300103

Chand, B., Trivedi, R., Biswas, A., Dubey, S., & Beg, M. (2012) Study on impact of saline water inundation on freshwater aquaculture in Sundarban using risk analysis tools. *Exploratory Animal and Medical Research*, 2, 170–178.

Chanda, A., Das, S., Bhattacharyya, S., Das, I., Giri, S., Mukhopadhyay, A. et al. (2019) CO_2 fluxes from aquaculture ponds of a tropical wetland: potential of multiple lime treatment in reduction of CO_2 emission. *Science of the Total Environment*, 655, 1321–1333. Available from: https://doi.org/10.1016/j.scitotenv.2018.11.332

Chatterjee, A., & Dewanji, A. (2014) Effect of varying Alternanthera philoxeroides (alligator weed) cover on the macrophyte species diversity of pond ecosystems: a quadrat-based study. *Aquatic Invasions*, 9(3), 343–355. Available from: https://doi.org/10.3391/ai.2014.9.3.09

Chowdhury, A.Z., Jahan, S.A., Islam, M.N., Moniruzzaman, M., Alam, M.K., Zaman, M.A. et al. (2012) Occurrence of organophosphorus and carbamate pesticide residues in surface water samples from the Rangpur district of Bangladesh. *Bulletin of environmental contamination and toxicology*, 89, 202–207. Available from: https://doi.org/10.1007/s00128-012-0641-8

Christensen, S.M., Tarp, P., & Hjortsø, C.N. (2008) Mangrove forest management planning in coastal buffer and conservation zones, Vietnam: a multimethodological approach incorporating multiple stakeholders. *Ocean and Coastal Management*, 51, 712–726. Available from: https://doi.org/10.1016/j.ocecoaman.2008.06.014

Christoplos, I., Ngoan, L.D., Sen, L.T.H., Huong, N.T.T., & Nguyen, H. (2017) Changing arenas for agricultural climate change adaptation in Vietnam. *Development in Practice*, 27(2), 132–142. Available from: https://doi.org/10.1080/09614524.2017.1285272

Clark, B., & York, R. (2005) Carbon metabolism: global capitalism, climate change, and the biospheric rift. *Theory and society*, 34(4), 391–428. https://doi.org/10.1007/s11186-005-1993-4

Clifford, J. (1983) On ethnographic authority. *Representations*, 2, 118–146. https://doi.org/10.2307/2928386

Colding, J., & Barthel, S. (2019) Exploring the social-ecological systems discourse 20 years later. *Ecology and Society*, 24(1), 2. Available from: https://doi.org/10.5751/ES-10598-240102

Crow, B., & Sultana, F. (2002) Gender, class, and access to water: three cases in a poor and crowded delta. *Soceity and Natural Resources*, 15(8), 709–724. Available from: https://doi.org/10.1080/08941920290069308

Dang, S.T.T., Petersen, A., Van Truong, D., Chu, H.T.T., & Dalsgaard, A. (2011) Impact of medicated feed on the development of antimicrobial resistance in bacteria at integrated pig-fish farms in Vietnam. *Applied and Environmental Microbiology*, 77(13), 4494–4498. Available from: https://doi.org/10.1128/AEM.02975-10

Davies, B., Biggs, J., Williams, P., Whitfield, M., Nicolet, P., Sear, D. et al. (2008) Comparative biodiversity of aquatic habitats in the European agricultural landscape. *Agriculture, Ecosystems & Environment*, 125, 1–8. Available from: https://doi.org/10.1016/j.agee.2007.10.006

Dayan, A.D., & Paine, A.J. (2001) Mechanisms of chromium toxicity, carcinogenicity and allergenicity: review of the literature from 1985 to 2000. *Human and Experimental Toxicology*, 20, 439–451. Available from: https://doi.org/10.1191/096032701682693062

Desvaux, S., Grosbois, V., Pham, T.T.H., Fenwick, S., Tollis, S., Pham, N.H. et al. (2011) Risk factors of highly pathogenic avian influenza H5N1 occurrence at the village and farm levels in the red river delta region in Vietnam. *Transboundary and Emerging Diseases*, 58(6), 492–502. Available from: https://doi.org/10.1111/j.1865-1682.2011.01227.x

Dey, M., Bose, M., & Alam, M. (2008). *Recommendation domains for pond aquaculture: Country case study: development and status of freshwater aquaculture in Bangladesh*.Working Paper, 1872, Penang, Malaysia: The WorldFish Center. https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/1564/WF_1104.pdf?sequence=1&isAllowed=y

Dey, N., Alam, M., Sajjan, A., Bhuiyan, M., Ghose, L., Ibaraki, Y. et al. (2011) Assessing environmental and health impact of drought in the Northwest Bangladesh. *Journal of Environmental Science and Natural Resources*, 4(2), 89–97. Available from: https://doi.org/10.3329/jesnr.v4i2.10141

Dey, S., & Dey, M. (2015) Deterioration and degradation of aquatic systems due to brick kiln industries-a study in cachar District. *Assam. Current World Environment*, 10(2), 467–472. Available from: https://doi.org/10.12944/CWE.10.2.10

Do, N.T., & Nishida, K. (2014) A nitrogen cycle model in paddy fields to improve material flow analysis: the Day-Nhue River Basin case study. *Nutrient Cycling in Agroecosystems*, 100(2), 215–226. Available from: https://doi.org/10.1007/s10705-014-9639-4

Do, T.N., Tran, V.B., Trinh, A.D., & Nishida, K. (2019) Quantification of nitrogen load in a regulated river system in Vietnam by material flow analysis. *Journal of Material Cycles and Waste Management*, 21(4), 974–983. Available from: https://doi.org/10.1007/s10163-019-00855-z

DPHE, & UNICEF, (1989) *A report on the development of pond sand filtration*. Dhaka, Bangladesh: Department of Public Health Engineering.

Dubey, S.K., Chand, B.K., Trivedi, R.K., Mandal, B., & Rout, S.K. (2016) Evaluation on the prevailing aquaculture practices in the Indian Sundarban delta: an insight analysis. *Journal of Food, Agriculture and Environment*, 14(2), 133–141.

Dubey, S.K., Trivedi, R.K., Chand, B.K., Mandal, B., & Rout, S.K. (2017) Farmers' perceptions of climate change, impacts on freshwater aquaculture and adaptation strategies in climatic change hotspots: a case of the Indian Sundarban delta. *Environmental Development*, 21, 38–51. Available from: https://doi.org/10.1016/j.envdev.2016.12.002

Dunn, F.E., Darby, S.E., Nicholls, R.J., Cohen, S., Zarfl, C., & Fekete, B.M. (2019) Projections of declining fluvial sediment delivery to major deltas worldwide in response to climate change and anthropogenic stress. *Environmental Research Letters*, 14, Available from: https://doi.org/10.1088/1748-9326/ab304e

Edmonds, D., Caldwell, R., Baumgardner, S., Paola, C., Roy, S., Nelson, A. et al. (2017) A global analysis of human habitation on river deltas. In *EGU General Assembly Conference Abstracts*, p. 10832.

EPA. (1999) *Environmental Protection Agency*. Integrated risk information system (IRIS) on Carbaryl National Center for Environmental Assessment.

EPCN. European Pond Conservation Network. Available from https://freshwaterhabitats.org.uk/wp-content/uploads/2016/06/EPCN-MANIFESTO.pdf [Accessed 2nd May, 2020]

Eslami, S., Hoekstra, P., Trung, N.N., Kantoush, S.A., Binh, D.V., Dung, D.D. et al. (2019) Tidal amplification and salt intrusion in the Mekong Delta driven by anthropogenic sediment starvation. *Scientific Reports*, 9, 18746. Available from: https://doi.org/10.1038/s41598-019-55018-9

FAO. (2015) *Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series*. Rome: FAO Fisheries and Aquaculture Department [online]. Updated 16 February 2015.

FAO. (2014) *The state of world fisheries and aquaculture*. Rome: FAO.

FAO. (2020). Q&A: COVID-19 pandemic—Impact on fisheries and aquaculture. http://www.fao.org/2019-ncov/q-and-a/impact-on-fisheries-and-aquaculture/en/ [Accessed 1st October, 2020]

Fu, B., Xu, P., Wang, Y., Yan, K., & Chaudhary, S. (2018) Assessment of the ecosystem services provided by ponds in hilly areas. *Science of the Total Environment*, 642, 979–987. Available from: https://doi.org/10.1016/j.scitotenv.2018.06.138

Furnas, M.J. (1992) The behavior of nutrients in tropical aquatic ecosystems. *Pollution in Tropical Aquatic Systems*, 1, 30–65.

Gammage, S., Swanburg, K., Khandkar, M., Islam, M.Z., Zobair, M., & Muzareba, A.M. (2006) *A gendered analysis of the shrimp sector in Bangladesh*. Greater Access to Trade and Expansion. USAID, Bangladesh.

GED. (2018) Sustainable Development Goals: Bangladesh First Progress Report 2018. SDGs Publication No. # 14, General Economics Division, Bangladesh Planning Commission, Ministry of Planning, Government of Bangladesh.

Ghosal, T., Kaviraj, A., & Das, B. (1997) Preliminary observation of heavy metal speciation in some brackish water ponds of Kakdwip and Tona of Sunderban, India. *Proceedings of the Zoological Society, Calcutta, India*, 50, 146–152.

Ghosh, P. (2015) Conservation and conflicts in the Sundarban biosphere reserve, India. *Geographical Review*, 105(4), 429–440. Available from: https://doi.org/10.1111/j.1931-0846.2015.12101.x

Goad, R.T., Goad, J.T., Atieh, B.H., & Gupta, R.C. (2004) Carbofuran-induced endocrine disruption in adult male rats. *Toxicology mechanisms and methods*, 14, 233–239. Available from: https://doi.org/10.1080/15376520490434476

Gorsky, A.L., Racanelli, G.A., Belvin, A.C., & Chambers, R.M. (2019) Greenhouse gas flux from stormwater ponds in southeastern Virginia (USA). *Anthropocene*, 28, 100218. Available from: https://doi.org/10.1016/j.ancene.2019.100218

Government of Bangladesh (2017) Technical Feasibility Report - Enhancing adaptive capacities of coastal communities, especially women, to cope with climate change induced salinity, Green Climate Fund Funding Proposal. Available at: https://www.greenclimate.fund/project/fp069 [Accessed 1st May, 2021]

Guhathakurta, H., & Kaviraj, A. (2004) Effects of salinity and mangrove detritus on desorption of metals from brackish water pond sediment and bioaccumulation in fish and shrimp. *Acta Hydrochimica et Hydrobiologica*, 32(6), 411–418. Available from: https://doi.org/10.1002/aheh.200400546

Ha, T.T.T., van Dijk, H., & Bush, S.R. (2012) Mangrove conservation or shrimp farmer's livelihood? The devolution of forest management and benefit sharing in the Mekong Delta, Vietnam. *Ocean and Coastal Management*, 69, 185–193. Available from: https://doi.org/10.1016/j.ocecoaman.2012.07.034

Habib, K.A., Kim, C.G., Oh, J., Neogi, A.K., & Lee, Y.H. (2017) *Aquatic biodiversity of sundarbans Bangladesh*, 2nd ed. Jeollanam-do, South Korea: Korea Institute of Ocean Science and Technology (KIOST).

Hackney, C.R., Darby, S.E., Parsons, D.R., Leyland, J., Best, J.L., Aalto, R. et al. (2020) River bank instability from unsustainable sand mining in the lower Mekong River. *Nature Sustainability*, 3, 217–225. Available from: https://doi.org/10.1038/s41893-019-0455-3

Hambrey, J. (2017) *The 2030 Agenda and the sustainable development goals: The challenge for aquaculture development and management*. FAO Fisheries and Aquaculture Circular, C1141.

Hamilton, S. (2013) Assessing the role of commercial aquaculture in displacing mangrove forest. *Bulletin of Marine Science*, 89, 585–601. Available from: https://doi.org/10.5343/bms.2012.1069

Haque, M.M., Belton, B., Alam, M.M., Ahmed, A.G., & Alam, M.R. (2016). Reuse of fish pond sediments as fertiliser for fodder grass production in Bangladesh: potential for sustainable intensification and improved nutrition. *Agriculture, Ecosystems and Environment*, 216, 226–236. Available from: https://doi.org/10.1016/j.agee.2015.10.004

Haque, M.I., Chowdhury, A.A., Shahjahan, M., & Harun, M.G.D. (2018) Traditional healing practices in rural Bangladesh: A qualitative investigation. *BMC Complementary and Alternative Medicine*, 18(1), 62. Available from: https://doi.org/10.1186/s12906-018-2129-5

Haque, M.Z., & Saifuzzaman, M. (2003) *Social and environmental effects of shrimp cultivation in Bangladesh: Notes on study methods*. Globalization, Environmental Crisis and Social Change in Bangladesh, Dhaka, Bangladesh, UPL.

Harun, M.A., & Kabir, G. (2013) Evaluating pond sand filter as sustainable drinking water supplier in the Southwest coastal region of Bangladesh. *Applied Water Science*, 3, 161–166. Available from: https://doi.org/10.1007/s13201-012-0069-7

Herbst, S., Benedikter, S., Koester, U., Phan, N., Berger, C., Rechenburg, A. et al. (2009) Perceptions of water, sanitation and health: a case study from the Mekong Delta. *Vietnam. Water Science and Technology*, 60(3), 699–707. Available from: https://doi.org/10.2166/wst.2009.442

Hill, M.J., Hassall, C., Oertli, B., Fahrig, L., Robson, B.J., Biggs, J. et al. (2018) New policy directions for global pond conservation. *Conservation Letters*, 11, e12447. Available from: https://doi.org/10.1111/conl.12447

Holgerson, M.A., & Raymond, P.A. (2016) Large contribution to inland water CO_2 and CH_4 emissions from very small ponds. *Nature Geoscience*, 9(3), 222–226. Available from: https://doi.org/10.1038/ngeo2654

Hossain, M.Y., Jasmine, S., Ibrahim, A.H.M., Ahmed, Z.F., Ohtomi, J., Fulanda, B. et al. (2007) A preliminary observation on water quality and plankton of an earthen fish pond in Bangladesh: recommendations for future studies. *Pakistan Journal of Biological Sciences*, 10, 868–873. Available from: https://doi.org/10.3923/pjbs.2007.868.873

Huda, K.M.S., Atkins, P.J., Donoghue, D.N.M., & Cox, N.J. (2010) Small water bodies in Bangladesh. *Area*, 42, 217–227. Available from: https://doi.org/10.1111/j.1475-4762.2009.00909.x

Inglis, V. (2000) *Antibacterial chemotherapy in aquaculture: review of practice, associated risks and need for action*. Presented at the Use of Chemicals in Aquaculture in Asia: Proceedings of the Meeting on the Use of Chemicals in Aquaculture in Asia 20-22 May 1996, Tigbauan, Iloilo, Philippines, Aquaculture Department, Southeast Asian Fisheries Development Center, pp. 7–22.

Inoue, T., & Asano, T. (2013) Characteristics of water quality and nitrogen-associated bacterial functions in Mekong delta mangroves. *Global Environmental Research*, 17, e206.

Islam, M.S., Begum, A., Khan, S.I., Sadique, M.A., Khan, M.N.H., Albert, M.J. et al. (2000) Microbiology of pond ecosystems in rural Bangladesh: its public health implications. *International Journal of Environmental Studies*, 58, 33–46. Available from: https://doi.org/10.1080/00207230008711315

Islam, M.M., Hofstra, N., & Islam, M.A. (2017) The impact of environmental variables on faecal indicator bacteria in the Betna river basin, Bangladesh. *Environmental Processes*, 4(2), 319–332. Available from: https://doi.org/10.1007/s40710-017-0239-6

Islam, M.S., Mahmuda, S., Morshed, M.G., Bakht, H.B.M., Khan, M.N.H., Sack, R.B. et al. (2004) Role of cyanobacteria in the persistence of *Vibrio cholerae* O139 in saline microcosms. *Canadian Journal of Microbiology*, 50, 127–131. Available from: https://doi.org/10.1139/w03-114

Islam, M.A., Sakakibara, H., Karim, M.R., Sekine, M., & Mahmud, Z.H. (2011) Bacteriological assessment of drinking water supply options in coastal areas of Bangladesh. *Journal of Water and Health*, 9(2), 415–428. Available from: https://doi.org/10.2166/wh.2011.114

Jackson, B., Boyd, D.S., Ives, C.D., Sparks, J.L.D., Foody, G.M., Marsh, S. et al. (2020) Remote sensing of fish-processing in the Sundarbans Reserve Forest, Bangladesh: an insight into the modern slavery-environment nexus in the coastal fringe. *Maritime Studies*, 19(4), 429–444. https://doi.org/10.1007/s40152-020-00199-7

Jahan, R., Khan, S., Haque, M.M., & Choi, J.K. (2010) Study of harmful algal blooms in a eutrophic pond, Bangladesh. *Environmental Monitoring and Assessment*, 170, 7–21. Available from: https://doi.org/10.1007/s10661-009-1210-4

Järup, L. (2003) Hazards of heavy metal contamination. *British Medical Bulletin*, 68, 167–182. Available from: https://doi.org/10.1093/bmb/ldg032

Jasovský, D., Littmann, J., Zorzet, A., & Cars, O. (2016) Antimicrobial resistance—A threat to the world's sustainable development. *Upsala Journal of Medical Sciences*, 121(3), 159–164. Available from: https://doi.org/10.1080/03009734.2016.1195900

Johnson, H.L., Liu, L., Fischer-Walker, C., & Black, R.E. (2010) Estimating the distribution of causes of death among children age 1–59 months in high-mortality countries with incomplete death certification. *International Journal of Epidemiology*, 39(4), 1103–1114. Available from: https://doi.org/10.1093/ije/dyq074

Johnston, D., Lourey, M., Van Tien, D., Luu, T.T., & Xuan, T.T. (2002) Water quality and plankton densities in mixed shrimp-mangrove forestry farming systems in Vietnam. *Aquaculture Research*, 33(10), 785–798. Available from: https://doi.org/10.1046/j.1365-2109.2002.00722.x

Joshi, D., Fawcett, B., & Mannan, F. (2011) Health, hygiene and appropriate sanitation: experiences and perceptions of the urban poor. *Environment and Urbanization*, 23(1), 91–111. Available from: https://doi.org/10.1177/0956247811398602

Kale, E. (2017) Problematic uses and practices of farm ponds in Maharashtra. *Economic and Political Weekly*, 52(3), 21.

Kam, S.P., Badjeck, M.C., Teh, L. & Tran, N. (2012) Autonomous adaptation to climate change by shrimp and catfish farmers in Vietnam's Mekong River delta. Working Paper. The WorldFish Center. Available at: http://hdl.handle.net/1834/26881

Keiser, J., & Utzinger, J. (2009) Food-borne trematodiases. *Clinical Microbiology Reviews*, 22(3), 466–483. Available from: https://doi.org/10.1128/CMR.00012-09

Khan, A.E., Ireson, A., Kovats, S., Mojumder, S.K., Khusru, A., Rahman, A. et al. (2011) Drinking water salinity and maternal health in coastal Bangladesh: implications of climate change. *Environmental Health Perspectives*, 119(9), 1328–1332. Available from: https://doi.org/10.1289/ehp.1002804

Kim, D.P., Saegerman, C., Douny, C., Dinh, T.V., Xuan, B.H., Vu, B.D. et al. (2013) First survey on the use of antibiotics in pig and poultry production in the Red River Delta region of Vietnam. *Food Public Health*, 3(5), 247–256. Available from: https://doi.org/10.5923/j.fph.20130305.03

Kondolf, G.M., Schmitt, R.J.P., Carling, P., Darby, S., Arias, M., Bizzi, S. et al. (2018) Changing sediment budget of the Mekong: cumulative threats and management strategies for a large river basin. *Science of the Total Environment*, 625, 114–134. Available from: https://doi.org/10.1016/j.scitotenv.2017.11.361

Kränzlin, I. (2000) Pond management in rural Bangladesh: problems and possibilities in the context of the water supply crisis. *Natural Resources Forum*, 24, 211–223. Available from: https://doi.org/10.1111/j.1477-8947.2000.tb00945.x

Kumar, S. (2011) Aquatic weeds problems and management in India. *Indian Journal of Weed Science*, 43, 118–138.

Kuroda, K., Hayashi, T., Watanabe, N., Oguma, K., Nga, T., & Takizawa, S. (2013) Influence of pond seepage on groundwater pollution by arsenic in Hanoi, Viet Nam. *Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research)*, 69, III_17-III_28. Available from: https://doi.org/10.2208/jscejer.69.III_17

Lewis-Phillips, J., Brooks, S., Sayer, C.D., McCrea, R., Siriwardena, G., & Axmacher, J.C. (2019) Pond management enhances the local abundance and species richness of farmland bird communities. *Agriculture, Ecosystems and Environment*, 273, 130–140. Available from: https://doi.org/10.1016/j.agee.2018.12.015

Lewis-Phillips, J., Brooks, S.J., Sayer, C.D., Patmore, I.R., Hilton, G.M., Harrison, A. et al. (2020) Ponds as insect chimneys: restoring overgrown farmland ponds benefits birds through elevated productivity of emerging aquatic insects. *Biological Conservation*, 241, 108253. Available from: https://doi.org/10.1016/j.biocon.2019.108253

Little, D.C., Karim, M., Turongruang, D., Morales, E.J., Murray, F.J., Barman, B.K. et al. (2007) Livelihood impacts of ponds in Asia-opportunities and constraints. In A.J. van der Zijpp, J.A.J. Verreth, M.E.F. van Mensvoort, R.H. Bosma, & M.C.M. Beveridge (Eds.), *Fish ponds in farming systems*. Wageningen, Netherlands: Wageningen Academic Publishers, pp. 177–202.

Little, D., & Muir, J. (1987) *A guide to integrated warm water aquaculture*. University of Stirling, Scotland, UK: Institute of Aquaculture.

Lun, Y. (2011) Water knowledge, use, and governance: tibetan participatory development along the Mekong (Langcangjiang) River, in Yunnan, China. *Water, cultural diversity, and global environmental change*. Netherlands and UNESCO/Jakarta: Springer, pp. 185–201.

Lutaenko, K.A., Prozorova, L.A., Quang, N.X., & Bogatov, V.V. (2019) First reliable record of Mytilopsis sallei (Récluz, 1849)(Bivalvia: Dreissenidae) in Vietnam. *Korean Journal of Malacology*, 35(4), 355–360. Available from: https://doi.org/10.9710/kjm.2019.35.4.355

Luttrell, C. (2006) Adapting to aquaculture in Vietnam: securing livelihoods in a context of change in two coastal communities. *Environment and Livelihoods in Tropical Coastal Zones: Managing Agriculture-Fishery-Aquaculture Conflicts*, 2, 17–29.

Luu, T.N.M., Do, T.N., Matiatos, I., Panizzo, V.N., & Trinh, A.D. (2020) Stable isotopes as an effective tool for N nutrient source identification in a heavily urbanized and agriculturally intensive tropical lowland basin. *Biogeochemistry*, 149, 17–35. Available from: https://doi.org/10.1007/s10533-020-00663-w

Macintosh, D.J. (1983) Fisheries and aquaculture significance of mangrove swamps, with special reference to the Indo-west Pacific region. In: J.F. Muir, & R.J. Roberts (Eds.) *Recent advances in aquaculture*. London: Croom Helm, pp. 5-85.

Manoj, K., & Padhy, P.K. (2015) Environmental perspectives of pond ecosystems: global issues, services and Indian scenarios. *Current World Environment*, 10, 848–867. Available from: https://doi.org/10.12944/CWE.10.3.16

Martin, M., Billah, M., Siddiqui, T., Black, R., & Kniveton, D. (2013) *Climate change, migration and human cognition in an Asian megadelta*. Working paper 1. RMMRU of University of Dhaka and SCMR of University of Sussex research on Climate Change related migration in Bangladesh, Supported by Climate and Development Knowledge Network (CDKN),

McCloskey, S. (2015) From MDGs to SDGs: we need a critical awakening to succeed. *Policy and Practice: A Development Education Review*, 12(20), 186–194.

McLane, J.R. (1993) *Land and local Kingship in Eighteenth Century Bengal, South Asian Studies*. Cambridge: Cambridge University Press, p. 53.

Men, B.X., Ogle, B., & Preston, T. (1995) Use of duckweed (*Lemna* spp) as replacement for soya bean meal in a basal diet of broken rice for fattening ducks. *Livestock Research for Rural Development*, 7(3), 5–8. http://www.fao.org/ag/aga/AGAP/frg/lrrd/lrrd7/3/2.htm

Merritt, R.W., Benbow, M.E., & Small, P.L. (2005) Unraveling an emerging disease associated with disturbed aquatic environments: the case of Buruli ulcer. *Frontiers in Ecology and the Environment*, 3(6), 323–331. Available from: https://doi.org/10.1890/1540-9295(2005)003[0323:UAEDAW]2.0.CO;2

Miah, M.G., Bari, M.N., & Rahman, M.A. (2003) Agricultural activities and their impacts on the ecology and biodiversity of the Sundarbans area of Bangladesh. *Journal of the National Science Foundation of Sri Lanka*, 31(1-2), 1–2. Available from: https://doi.org/10.4038/jnsfsr.v31i1-2.3032

Minderhoud, P., Middelkoop, H., Erkens, G., & Stouthamer, E. (2020) Groundwater extraction may drown mega-delta: Projections of extraction-induced subsidence and elevation of the Mekong delta for the 21st century. *Environmental Research Communications*, 2(1), 011005. Available from: https://doi.org/10.1088/2515-7620/ab5e21

Mitra, A., & Ghosh, R. (2014) Bioaccumulation pattern of heavy metals in commercially important fishes on and around Indian Sundarbans. *Global Journal of Animal Scientific Research*, 2, 33–44. http://hdl.handle.net/10535/9269

Mookherjee, D., Raihan, S., Jalal, M.J.E., Sharmin, E., & Eusuf. (2020) Chapter 9: Challenges in land administration and management in Bangladesh. (WP20/BDID[09]). Economic Development & Institutions.

Mukherjee, R., Halder, D., Saha, S., Shyamali, R., Subhranshu, C., Ramakrishnan, R. et al. (2011) Five Pond-centred Outbreaks of Cholera in Villages of West Bengal, India: evidence for focused interventions. *Journal of Health, Population and Nutrition*, 29, 421–428. Available from: https://doi.org/10.3329/jhpn.v29i5.8895

Mukhopadhyay, G., & Dewanji, A. (2005) Presence of tropical hydrophytes in relation to limnological parameters - A study of two fresh-water ponds in Kolkata, India. *Annales de Limnologie - International Journal of Limnology*, 41(4), 281–289. http://dx.doi.org/10.1051/limn/2005019

Nam, V., Thi Yen, N., Holynska, M., Reid, J., & Kay, B. (2000) National progress in dengue vector control in Vietnam: survey for Mesocyclops (Copepoda), Micronecta (Corixidae), and fish as biological control agents. *The American Journal of Tropical Medicine and Hygiene*, 62, 5–10. Available from: https://doi.org/10.4269/ajtmh.2000.62.5

Neumann, R.B., Ashfaque, K.N., Badruzzaman, A., Ali, M.A., Shoemaker, J.K., & Harvey, C.F. (2010) Anthropogenic influences on groundwater arsenic concentrations in Bangladesh. *Nature Geoscience*, 3, 46–52. Available from: https://doi.org/10.1038/ngeo685

Ngoc, T., & Demaine, H. (1996) Potentials for different models for freshwater aquaculture development in the Red River Delta (Vietnam) using GIS analysis, Naga. *The ICLARM Quarterly*, 19, 29–32.

Nguyen, M.T., Renaud, F.G., & Sebesvari, Z. (2019) Drivers of change and adaptation pathways of agricultural systems facing increased salinity intrusion in coastal areas of the Mekong and Red River deltas in Vietnam. *Environmental Science and Policy*, 92, 331–348. Available from: https://doi.org/10.1016/j.envsci.2018.10.016

Nhan, D.K., Duong, L.T., Sanh, N.V., & Verdegem, M.C. (2005) Development of 'VAC' Integrated Farming Systems in the Mekong Delta, Vietnam-A View of a System and a Participatory Approach. Development of Integrated Agiculture Farming Systems in the Mekong Delta. Tuoitre, 101–125.

Nhan, D.K., Phong, L.T., Verdegem, M.J.C., Duong, L.T., Bosma, R.H., & Little, D.C. (2007) Integrated freshwater aquaculture, crop and live-stock production in the Mekong delta, Vietnam: determinants and the role of the pond. *Agricultural Systems*, 94, 445–458. Available from: https://doi.org/10.1016/j.agsy.2006.11.017

Nhung, T.T., Le Vo, P., Van Nghi, V., & Bang, H.Q. (2019) Salt intrusion adaptation measures for sustainable agricultural development under climate change effects: a case of Ca Mau Peninsula. *Vietnam. Climate Risk Management*, 23, 88–100. Available from: https://doi.org/10.1016/j.crm.2018.12.002

Ohba, S., Huynh, T.T., Le, L.L., Ngoc, H.T., Le Hoang, S., & Takagi, M. (2011) Mosquitoes and their potential predators in rice agroecosystems of the Mekong Delta, Southern Vietnam. *Journal of the American Mosquito Control Association*, 27(4), 384–392. Available from: https://doi.org/10.2987/11-6163.1

Ohba, S., Van Soai, N., Van Anh, D.T., Nguyen, Y.T., & Takagi, M. (2015) Study of mosquito fauna in rice ecosystems around Hanoi, Northern Vietnam. *Acta Tropica*, 142, 89–95. Available from: https://doi.org/10.1016/j.actatropica.2014.11.002

Oppenheimer, M., Glavovic, B., Hinkel, J., van de Wal, R., Magnan, A.K., Abd-Elgawad, A. et al. (2019) Sea level rise and implications for low lying islands, coasts and communities. In: H.-O. Pörtner, D.C.R.V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N.M. Weyer (Eds.) *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*.

Ottinger, M., Clauss, K., & Kuenzer, C. (2016) Aquaculture: relevance, distribution, impacts and spatial assessments–a review. *Ocean and Coastal Management*, 119, 244–266. Available from: https://doi.org/10.1016/j.ocecoaman.2015.10.015

Panigrahy, S., Murthy, T., Patel, J., & Singh, T. (2012) Wetlands of India: inventory and assessment at 1: 50,000 scale using geospatial techniques. *Current Science*, 852–856. https://www.jstor.org/stable/24084499

Phan, V.T., Ersbøll, A.K., Nguyen, T.T., Nguyen, K.V., Nguyen, H.T., Murrell, D. et al. (2010) Freshwater aquaculture nurseries and infection of fish with zoonotic trematodes, Vietnam. *Emerging Infectious Diseases*, 16(12), 1905–1909. Available from: https://doi.org/10.3201/eid1612.100422

Pokhrel, Y., Burbano, M., Roush, J., Kang, H., Sridhar, V., & Hyndman, D.W. (2018) A review of the integrated effects of changing climate, land use, and dams on Mekong river hydrology. *Water*, 10(3), 266. Available from: https://doi.org/10.3390/w10030266

Prein, M. (2002) Integration of aquaculture into crop–animal systems in Asia. *Agricultural systems*, 71, 127–146. Available from: https://doi.org/10.1016/S0308-521X(01)00040-3

Pucher, J., Mayrhofer, R., El-Matbouli, M., & Focken, U. (2015) Pond management strategies for small-scale aquaculture in northern Vietnam: fish production and economic performance. *Aquaculture International*, 23, 297–314. Available from: https://doi.org/10.1007/s10499-014-9816-0

Rabbani, G., Rahman, A., Khandaker, M., & Shoef, I.J. (2013) *Loss and damage from salinity intrusion in Sathkira District, coastal Bangladesh. Loss and Damage in Vulnerable Countries Initiative, case study report*. Bonn: United Nations University Institute for Environment and Human Security.

Rabbani, M.G., Rahman, S.H., & Munira, S. (2018) Prospects of pond ecosystems as resource base towards community based adaptation (CBA) to climate change in coastal region of Bangladesh. *Journal of Water and Climate Change*, 9(1), 223–238. Available from: https://doi.org/10.2166/wcc.2017.047

Rahman, M. (2000) Pestcides: their uses and problems in context of Bangladesh. Presented at the National Workshop on conventional and nuclear Technique for Pesticide Residues studies in Food and Environment at IFRB, pp.15–19.

Rahman, M.M., Giedraitis, V.R., Lieberman, L.S., Akhtar, T., & Taminskiene, V. (2013) Shrimp cultivation with water salinity in Bangladesh: the implications of an ecological model. *Universal Journal of Public Health*, 1(3), 131–142. Available from: https://doi.org/10.13189/ujph.2013.010313

Rahman, M.M., Rahman, M.M., & Islam, K.S. (2010) The causes of deterioration of Sundarban mangrove forest ecosystem of Bangladesh: conservation and sustainable management issues. *Aquaculture, Aquarium, Conservation and Legislation*, 3, 77–90. https://hdl.handle.net/10535/6481

Ramsar Convention Secretariat (2010) *Designating Ramsar Sites: Strategic Framework and guidelines for the future development of the List of Wetlands of International Importance, Ramsar handbooks for the wise use of wetlands*, Vol. 17, 4th ed. Gland, Switzerland: Ramsar Convention Secretariat.

Rauh, V.A., Garfinkel, R., Perera, F.P., Andrews, H.F., Hoepner, L., Barr, D.B. et al. (2006) Impact of prenatal chlorpyrifos exposure on neurodevelopment in the first 3 years of life among inner-city children. *Pediatrics*, 118, e1845–e1859. Available from: https://doi.org/10.1542/peds.2006-0338

Renaud, F.G., Syvitski, J.P., Sebesvari, Z., Werners, S.E., Kremer, H., Kuenzer, C. et al. (2013) Tipping from the Holocene to the Anthropocene: how threatened are major world deltas? *Current Opinion in Environmental Sustainability*, 5(6), 644–654. Available from: https://doi.org/10.1016/j.cosust.2013.11.007

Roy, M., & Nandi, N.C. (2010) Effect of insolation and overhead canopy on macrozoobenthos of tropical freshwater ponds. *Russian Journal of Ecology*, 41(5), 428–435. Available from: https://doi.org/10.1134/S1067413610050115

Roy, P. (2020) Coronavirus destroys Bangladesh's crab exports. Eco-Business. Available at: https://www.eco-business.com/news/coronavirus-destroys-bangladeshs-crab-exports/ [Accessed 1st February, 2021]

Rudra, K. (2018) Conflicts over sharing the waters of transboundary rivers. In: *Rivers of the Ganga-Brahmaputra-Meghna delta*. Cham: Springer, pp. 163–172.

Salehin, M., Chowdhury, M.M.A., Clarke, D., Mondal, S., Nowreen, S., Jahiruddin, M. et al. (2018) Mechanisms and drivers of soil salinity in coastal Bangladesh. In: *Ecosystem services for well-being in deltas*. Cham: Palgrave Macmillan, pp. 333–347.

Sathiadhas, R., & Najmudeen, T. (2004) Economic evaluation of mud crab farming under different production systems in India. *Aquaculture Economics and Management*, 8(1–2), 99–110. Available from: https://doi.org/10.1080/13657300409380355

Satpati, G.G., Barman, N., & Pal, R. (2013) A study on green algal flora of Indian Sundarbans mangrove forest with special reference to morphotaxonomy.

Schriewer, A., Odagiri, M., Wuertz, S., Misra, P.R., Panigrahi, P., Clasen, T. et al. (2015) Human and animal fecal contamination of community water sources, stored drinking water and hands in rural India measured with validated microbial source tracking assays. *The American Journal of Tropical Medicine and Hygiene*, 93(3), 509–516. Available from: https://doi.org/10.4269/ajtmh.14-0824

Schummer, M.L., Palframan, J., McNaughton, E., Barney, T., & Petrie, S.A. (2012) Comparisons of Bird, aquatic macroinvertebrate, and plant communities among dredged ponds and natural wetland habitats at long point, Lake Erie, Ontario. *Wetlands*, 32, 945–953. Available from: https://doi.org/10.1007/s13157-012-0328-2

Selakovic, S., de Ruiter, P.C., & Heesterbeek, H. (2014) Infectious disease agents mediate interaction in food webs and ecosystems. *Proceedings of the Royal Society B: Biological Sciences*, 281(1777), 20132709. Available from: https://doi.org/10.1098/rspb.2013.2709

Sivakumar, M.V., & Stefanski, R. (2010) Climate change in South Asia. *Climate change and food security in South Asia*. Dordrecht: Springer, pp. 13–30.

Stark, M.T. (2006) Early mainland Southeast Asian landscapes in the first millennium AD. *Annual Review of Anthropology*, 35, 407–432. Available from: https://doi.org/10.1146/annurev.anthro.35.081705.123157

Stewart, R.I., Andersson, G.K., Brönmark, C., Klatt, B.K., Hansson, L.-A., Zülsdorff, V. et al. (2017) Ecosystem services across the aquatic–terrestrial boundary: linking ponds to pollination. *Basic and Applied Ecology*, 18, 13–20. Available from: https://doi.org/10.1016/j.baae.2016.09.006

Suchana, S.B., Soud, S.I. & Trisha, S.H. (2020) Restoration and Transformation of Small Stagnant Urban Water bodies (ponds) of Dhaka for Sustainability.

Suhrke, A., & Hazarika, S. (1993) *Pressure points: environmental degradation, migration and conflict*. Cambridge, MA: American Academy of Arts and Sciences.

Szabo, S., Adger, W.N., & Matthews, Z. (2018) Home is where the money goes: migration-related urban-rural integration in delta regions. *Migration and Development*, 7(2), 163–179. Available from: https://doi.org/10.1080/21632324.2017.1374506

Szabo, S., Brondizio, E., Renaud, F.G., Hetrick, S., Nicholls, R.J., Matthews, Z. et al. (2016) Population dynamics, delta vulnerability and environmental change: comparison of the Mekong, Ganges-Brahmaputra and Amazon delta regions. *Sustainability Science*, 11(4), 539–554. Available from: https://doi.org/10.1007/s11625-016-0372-6

Thai, T.T., & Quang, N.X. (2018) Assessment of the ecological quality status of sediment in the organic shrimp farming ponds using Azti" s marine biotic index based on marobenthic communities. *VNU Journal of Science: Natural Sciences and Technology*, 34, 29–40. Available from: https://doi.org/10.25073/2588-1140/vnunst.4733

Thai, T.T., Yen, N.T.M., Tho, N., & Quang, N.X. (2017) Meiofauna in the mangrove–shrimp farms ponds, Ca Mau province. *Vietnam Journal of Science and Technology*, 55, 271–284.

Thakur, J. (2020) Hit by cyclone Amphan, villages in Sunderbans face drinking water crisis. Hindustan Times. Available at: https://www.hindustantimes.com/india-news/hit-by-cyclone-amphan-villages-in-sunderbans-face-drinking-water-crisis/story-BNVxcKQ72yufsOG5LDOZII.html [Accessed 1st February, 2021]

Thien, P.C., Madsen, H., Nga, H.T.N., Dalsgaard, A., & Murrell, K.D. (2015) Effect of pond water depth on snail populations and fish-borne zoonotic trematode transmission in juvenile giant gourami (*Osphronemus goramy*) aquaculture nurseries. *Parasitology International*, 64(6), 522–526. Available from: https://doi.org/10.1016/j.parint.2015.07.005

Tho, N., Merckx, R., & Ngoc Ut, V. (2014) Impacts of saline water irrigation and shrimp pond discharges on the surrounding waters of a coastal district in the Mekong delta of Vietnam. *Environmental earth sciences*, 71, 2015–2027. Available from: https://doi.org/10.1007/s12665-013-2603-9

Tho, N., Vromant, N., Hung, N.T., & Hens, L. (2006) Organic pollution and salt intrusion in Cai Nuoc District, Ca Mau Province. *Vietnam. Water Environment Research*, 78, 716–723. Available from: https://doi.org/10.2175/106143006X101755

UN. (2019) *'Transformational benefits' of ending outdoor defecation: why toilets matter*. United Nations News. Available at: https://www.un.org/development/desa/en/news/sustainable/world-toilet-day2019.html. [Accessed 1st May, 2020]

UN SDG. (2019) *Webpage: United Nations, Sustainable Development Goals, Goal 6*. Ensure access to water and sanitation for all. Available at: https://www.un.org/sustainabledevelopment/water-and-sanitation/. [Accessed 1st May, 2020]

University of Nottingham Rights Lab. (2018) Modern Slavery, Environmental Destruction and Climate Change: Fisheries, Field, Forests and Factories. A research report from the University of Nottingham's Rights Lab, Royal Holloway University of London, and the Independent Anti-Slavery Commissioner. 38 pp.

Upadhyay, B. (2005) Women and natural resource management: illustrations from India and Nepal. *Natural Resources Forum*, 29(3), 224–232. Available from: https://doi.org/10.1111/j.1477-8947.2005.00132.x

Van Liere, W.J. (1980) Traditional water management in the lower Mekong Basin. *World Archaeology*, 11, 265–280. Available from: https://doi.org/10.1080/00438243.1980.9979766

Venugopal, G. (1998) Monitoring the effects of biological control of water hyacinths using remotely sensed data: a case study of Bangalore. *India. Singapore Journal of Tropical Geography*, 19(1), 91–105. Available from: https://doi.org/10.1111/1467-9493.00027

Vuong, D.Q.T., & Lin, C.K. (2001) Rice-shrimp farming in the seawater intrusion zone of the Mekong delta, Vietnam. *ITCZM Monograph*, 6

Warne, K. (2012) *Let them eat shrimp: the tragic disappearance of the rainforests of the sea*. Washington, DC: Island Press.

Wassmann, R., Hien, N.X., Hoanh, C.T., & Tuong, T.P. (2004) Sea level rise affecting the vietnamese mekong delta: water elevation in the flood season and implications for rice production. *Climatic Change*, 66, 89–107. Available from: https://doi.org/10.1023/B:CLIM.0000043144.69736.b7

Wassmann, R., Jagadish, S.V.K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A. et al. (2009) Chapter 3 regional vulnerability of climate change impacts on asian rice production and scope for adaptation. In: *Advances in agronomy*. Amsterdam, Netherlands: Elsevier, pp. 91–133.

Welker, M., Chorus, I., Fastner, J., Khan, S., Haque, M.M., Islam, S. et al. (2005) Microcystins (cyanobacterial toxins) in surface waters of rural Bangladesh: pilot study. *Journal of Water and Health*, 3, 325–337. Available from: https://doi.org/10.2166/wh.2005.009

Weterings, R., Umponstira, C., & Buckley, H.L. (2018) Landscape variation influences trophic cascades in dengue vector food webs. *Science Advances*, 4(2), eaap9534. Available from: https://doi.org/10.1126/sciadv.aap9534

Wilbers, G.J., Becker, M., Nga, L.T., Sebesvari, Z., & Renaud, F.G. (2014) Spatial and temporal variability of surface water pollution in the Mekong Delta, Vietnam. *Science of the Total Environment*, 485–486, 653–665. Available from: https://doi.org/10.1016/j.scitotenv.2014.03.049

Woodroffe, C.D., Nicholls, R.J., Saito, Y., Chen, Z., & Goodbred, S.L. (2006) Landscape variability and the response of Asian megadeltas to environmental change. In: *Global change and integrated coastal management*. Dordrecht: Springer, pp. 277–314.

Yang, P., Zhang, Y., Lai, D.Y., Tan, L., Jin, B., & Tong, C. (2018) Fluxes of carbon dioxide and methane across the water–atmosphere interface of aquaculture shrimp ponds in two subtropical estuaries: the effect of temperature, substrate, salinity and nitrate. *Science of the Total Environment*, 635, 1025–1035. Available from: https://doi.org/10.1016/j.scitotenv.2018.04.102

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