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Challenges and considerations of applying nature-based solutions in low- and middle-income countries in Southeast and East Asia

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Abstract

Low- and middle-income countries in Southeast and East Asia face a range of challenges related to the rapid pace of urbanisation in the region, the scale of pollution, climate change, loss of ecosystem services and associated difficulties for ecological restoration. Possible pathways towards a more sustainable future lie in the applications of nature-based solutions (NBS). However, there is relatively little literature on the application of NBS in the region, particularly Southeast Asia. In this paper we address this gap by assessing the socio-ecological challenges to the application of NBS in the region – one of the most globally biodiverse. We first provide an overview and background on NBS and its underpinnings in biodiversity and ecosystem services. We then present a typology describing five unique challenges for the application of NBS in the region: (1) Characteristics of urbanisation; (2) Biophysical environmental and climatic context; (3) Environmental risks and challenges for restoration; (4) Human nature relationships and conflicts; and (5) Policy and governance context. Exploiting the opportunities through South-South and North-South collaboration to address the challenges of NBS in Southeast and East Asia needs to be a priority for government, planners and academics.

Key words: blue-green infrastructure, China, ecosystem services, nature-based solutions, Southeast Asia, Sponge cities

Highlights

- Most research on Nature-Based Solutions (NBS) is in high income nations with low population growth rates and regulated urban planning.
- Urban blue-green infrastructure is being degraded in low and middle-income Southeast and East Asian countries.
- Applications of NBS in the region need to address the unique socio-ecological challenges.
- We provide an overview of key knowledge gaps to support the implementation of NBS.

INTRODUCTION

Urbanisation is occurring rapidly across the globe. By 2050 over 60% of the global population is projected to be urban, compared with 30% in 1950 (United Nations 2018) (Figure 1). Rapid urbanisation combined with pressures like climate change, biodiversity loss and increased greenhouse emissions have inter-connected effects on human health and well-being, infrastructure and governance systems (Díaz *et al.* 2019; Elmqvist *et al.* 2019). As well as experiencing major population growth, many low- and middle-income Asian countries have undergone rapid urbanisation. Approximately 65 and 78% of populations or ~1.8 billion people in Southeast Asia and East Asia, respectively, are projected to reside in urban areas by 2050 compared to 18 and 16% in 1950 (Schneider *et al.* 2015;

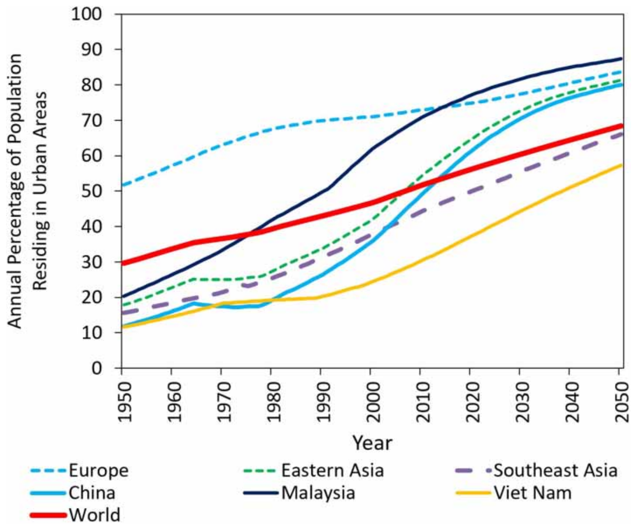

Figure 1 | Percentage of population residing in urban areas in Asia; historical and projected (Data from United Nations (2018) World Urbanization Prospects). Malaysia is the most urbanised low- and middle-income nation in 2050 and Viet nam is the least in Southeast Asia.

Figure 1). These numbers indicate an unprecedented and rapidly changing context, already manifesting new and complex environmental challenges. China has experienced some of the most rapid changes; for example, the population of the Chinese cities of Shenzhen and Guangzhou have grown 30- and 10-fold respectively from the late 1970s (Chan *et al.* 2012). This rapid growth within a few decades has transformed them into megacities with populations of over 10 million (Chan *et al.* 2012) and levels of urbanisation of almost 100% (Yeung 2011).

The rapid and often poorly managed growth witnessed in many low- and middle-income Southeast and East Asian cities has resulted in decreased quality of life (hereafter, for brevity when we refer to Southeast and East Asia we are referring to low- and middle-income countries or locations) (The OECD Development Assistance Committee (OECD) Development Assistance Committee (DAC) list the low income (least developed) countries in Southeast and East Asia as Cambodia, Democratic People's Republic of Korea, Lao PDR, Myanmar and Timor-Leste (OECD, 2020). The middle-income countries are China (People's Republic of), Indonesia, Malaysia, Philippines, Thailand and Viet Nam (OECD, 2020). Note that North Korea was not included due to a lack of data.). Despite the desire to move to urban areas (Hee & Dunn 2013; Aritenang 2014), 'liveability' in cities is often very poor and inhabitants face issues such as congestion, poor housing conditions (Ellis & Roberts 2016), water and/or air pollution (Zhang *et al.* 2018; Khan & Zhao 2019) and loss of natural blue-green spaces in pursuit of space for buildings (Mohd Noor *et al.* 2013; Yen *et al.* 2017). Furthermore, the continued loss of mangrove forests (Richards & Friess 2016), rising seas and change in weather patterns due to climate change are increasing the exposure of populations in coastal cities to hydro-meteorological hazards (Brander *et al.* 2012).

NBS can support the management of pressing issues related to urbanisation. NBS incorporate connected green (i.e. vegetation), blue (i.e. water) and grey (i.e. unsealed roads) infrastructure in order to improve environmental, social, cultural and economic conditions in cities (Lafortezza *et al.* 2017; Nesshöver *et al.* 2017; van den Bosch & Ode Sang 2017). In recent years, the concept has become established 'within the spectrum of ecosystem-based approaches' (Faivre *et al.* 2017) enabling researchers and practitioners to find innovative solutions by using nature to address urban challenges. NBS use natural ecosystem processes and functions to provide services that, for instance, help alleviate flood risk, provide water supply and wastewater treatment needs of urban residents through various approaches such as sustainable drainage systems (SusDrain) and water sensitive urban design (WSUD) (Li *et al.* 2017; Pauleit *et al.* 2017; O'Donnell *et al.* 2020). Blue-green infrastructure

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also helps support biodiversity and so have an important positive effect not only on the environment but also on residents' well-being (i.e. cultural ecosystem services), and support tourism (Nesshöver *et al.* 2017; Raymond *et al.* 2017). An important element of NBS scholarship has emphasised how multi-level governance and knowledge co-creation and participatory approaches can support implementation (Raymond *et al.* 2017; Bulkeley *et al.* 2019; Frantzeskaki *et al.* 2019).

The NBS approach is currently being applied extensively in Europe (Calliari *et al.* 2019; Dumitru *et al.* 2020; Frantzeskaki 2019; O'Donnell *et al.* 2020; Oral *et al.* 2020) and multiple NBS research and demonstration projects are showing its benefits for addressing urbanisation and other challenges, including adaptation to climate change. These projects include NATURVATION, Connecting Nature, CLEVER Cities, NAIAD, UNALAB and Grow Green (see Think Nature (2020) and Natural Hazards Nature-based Solutions (2017) platforms for a comprehensive list). In the context of global climate change, NBS are increasingly considered and implemented to mitigate climate-change impacts, such as coastal flooding across the US and Europe (Temmerman *et al.* 2013). Soon, there will be NBS demonstration projects focusing on EU-China (European Commission 2017) and EU-Caribbean and Latin America cooperation (European Commission 2019).

There are also some successful examples in Southeast and East Asia, especially in China. The 13th Five Year Plan for China, focusing on transformation, highlights Sponge Cities, a similar concept to the Blue-Green Infrastructure (KPMG 2016). There are 30 Sponge City projects across China (Xia *et al.* 2017), one of which is in Ningbo where nature-based water management includes the adoption of the low impact and sensitive designs pioneered in the United States and Australia (Tang *et al.* 2018). The Ningbo project mitigates urban flood risk by storing excessive stormwater during intense rainstorms and includes stormwater treatment for reuse of water (Wang *et al.* 2017) and an award-winning blue-green 'eco-corridor' (ASLA 2013). In Southeast Asia there are a number of recent projects, including examples in Viet Nam using water sensitive urban design (Asian Development Bank 2019) and in Laos where wetland habitats have been rebuilt in four cities on the Mekong river (Sales 2019); such projects are funded by agencies such as the UN's Green Climate Fund, Rockefeller foundation and Asia Development Bank.

Despite some success stories, the adoption of NBS in Asia, especially in Southeast Asia, is generally limited. One reason for this may be the very different constraints when compared to the countries where NBS were developed and have so far mostly been applied. Some of these constraints are environmental, while some relate to planning or legislative restrictions that offer very little flexibility for new strategies. In addition, there are major differences in culture and as culture drives preferences and expectations (Home *et al.* 2010) these differences drive what people are seeking from their cities. There are also overarching challenges related simply to the rapid pace of urbanisation in the region and the scale of pollution and challenges for restoration. In contrast to other regions in the world, there is relatively little literature on the application of NBS and ecosystem services, especially for Southeast Asia. To our knowledge there has been no holistic and systematic consideration of the constraints associated with the adoption of NBS in Southeast and East Asia within the peer-reviewed literature.

The objective of this paper is to characterise the challenges and considerations of applying NBS in low- and middle-income countries in Southeast and East Asia. We first provide an overview and background on NBS and its underpinnings in biodiversity and ecosystem services. We then argue that there are unique socio-ecological challenges associated with ecological processes and functions, and biodiversity and their link to the characteristics of culture and urbanisation, which create very real challenges for the application of NBS in many Asian countries. We then discuss the unique needs of NBS schemes in the region. We focus on differences in biodiversity and its environmental drivers, the links between biodiversity and cultural perceptions of the natural environment, and how they influence the acceptance and likely success of NBS. To aid conceptualisation of these challenges, we present a typology to support the application of NBS in the region and identify key knowledge gaps that can help direct future research.

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This paper and the views represented are the outcome of an interdisciplinary collaboration among researchers who attended three workshops held in the UK, Malaysia and China. The paper was conceptualised in these three workshops in which colleagues from different geographic areas and disciplines explored and discussed the application of NBS and urbanisation in Southeast and East Asia. We focused on this region as it has extensive cultural, environmental, political, historical, and economic similarities. China is the outlier in the group; however, it was included as the only representative from East Asia which is a low- or middle- income country and tropical Southern China and the regions near the South China Sea have similar challenges to Southeast Asia. Other East Asian countries such as Japan and South Korea are all high-income countries and thus have very different development trajectories so were not included, even though they may experience similar environmental issues. The workshops included 34 attendees from a range of disciplines, including engineering, urban planning, social sciences, political science and environmental sciences who have an interest in NBS. The authors of this manuscript represent a subset of all the workshop participants who played key roles in the conceptualisation and the writing of the manuscript. Subsequently, we also invited a number of academics outside of the workshop participants as they addressed specific and important knowledge/discipline gaps in the existing team. The findings in this paper represent a synthesis of these discussions supported by literature review.

A REVIEW OF NATURE-BASED SOLUTIONS FOR URBAN CHALLENGES

While the concept and the application of NBS are evolving and varies between authors and organisations, the following eight elements are commonly considered important requirements of NBS: (i) embrace nature conservation norms and principles; (ii) can be implemented alone or in an integrated manner; (iii) are determined by site-specific natural and cultural contexts; (iv) produce societal benefits in a fair and equitable way, promoting transparency and broad participation; (v) maintain biological and cultural diversity and the ability of ecosystems to evolve; (vi) are applied at a landscape scale; (vii) recognise and address co-benefits and trade-offs, and (viii) are an integral part of the overall design of policies and measures or actions (IUCN 2017). They build on traditional biodiversity conservation and management philosophies (Eggermont *et al*. 2015) to provide a conceptual framework that allows for a new, more holistic or systemic and innovative approach to urban planning grounded in active urban experimentation (Nesshöver *et al*. 2017; Raymond *et al*. 2017).

Two important motivations for the application of NBS are the benefits to biodiversity and society. NBS promote the development and conservation of more diverse nature and natural features in urban areas through the ecosystem services they provide (Eggermont *et al*. 2015). NBS range from highly engineered solutions such as green walls and hydroponics, to the use of more natural managed ecosystems such as parklands and wetlands (Eggermont *et al*. 2015; Maes & Jacobs 2017; Silva *et al*. 2018) (Figure 2). Highly engineered NBS do not necessarily have a focus on biodiversity, although Eggermont *et al*. (2015) suggested that such approaches should not be considered as NBS if biodiversity and ecological functions are not a key consideration. For example, they pointed out that if species chosen for green roofs or walls are not native or are created from clones, the features should not be considered nature based. Thus, biodiversity and ecosystem function should be an integral consideration for NBS, in particular for Southeast and East Asia, which is home to important global biodiversity hotspots (Myers *et al*. 2000).

NBS benefit from biodiversity, as biodiversity is important for supporting ecosystem structure and the maintenance of ecosystem processes and functions, which in turn affect the delivery of ecosystem services (Mace *et al*. 2012). The degree to which biodiversity affects the delivery of ecosystem services varies between locations and between services. Furthermore, the degree to which a service provides benefits to society changes in time and space, is a result of trade-offs between services (Turkelboom

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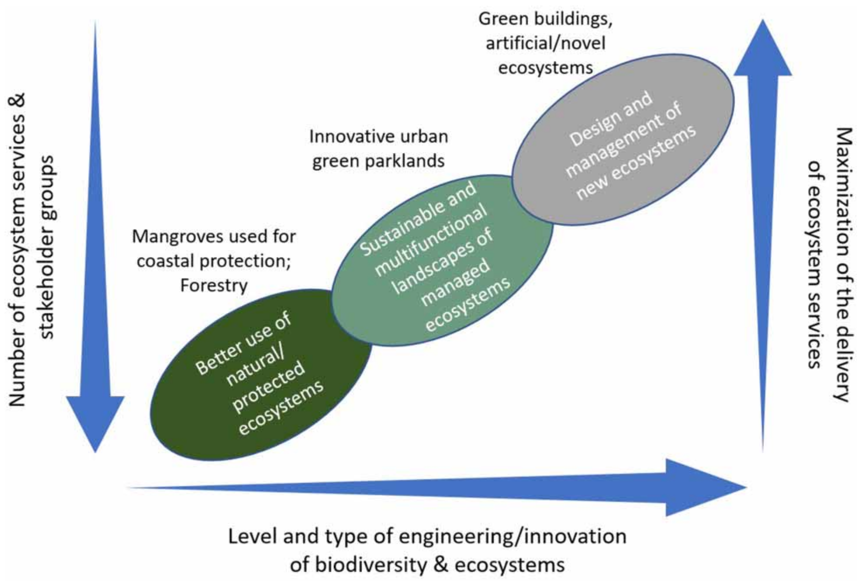

Figure 2 | Level and type of engineering/innovation of nature versus delivery of ecosystem services and number of ecosystem services and stakeholder groups. NBS can range from more natural solutions including managed ecosystems to highly engineered novel ecosystems (adapted from Eggermont *et al.* 2015).

et al. 2018), and a function of the complexities associated with realised and potential ecosystem services (Mace *et al.* 2012).

In urban environments, even though blue-green spaces are encroached upon, degraded and/or fragmented, they still can be important for biodiversity conservation as they can harbour unique threatened species not found elsewhere (Miller & Hobbs 2002; Secretariat of the Convention on Biological Diversity 2012; Ives *et al.* 2016). An often-desired end goal, in addition to ecosystem service provision, is to bring biodiversity and more natural ecosystems back into urban areas. However, heavily degraded urban environments can be challenging for restoration and rehabilitation (Pavao-Zuckerman 2008; Coleman *et al.* 2011; Fernandes & Guiomar 2018). For example, they commonly include a range of novel combinations of native and invasive species (Kowarik 2011) that may constrain the extent to which natural ecosystem processes and functions can be recovered. Restoration is particularly problematic for urban soils due to the extreme changes to soil properties from pollution and physical alteration, especially in brownfield sites, and where they are located downstream of currently active and historical metal mining and processing centres (Macklin *et al.* 2006), resulting in the creation of often novel soil types (Pavao-Zuckerman 2008).

A key element of the NBS approach is ensuring societal benefits. Thus, it is important to consider explicitly the nature of these benefits and address the societal and technological challenges that may influence project success. The application of NBS in low- to middle-income countries can map to the challenges of relevant Sustainable Development Goals, especially SDG 11 Sustainable cities and communities, SDG 3 Good health and wellbeing, SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water and SDG 15 Life on land (United Nations General Assembly 2015). The application of NBS potentially needs to consider and will benefit all SDGs to varying degrees. However, in certain cases there is a lack of clarity on the benefits of NBS, particularly for urban planners and decision-makers (Rall *et al.* 2015; Kaczorowska *et al.* 2016; Cortinovis & Geneletti 2018).

As outlined above there are numerous complexities and nuances associated with the consideration and application of NBS. There are a number of guidelines for the successful application of NBS globally, which include coordination of stakeholders, technological challenges, educating and engaging citizens including communication, and consideration of socio-spatial inequalities (Haase *et al.* 2017; Nesshöver *et al.* 2017; Raymond *et al.* 2017). In the following section we argue that there

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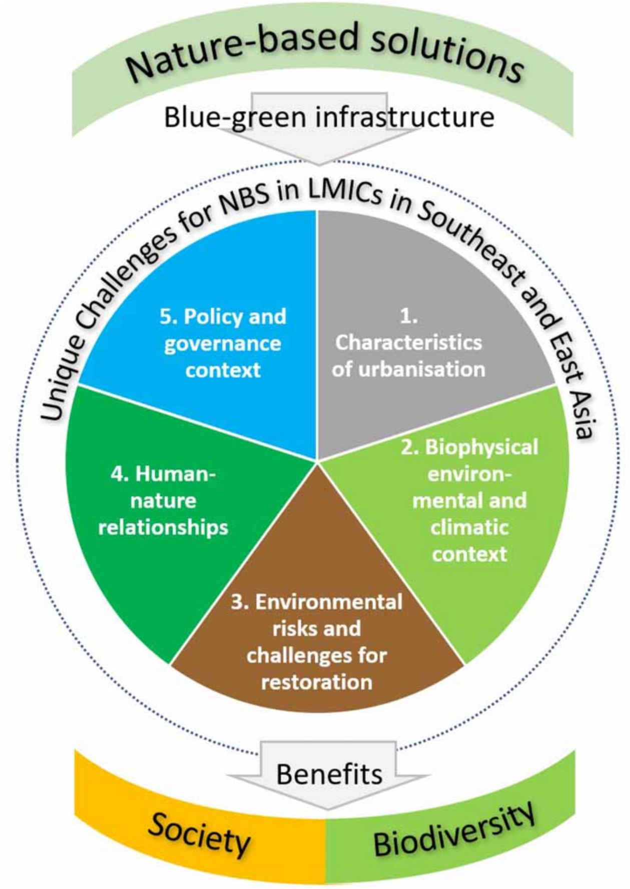

Figure 3 | Typology describing the five unique challenges and considerations of applying NBS in low- and middle-income countries (LMIC) in Southeast Asia and East Asia.

are five unique challenges and considerations for the application of NBS specific to Southeast and East Asia, represented by the typology described by Figure 3:

1. Characteristics of urbanisation;
2. Biophysical environmental and climatic context;
3. Environmental risks and challenges for restoration;
4. Human nature relationships and conflicts; and
5. Policy and governance context.

Each of these challenges is a very substantial research topic, so in the following section we have provided selected examples of these unique challenges and considerations.

Characteristics of urbanisation

The grand overarching challenge for sustainability in Southeast and East Asia is addressing rapidly increasing rates of population growth and urbanisation which have resulted in a considerable reduction and impacts to natural areas because of increased pressure for housing and related essential infrastructure (World Bank Group 2015; Nath *et al*. 2018). The very high density of Asian cities puts a great deal of pressure on blue-green infrastructure to deliver benefits. Asia and especially China is unique in terms of population densities and total population size (Schneider *et al*. 2015; World Bank Group 2015). The region is also a global focus for infrastructure investment such as the Belt

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and Road Initiative which includes industrial parks, transport infrastructure and power generation (Teo *et al*. 2019; Ng *et al*. 2020).

Recent critiques have highlighted that NBS can promote gentrification and inequalities necessitating deeper consideration of access to and dominant views about what nature is, and for whom (Anguelovski *et al*. 2019; Tozer *et al*. 2020). New methods are also required for integrating diverse residents' values for urban blue-green infrastructure into ecosystem management (Tozer *et al*. 2020). These issues are especially concerning in Southeast and East Asia as the rapid urban growth of cities such as Bangkok, Jakarta and Manila are associated with a lack of affordable housing provision. Rural to urban migration has also resulted in the densification of illegal informal settlements along marginal areas by riverbanks and in open spaces, compounded by lack of appropriate drainage and waste management (Ishtiyaq & Kumar 2010). This exacerbates urban pollution and exposure to natural disasters such as floods, making citizens located in these areas more susceptible to climate change impacts (Sheng & Thuzar 2010; Storey 2012; Remondi *et al*. 2016). While housing located near to blue-green spaces in cities is often expensive and the willingness or capability to pay for such housing means that the distribution of blue-green spaces benefits accrued from NBS is often uneven (Poon 2018), with more affluent citizens benefitting most from certain ecosystem services (i.e. urban heat island, cultural ecosystem services).

Fast growing, developing cities mean there is a need to integrate NBS during planning and design, rather than retrofitting, as is frequently the case in already urbanised countries (i.e. in Europe). Retrofitting is usually more expensive and, in some cases impossible, due to a range of constraints including existing incompatible infrastructure and complex planning processes. However, in cases where NBS have been utilised, they may represent only short-term solutions, as rapid development, weak commitments and poor planning mean areas dedicated to NBS may be lost to urban development in the future. Long term visions and strategies for NBS integration are required.

Biophysical environmental and climatic context

The combined influence of climate change-induced rises in global temperature and urban heat island effects are increasingly linked to concerns over urban heatwaves (Mishra *et al*. 2015), and their negative impacts on public health, infrastructure and economic productivity (Hatvani-Kovacs *et al*. 2018). Several global analyses of projected changes in heat stress during the 21st century identify cities in Southeast and East Asia, which have hot and humid baseline climates, on at least a seasonal basis, as the most affected (Matthews *et al*. 2017; Mora *et al*. 2017). This means cities in these areas are particularly vulnerable to a range of heat related health issues for citizens (Kenney *et al*. 2014; Anita *et al*. 2018). Myanmar, Philippines, Viet Nam and Thailand and are among the top 10 countries most affected by extreme weather events between 1999 and 2018 (Eckstein *et al*. 2020).

In conjunction with increased temperature there is projected to be increased frequency of floods, both riverine and coastal, due to more intense monsoons and sea-level rise increasing water levels during storm surges and facilitating coastal erosion (Hallegatte *et al*. 2013). Many major urban centres and settlements located along the coastlines of Indonesia, Philippines and China are highly susceptible to coastal flooding associated with tsunamis and storm surges, while Malaysia and Thailand have experienced monsoon and flash floods resulting in very significant socio-ecological, environmental and economic impacts. This is exacerbated by the projected increase in tropical cyclone intensity, globally and regionally in Southeast and East Asia (Peduzzi *et al*. 2012). According to the Malaysian Department of Irrigation and Drainage, annual flooding affects more than 22% of the country's population (4.82 million) and about 9% (29,000 sq. km) of total land area (Raman *et al*. 2015). In addition, an average of RM 915 million (~168 million GBP) is lost annually in Malaysia due to flooding (Raman *et al*. 2015). In the Jakarta region in February 2007, 190,000 people were affected by a catastrophic flood resulted in US$ 453 million damages and 80 casualties (Remondi

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et al. 2016). Increased flooding can also have severe human health costs, as well as such as an increase in infectious diseases like gastrointestinal infections (Saulnier *et al.* 2017). In Manila, the 2009 Ondoy Typhoon caused a large outbreak of leptospirosis (Jalilov *et al.* 2018).

The majority of megacities in Southeast and East Asia are located in coastal regions (Neumann *et al.* 2015) and often situated on river deltas that may be subject to higher than average rates of relative sea-level rise (Tessler *et al.* 2018). In combination with population growth, these cities are increasingly exposed to coastal flooding, with severe consequences for the local health and wellbeing as well as local economies (Hallegatte *et al.* 2013). NBS, such as the restoration of estuarine mangrove forests, can be potentially used to manage and mitigate flooding and protect coastlines, thus reducing the associated health risks and infrastructure loss (Temmerman *et al.* 2013; Neumann *et al.* 2015). However, their effectiveness in the face of global climate change extremes, which are especially extreme in Southeast and East Asia, are untested.

While the effectiveness of NBS-type approaches has been confirmed across climate types (Saaroni *et al.* 2018), there is little literature relevant to Southeast and East Asia that takes an integrated perspective in assessing the combined climatic and environmental impacts on blue-green spaces in complex urban systems (Gunawardena *et al.* 2017). For example, during the dry season the concentration of pollutants increases due to the reduced river flow (Costa *et al.* 2016). During the wet season however, there is overflow of pollutant discharge in waterbodies caused by poor stormwater and wastewater drainage systems, as reported in Jakarta, Hanoi, Metro Manila and cities across China (Costa *et al.* 2016; Padawangi *et al.* 2016; Remondi *et al.* 2016; Jalilov *et al.* 2018; Xu *et al.* 2019).

Environmental risks and challenges for restoration

One of the great challenges for the application of NBS is remediating and restoring ecosystems. The spatial scale (area and intensity) of air, water and soil pollution in China and Southeast Asia is extensive, much larger than Europe during the industrial revolution (i.e. China has become known as 'the world's factory' (Lomas 2017)) and remediation of these industrialised landscapes is challenging and costly. This challenge is significant for four main reasons. First, the rates of industrialisation and urbanisation are increasing, while the pace and type of changes are unpredictable. Second, the data and knowledge base required for implementing remediation and restoration processes remains limited or sometimes non-existent, or historical and no longer relevant. Third, the speed of urbanisation and industrialisation has outpaced the ability to deal with resulting pollution (e.g. limited legislation or poor policing). Finally, uncertainties in climate change projections (at local scales where measures are implemented) places pressures on both future urbanisation and industrialisation, and so futureproofing of remediation and restoration processes is difficult.

Pollution is a serious health issue for human longevity, and long-term and low-dose exposure result in chronic health problems (Honda *et al.* 2015; Hong *et al.* 2018; Qu *et al.* 2019). Historically important pollutants such as particulates in air (i.e. PM2.5) continue to have a detrimental impact to human health (Lu *et al.* 2019) and still require solutions. However, the types, sources and prevalence of pollution encountered are also changing. There are new or 'emerging' pollutants such as macro- and micro-plastics and pharmaceutical products (Geissen *et al.* 2015). Thus, against this landscape in constant flux with the changing nature of contaminants, the design and delivery of NBS is challenging.

Overexploitation and contamination of freshwater systems poses major challenges. Contamination of water bodies as a result of landfill leachate is becoming a major issue in tropical Southeast Asia along with increasing consumption and waste generation. Frequent intense rainfall events, along with hot weather (Loo *et al.* 2015) increase the loss into the surrounding environment of the liquid stream of leachate from landfill sites (Sivathass *et al.* 2017). This is compounded by the fact that

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landfills in this region are receiving increasing amounts of solid organic waste (Hoornweg & Bhada-Tata 2012) as a result of rapid economic growth (Singapore Economic Development Board 2016). There are untapped opportunities to utilise NBS, not only to treat leachate from waste (Kamaruddin *et al.* 2017) but in so doing also provide blue-green spaces; for instance, landfill leachate in Singapore is being treated using constructed wetland systems (Yi *et al.* 2017).

Urban freshwater systems in Southeast and East Asia are exploited for drinking and other municipal uses, as well as industry, agriculture and hydropower. Flow change associated with these uses, along with water contamination potentially compromise the ability of these systems to deliver ecosystem services that include recreational sites and recreational fishing activities (Postel & Carpenter 1997; Aylward *et al.* 2005). Even if wastewater entering the environment has undergone treatment to improve water quality, current wastewater treatment processes have not yet been designed to remediate emerging contaminants such as microplastics (Shahul Hamid *et al.* 2018). Similarly, increasing urbanisation gives rise to increasing contamination by pharmaceutical drugs (Hong *et al.* 2018), metals (Qu *et al.* 2019) and associated development and spread of antimicrobial resistance (AMR) (Honda *et al.* 2015). Better data on spatial patterns of contamination and concentrations in water and river sediments, as well as soils and atmospheric pollution, are needed to help design and prioritise remediation.

Human–nature relationships and conflicts

As deforestation and urban development reduce available habitat (Pavao-Zuckerman 2008), wildlife in remnant blue-green spaces come into closer contact with humans. In addition, wildlife from surrounding contiguous natural areas may actively seek out and colonise urban areas which may be free from predators and provide an abundance of food and shelter (Soorae 2018). This animal–human cohabitation gives rise to several problems, and is particularly relevant to Southeast Asia due to its high biodiversity and characteristics of some of the species present in urban areas (Sodhi *et al.* 2004; Tee *et al.* 2019). There is great potential for human–wildlife conflict due to the perception (and at times real risk) that wildlife is dangerous (snakes, large predators) or carries diseases (e.g. malaria in monkeys) (Mackenstedt *et al.* 2015). Human–wildlife conflict is a complex issue with risks to wildlife and humans, such as roadkill and traffic accidents. In addition, residents feeding wildlife can lead to wildlife habituation and increased aggressiveness. Compared to European cities experiencing high rates of urbanisation, the human–nature relationships and potential for conflict in Asian cities are therefore quite distinct.

Such issues exist where NBS are applied in cities and is potentially exacerbated when ecosystems are restored in order to bring back nature and wildlife for biodiversity conservation. Of particular concern, though an often neglected point, is by increasing local floodwater storage through the construction of small retention ponds we unwittingly create new habitats for mosquitos, which if poorly maintained can result in the development of malarial hotspots (Smith *et al.* 2013). Urban planners need to consider conflict mitigation methods when planning NBS projects to minimise such unwanted outcomes. The acceptance of the type of NBS utilised will vary with the city's levels of acceptance of naturalness (Pavao-Zuckerman 2008). Acceptance of nature is connected to concerns around spread of disease associated with wildlife, in conjunction with increased AMR diseases; Southeast Asia is considered an emerging global hotspot for AMR (Zellweger *et al.* 2017). Increasing urbanisation and encroachment of wildlife into the urban environment promotes AMR as an emerging anthropogenically driven threat to and from wildlife living adjacent to humans (Swift *et al.* 2019). The recent/current experience of the COVID 19 pandemic also highlights the risks of human wildlife transmission.

Incorporating NBS in urban areas would first require a thorough understanding of the local needs and perceptions towards blue-green infrastructures and the characteristics of local ecosystems and wildlife. This includes appreciating that implementation of NBS may result in human–nature

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relationships and conflicts that were previously not present. Perceptions of natural spaces are shaped by the local culture, religion, level of environmental knowledge and experiences associated with nature (Barau 2015; Norhuzailin & Norsidah 2015; Hwang & Roscoe 2017). While Southeast and East Asia are some of the longest 'settled' parts of the world with strong 'river literacy' and demand for blue-green spaces extending back millennia, this has been lost during the mid-late 20th century as a consequence of urban and agricultural encroachment (Macklin & Lewin 2020). However, in some regions there is increased demand for blue-green spaces for their educational, recreational and health benefits (Dreyer *et al.* 2018). Yen *et al.* (2017) suggest that the increased local demand for urban blue-green spaces in Phnom Penh, Cambodia, was supported by a high proportion (83.1%) of young residents. Ecological benefits and environmental understanding aside, studies have highlighted that perceived safety of local residents when utilizing or being in close proximity to urban green spaces is a concern (Hwang & Roscoe 2017; Yen *et al.* 2017). Given the variation in socio-ecological perceptions and conflicts between development and conservation even within the same community (Lechner *et al.* 2020), urban planners need to consider the needs of local stakeholders and their evolving relationships with nature when implementing NBS. These perceptions are likely to improve with the recognition of the value of NBS.

Policy and governance context

NBS are intended to promote transparency and include broad participation (IUCN 2017; Raymond *et al.* 2017; Frantzeskaki 2019; Tozer *et al.* 2020). However, many nations within Southeast and East Asia, even though they are broadly democratic, have illiberal politics and authoritarian leadership styles (Pepinsky 2017). In the context of risk governance, leaders play an important role in mitigation planning and approaches (Sagala *et al.* 2018). The extent and nature of the connection between NBS and the requirement of 'broad participation' (participatory democracy and other 'alternative' forms of democratic decision-making) are open to debate, both theoretically and empirically. One does not necessarily flow from the other. Alternatives to a more participatory decision making process, namely liberal democracy and authoritarianism are problematic: the former is arguably part of the problem (Klein 2014) and the latter, despite renewed interest based on China and Singapore as models, can be seen as dubious (Shahar 2015; Schneider-Mayerson 2017).

In Southeast and East Asia many governments, despite the lack of strong democracies, have pro-environmental policies. For example, in response to extensive environmental problems due to economic growth President Xi Jinping of China proposed an ambitious blueprint of 'ecological civilization' (Xiao & Zhao 2017) and the 13th Five Year Plan provides a roadmap for construction of sponge cities (China's term for the European-coined blue-green Infrastructure) (KPMG 2016). Kuala Lumpur has the aspiration to be a Tropical Garden City and a top 20 most liveable city globally (DBKL 2008), while the Greening Master Plan in Hong Kong was developed in response to a study on the benefits of greening the urban environment and promoting liveability (Rosenzweig *et al.* 2011) and a consultancy study on sustainable building design. The Hong Kong Housing Authority has set green coverage targets of at least 20% for new estates and 30% for sites over two hectares (Hong Kong Housing Authority 2020).

While low- to middle-income countries in Southeast Asia are facing serious environmental problems, the political context and economic factors are drivers for most decisions in development planning, which favour market-driven infrastructure projects (Brown *et al.* 2012; Sadeka *et al.* 2018). For example, scholars and public discourses have pointed out that flooding in Jakarta is caused by the conversion of natural areas and the expansion of urbanisation into floodplain areas (Teo *et al.* 2020). However, Indonesia's National Action Plan for Disaster Risk Reduction 2010–2012 attributed flooding to the lack of a stormwater drainage system (Padawangi *et al.* 2016). There is currently little awareness that NBS, for example, in the context of climate adaptation strategies may be the most cost-effective type of infrastructure to maintain/develop economic prosperity in urban environments (e.g. Du *et al.* 2020).

DIRECTIONS FOR FUTURE RESEARCH AND IMPLEMENTATION

The need for improved understanding is shown by the fact that research on key urban sustainability topics is underdeveloped when set against the total population of, and the pressing needs within, Southeast and East Asia. For instance, of 520 publications on 'Nature Based Solutions' retrieved from a Scopus search (17/08/20) only 16 were from Southeast Asia and 45 from East Asia (all China), with the majority published only recently (Figure 4). The lack of research on this topic is particularly apparent for Southeast Asia and is characteristic of the general lack of funding and research capacity in low- and middle-income countries (Giam & Wilcove 2012). Clearly there is great potential for capacity building in the region, derived from developing partnerships with countries that have a track record in successfully applying NBS to support original and novel knowledge sharing via co-creation of research projects in the region, and also through the consolidation of existing research, knowledge and experiences. However, such collaborations should consider the distinctiveness in city profiles for Southeast and East Asia and implications for NBS design through to implementation and management.

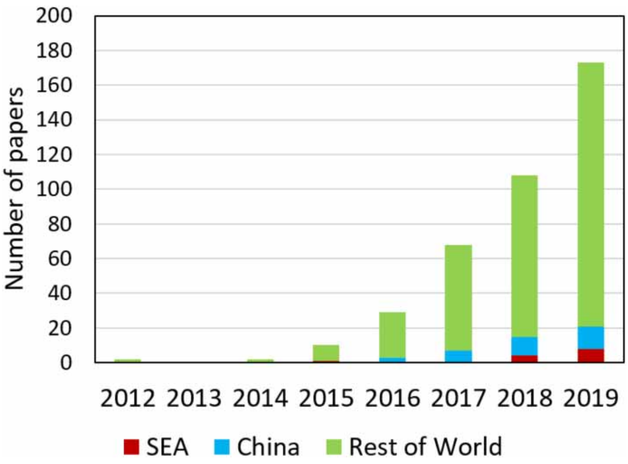

Figure 4 | Keyword search for papers on 'nature based solutions' in China and Southeast Asia compared to the rest of the world (17/08/2020) until 2019. In 2012 and 2014 there were only 2 hits from the rest of the world. In 2015 there was a single paper from China and in 2018 there were 4 papers from Southeast Asia.

Capacity building and collaboration should include both North-South and South-South collaboration. Clearly, China potentially has a very important role in sharing its learnings, especially from its extensive Sponge City program, with Southeast Asian countries. China is the most important economic partner for the majority of Southeast Asian nations and has also made significant investments in education and research in the region (Strangio 2020). However, it could be argued that the Sponge City program may not cover the diversity of approaches adopted by NBS. Sponge cities take inspiration from low impact development (LID), green infrastructure (GI), sustainable drainage systems (SusDrain) and water sensitive urban design (WSUD) approaches pioneered in the global North (Li *et al.* 2017) which represents a subset of the themes addressed by an NBS approach (Pauleit *et al.* 2017).

The nature and extent of collaboration to address the unique challenges outlined in this paper are likely to vary between and within countries, and between challenges. For example, western China is by some definitions considered to be central Asia and does not share the same environmental and

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climatic challenges as Southeast Asia, unlike coastal and tropical locations in China. While low-income countries such as Cambodia and Laos are more rural compared to middle-income Indonesia and the Philippines which are home to the mega cities of Jakarta and Manila. Even within countries, levels of urbanisation vary greatly; for example, there is widespread rural poverty in North-East Thailand compared to the capital, Bangkok (Parnwell 1988). Nevertheless, the region shares many similarities. For example, parts of China (especially southern China) and the majority of Southeast Asia is considered a biodiversity hotspot (Myers *et al*. 2000) and the region shares a common economic development trajectory, with Southeast Asian countries trying to emulate China's rise (Strangio 2020). It is the combination of challenges which are found to varying degrees across the different parts of the region that make a shared regional approach relevant, especially from a collaborative, planning, investment and a geopolitical perspective.

NBS offer an excellent opportunity to advance towards many of the goals of the urban sustainability agenda (i.e. SDGs). However, as outlined in the preceding section, there are barriers to adopting NBS in Southeast and East Asia due to the particular environmental, as well as social and structural characteristics of the region. Future research needs to review the application of NBS across the region, learning from the successes and failures of NBS approaches used to date and propose solutions (Table 1). In Table 1 we propose a selection of solutions to the highly complex challenges associated with implementing NBS across the region. Solutions vary from greater planning and enforcement to recognition of differences in governance, climates and attitudes to nature. It is also important that NBS represent cost-effective solutions which are better alternatives to engineered solutions commonly applied in the region.

Table 1 | Summary of the unique challenges in developing countries in Southeast and East Asia and recommendations for the implementation of NBS to address those challenges

Challenge	Unique characteristics	Recommendations
1. Characteristics of urbanisation		
Population growth rate and land cover change	Fast growing developing cities mean there is a need to integrate NBS in planning and design rather than retrofitting NBS as it frequently is done in already urbanised countries (influenced by space constraints in SE/E Asia, where every available space in urban areas is utilised – transport, domestic homes, work environments, waste piles). Populations in Asia have some of the highest percentage of citizens living in cities – megacities (>10 million residents). Very high proportion of urban dwellers in Asia-Pacific live in secondary cities.	Need to ensure that NBS is part of urban planning rather than retrofitting. Huge government effort needed, both in terms of legislation and infrastructure investment and support from the local community. The benefits of NBS, such as the increase of green space that are available for urban populations and the relief of pressure on urban infrastructure should be quantified at the onset of any projects in order for NBS to become an easily justifiable and go-to solution.
Population density of cities	Many Asia cities are very high density, putting a lot of pressure on blue-green infrastructure to deliver benefits due to high human to environment ratio.	
2. Biophysical environmental and climatic context		
Climate	Tropical areas have high intensity and a lot of rainfall. High temperature and high humidity. Faster growing vegetation due to climatic conditions.	Resilience of green-blue infrastructure and people to extreme weather needs to be addressed in the design of NBS. NBS should be considered as a positive contribution to reducing the impacts of extreme events and disasters, justifying its implementation.
Extreme weather and disasters	Many Asian megacities are located on river deltas experiencing higher than average relative sea-level rise and increased exposure to coastal flooding. Asia is projected to have more extreme weather events (i.e. flooding and typhoons) than other parts of the world, which will worsen due to climate change.	

(*Continued.*)

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Table 1 | Continued

Challenge	Unique characteristics	Recommendations
3. Environmental risks and challenges for restoration		
Characteristics and scale of pollution	The spatial scale (area) and intensity of pollution in China and SE Asia is massive and population density very high. The types of pollution encountered in Asia differs from addressed previously i.e. industrial pollution from plastics, nanomaterials, bioactive chemicals (e.g. pharmaceutical drugs) and antimicrobial resistance. Data is limited to non-existent on pollutant characteristics including source, prevalence, and temporal/spatial influence in environment. Ecological abiotic or biotic thresholds may have been passed in these heavily impacted ecosystems and can no longer be restored to a previous state and need to be treated as novel ecosystems.	There is a need to consider what can be achieved in anthropogenic highly polluted landscapes. Greater understanding of ecosystem restoration limits. Appropriate and cost-effective NBS considering wider and long-term benefits.
Perception and expectation of solutions	Increasing affluence for some citizens means higher expectations around levels of remediation and rehabilitation. What was previously acceptable is no longer acceptable. Solution capability may not be future proof. For instance, increasing pollution leading to a proposed/implemented NBS that is no longer fit for purpose because design was not for that load and/or type of pollution.	
4. Human-nature relationships and conflicts		
Perceptions of naturalness and risks of nature	Natural areas harbour dangerous wildlife and diseases – human wildlife conflict is a serious issue across the region. Aspiration toward urbanisation – move away from ‘natural areas’ which are perceived as poor areas. Source and fear of crime associated with green spaces. Urban planning (especially water management) seen as a battle or fight against nature. Land assigned/reassigned for nature conflicting with ‘better uses’ that directly advance human progress e.g. housing.	The types of solutions need to recognise that the notion of re-naturalisation may not be suitable for some regions. Important to educate and communicate the benefits of NBS. Include conflict mitigation in their designs such as wildlife crossing, prevent the spread novel zoonotic diseases (i.e. COVID-19), proper disposal of waste and be prepared to educate the public on dealing with conflicts that arise. Need to also account for social, cultural, political and religious diversity.
Human–wildlife conflict	As nature and urbanisation comes closer into contact there is greater potential for human wildlife conflict. Wildlife, from monkeys, large cats to mosquitos have potential harmful effects on health and safety.	
5. Policy and governance context		
Pro-environmental governments	Many governments in the region are quite positive in terms of sustainable urban planning i.e. Kula Lumper’s aspiration to be a Tropical Garden City and a top 20 most liveable city globally and China’s concept of ecological civilization. However, implementation is challenging.	Decision making is top-down, while NBS literature describe the importance of co-creation of knowledge and decision making. Regulations for new projects and retrofit should be in place to ensure appropriate management and availability of blue-green infrastructure. While many countries have urban plans and zoning and sustainable policies these may not be effectively enforced, and corruption can be an issue. Social, cultural, political and religious diversity in the region which influence adaptive capacity and need to be considered.
Political context	Many countries are undemocratic or have weak government with conflicting needs. Issues associated with social/environmental justice. Short term vs medium/long term stance. Industry/Government wants conflict with environmental/social (longer term) benefits. ack of legislation to implement change and/or lack of enforcement (e.g. mitigating pollution, sustainable environments).	

How NBS are implemented in the region depends greatly on the policy and governance context. Recent NBS scholarship has emphasised:

1. the importance of collaborative partnerships between academic, professional, policy and civil society stakeholders whereby knowledge about NBS is co-produced;

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2. integration of different forms of knowledge such as big data, scientific theory, socio-demographic information, and practice-based technical knowledge; and
3. exploration of novel financing models beyond public funding (Frantzeskaki *et al.* 2019).

However, some of these dimensions of implementation are particularly difficult in countries and regions where participatory democracy is lacking or techno-scientific approaches to decision-making persist (i.e. focus technical approaches rather than participatory decision making). Nevertheless, given NBS are typically implemented and experienced at local, neighbourhood scales, they offer an opportunity to open up new forms of decision-making in parts of Southeast and East Asia.

Civic engagement, while challenging, has been shown to be vital to the success of actions for sustainability across Asia (Indrawan 2020). As such, decision-makers should seek to engage citizens in NBS visioning and implementation, whether that be for reasons that are pragmatic (i.e. increasing likelihood of success through aligning with socio-cultural values and attitudes), or normative (i.e. upholding democratic ideals) (Reed 2008). In any case, given the priority given to economic growth in policies at national and regional scales across Southeast Asia, successful design, implementation and management of NBS must be taken seriously and emphasise the economic benefits of ecological solutions. This could include the financial costs avoided through effective climate change adaptation or the ancillary benefits to commercial activity from the strategic positioning of attractive and biodiverse parkland. Further scholarship on NBS implementation in Asia would do well to consider (i) physical solutions relative to biophysical constraints, (ii) the actors involved such as researchers, planners and community representatives, (iii) the process of decision making, implementation and evaluation and (iv) the potential of NBS to promote health and well-being in cities.

CONCLUSIONS

Urban blue-green spaces are increasingly being degraded and lost in many Southeast and East Asian countries due to rapid rates of urbanisation. The majority of research on this topic has been conducted in high income nations where population growth rates are relatively low and stable, combined with urban development that is more regulated. Due to the speed of development and urbanisation, we believe there is a greater urgency for research on the application of NBS in countries in Southeast and East Asia in order to address its unique socio-ecological challenges. There is also a greater opportunity for NBS to be imbedded in urban development at the feasibility and planning stages, rather than being retrofitted as commonly occurs in high income nations – often at a much greater cost. Exploiting the opportunities and addressing the challenges of NBS in Southeast and East Asia needs to be a priority for governments, planners and academics.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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