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The three points approach (3PA) applied to two Chinese and four European cities for knowledge exchange on stormwater challenges and strategies

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ABSTRACT
Urban stormwater is sometimes a risk, sometimes a resource. To address both aspects, the Three Points Approach (3PA) is advocated. This research applied the 3PA to map stormwater approaches in two Chinese and four European cities. While all cities have targets for the Technical Design Domain, none have targets for all domains; and thereby lack interventions to maximize benefits of frequent small events in the Day-to-Day Domain or minimize flood risks of rare large events in the Extreme Domain. Using open global precipitation data cities' stormwater targets were expressed as more comparable rain depths, demonstrating that event depths within the Day-to-Day Domain in Chinese cities, cover much of the same range as those within the Technical Design Domain in the European cities. Expressing targets as depths in the context of the 3PA framework may facilitate transdisciplinary and transnational knowledge sharing, paving the way for management strategies covering all three domains.

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1. Introduction

Urban water infrastructure provides many security and health benefits, however the conventional centralised paradigms related to drainage infrastructure are insufficient in terms of flood risk management under a changing climate and fail to deliver multiple long-term benefits to urban society and the environment. The stormwater management (SWM) systems in most modern cities evolved from those first developed in the second half of the 19th century in Europe. These systems have historically been designed, managed and built almost solely by specialists used to working within their own domains driven by technical performance and efficiency, relatively independently of other stakeholders of the city (Bertrand-Krajewski 2021). While this drainage infrastructure has contributed significantly to the improvement of public health, the negative environmental impacts related to peak discharges, reduction of aquifer recharge and pollution of surface water became evident by the 1970s and eventually spurred the development of new SWM infrastructure paradigms like Blue-Green Infrastructure (BGI) based rather on retention and detention than discharge, and encouraging contaminant control (Fang, Li, and Ma 2023; Su et al. 2023). This paper will use the term BGI; however, it should be noted that similar terms including Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID), Green Infrastructure (GI) and Nature-based Solutions (NbS) are often used interchangeably in SWM literature (Fletcher et al. 2015).

In Europe, the adoption of BGI has progressed since at least the 1970s when some of the earliest modern green roof and bioswale systems were developed in Germany (Grotehusmann et al. 1994). In China, the pursuit of more sustainable SWM approaches including the use of BGI started more recently, however has taken off at a rapid rate since initiation of the Sponge City Program. Started in 30 pilot cities across the country (MOHURD 2014), the national goal is that all Chinese cities with 1+ million inhabitants comply with Sponge City requirements by 2030. However, unclear requirements related to performance criteria and a lack of practical experience especially related to the long-term behaviour of BGI have necessitated unexpected and significant investments in time and resources in China (Li and Zhang 2022).

In addition to the technical barriers to the widespread adoption of BGI, there are numerous socio-political challenges. Jia et al. (2017) identified a lack of close coordination among agencies at the local level as one of the main barriers to implementation of Sponge City projects. In a study based on semi-structured interviews of institutional stakeholders (Thorne et al. 2018), found that overall socio-political factors exerted more negative influence on BGI decision-making than did scientific and physical limitations. As noted by Lems, Aarts, and van Woerkum (2011), recognising stakeholders' different frames of reference and knowledge of urban SWM can foster collaboration and overcome interagency fragmentation and ineffective communication.

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One conceptual and holistic approach developed to facilitate communication in the decision making processes dealing specifically with urban SWM is the Three-Point Approach (3PA), first described by Geldof and Kluck (2008) and later elaborated on by Fratini et al. (2012). The idea of the 3PA is to provide both planners and managers with a tool to communicate, discuss and reflect on possible SWM strategies and their impact on not only the drainage task but also on other urban spheres like the ecological, social and spatial. The 3PA divides the full span of rain events (from small frequent events to catastrophic rare downpours) into three domains: the Day-to-Day Domain (DDD), the Technical Design Domain (TDD), and the Extreme Domain (ED), and encourages decision makers to set targets and identify corresponding strategies for each domain. Co-benefits of SWM like sustaining urban nature, mitigating urban heat island, recharging water storages and other ecosystem services are all linked to the DDD and represents the resource aspect of stormwater. In the TDD, stormwater is managed in a controlled manner up to a politically decided service level, expressed as the minimum number of years between events that overload the system (return period, T, of a design storm). This domain is conventionally covered by a public sewer system. Rain events exceeding the TDD by definition belong to the ED. Such events cause the drainage system to surcharge; the surplus water ponds on the streets and flows with gravity through the city in an uncontrolled manner. Through spatial planning and building regulations, potential damage in this domain can be minimized, e.g. by elevating entrances to critical infrastructure, ensuring freeboard elevation of buildings, and by having good contingency plans and equipment like pumps, sandbags and evacuation facilities.

Reference to 3PA or similar approaches can be found in drainage documentation from several countries. The stormwater planning guidebook from British Columbia, Canada recommends a three tier approach with small events targeted with Tier A measures, these events make up approximately 90% of annual rainfall, Tier B targeting the large events defined as events that are greater than half the size of the mean annual rainfall, corresponding to approximately 10% of all rainfalls, and Tier C targeting the extreme events that may not occur in any given year (British Columbia Ministries 2002). In Norway, professor Oddvar Lindholm introduced a similar idea in 2008 (Lindholm et al. 2008), referred to as a three linked chain approach, where interventions in the first link collect and infiltrate all rain events up to 20 mm, second link interventions infiltrate and detain events between 20 and 40 mm depth, and third link interventions ensure safe discharge routes of events larger than 40 mm; these ideas were further refined by Paus (2018) and recently adopted by Municipality of Oslo as the three-step approach (Oslo Municipality 2023). In both the Canadian and Norwegian approaches, the third level refers to safe discharge of events exceeding the second level, but the upper limit of that service is not defined.

In a technical report targeting the city of Delft in the Netherlands, Dutch and British researchers suggested a four domain approach, 4DA, based on either 'benefits' (corresponding to DDD) or ability to recover from events, with 'easy recovery' corresponding to TDD, and 'difficult recovery' and 'no recovery' both corresponding to the ED but up to a certain level of control, and without an upper level of control, respectively (Gersonius et al. 2016). Strictly speaking, the ED is in Fratini et al. (2012) defined as the domain where the storm water is not managed but flows out of control and where the countermeasures include urban planning with lifting up of critical infrastructure and contingency plans. However, as these examples show, the third level (Tier C, step 3) is still within some level of control but without defining the upper level, resulting in a blurring of the definition. Most recently, the 4PA (Four-Point Approach) was proposed by Huang and Wang (2024), which, builds on the 3PA and has a focus on climate change scenarios and designing for failure. While there are similar approaches under different titles, as well as variations and expansions building on the 3PA, in the current work the description and terminology presented in Fratini et al. are adopted.

The 3PA has not yet gained wide adoption in practice and the number of academic publications which have applied it to real cases is small. In one study, Sørup et al. (2016) distinguished the three rainfall domains in terms of local return periods and rain depths for Danish conditions, suggesting DDD to cover events up to 20 mm (corresponding to 75% of the annual rain and return periods of 0.2 y), TDD to cover events from 20 mm to 70 mm (corresponding to an additional 24% of the annual rain and return period up to 10 y) and ED to cover events from 70 to 110 mm (corresponding to 1% of the annual rain and return periods up to 100 y), in this way providing an upper limit for the third level, but not considering extreme events beyond that, in which case the third level can be considered an extension of the TDD. Sørup et al. used this quantification to assess the ability of various interventions such as rainwater harvesting and soakaways to cope with the DDD and TDD.

In line with the approach of Sørup et al., Lerer et al. (2017) elaborated on the Copenhagen Cloudburst Plan (CCP) from 2012 (Copenhagen 2012) which prescribes a supplementary discharge system based on selected streets and new pipes to manage rain events with return periods between 10 y and 100 y. According to the CCP, only the designated discharge roads and their immediate neighbouring buildings will be disconnected from the combined sewer, which must still serve the city for rain events up to the 10-year event. As such, the CCP extends the TDD into what was previously the ED. Lerer et al. explored scenarios to link the CCP to the sewer-based TDD and the DDD. Their modelling indicated that if the cloudburst route of their case area was made 15% longer and if 49% of the area currently connected to the combined sewer was reconnected to the new cloudburst routes, a significant reduction in combined sewer overflow could be obtained, i.e. improving the TDD, and a significant increase in stormwater infiltration (29% less stormwater to the wastewater treatment plants) could be obtained if the reconnection passed through bio-infiltration elements, thereby improving the DDD. The study used the 3PA to critically analyse the CCP, pinpointing its focus on urban flooding protection and its shortcomings regarding services within TDD and DDD.

In the current study, which emerged from a China-European collaboration project 'CECoSC', the SWM of six cities have been described using the 3PA as a common framework. The 3PA is seen as relevant tool to apply here as it allows a homogeneous description of targets within the three domains (DDD, TD and ED), acknowledging stormwater as both a resource and a threat. The objective is to provide a common ground for professional decision makers operating in different domains to bridge over disciplinary gaps, and further to create a level playing field for inter-city comparison of targets and interventions despite varying climate conditions and planning contexts.

2. Study areas

With the aim of mapping stormwater practices in six partner cities and exchange experiences, the China-Europe Collaboration on Sponge Cities (CECoSC) project was conducted 2017–2022, under the China-Europe Water Platform (https://cewp.eu/). To this end, workshops were conducted involving representatives of the six cities and researchers from China, Denmark, Sweden, Finland and the Netherlands. The objective of these meetings was to identify and compare their SWM systems, targets and strategies and to map these results in a comparable way, using the 3PA as a framework. The six cities represent diverse geographical, climatic, and urban planning contexts and were chosen due to their locations in the home countries of the research partner institutions, as well as their inclusion on the list of Sponge Cities, in the case of the Chinese cities. The SWM in all six cities currently belongs predominantly to the TDD.

2.1. Beijing

Beijing is subject to fluvial flooding from its mountainous surroundings as well as to pluvial flooding or 'waterlogging' caused by runoff from rapidly expanding impervious urban surfaces. As the capital and most populated city in China, flood prevention has been important throughout Beijing's history. The oldest and most central part of the city is serviced by a combined sewer system, while areas outside of the fourth ring road have primarily separated sewers. The Urban Flood Prevention Plan (1995–2010) led to the development of intensified flood prevention measures throughout the city. Despite these, heavy downpours caused severe flooding on 21 July 2012 when Beijing experienced an extraordinary rainfall of 328 mm in 20 h, causing 79 casualties and at least 10 billion RMB in damages. Beijing's overall SWM strategy has shifted further towards control of floods since this 2012 event, accelerating the development of a series of plans and guidelines. Since 2015 when Beijing became one of China's Sponge City 'pilot cities', there has been growing emphasis on the use of BGI for the management of smaller rains and other benefits, especially groundwater recharge. In July of 2023, the city was again hit by extreme rainfall (over 500 mm in total, at some gauges) that caused over 33 casualties, severe flood damage and evacuation of over 820,000 people (Xinhua News 新华社 2023).

2.2. Changde

Changde is a prefecture-level city in the northwest of China's Hunan province and has a monsoon-influenced, four-season humid subtropical climate, with cool, damp winters, and hot, humid summers. It is a floodplain city with an annual precipitation of 1365 mm. Changde was selected as one of the 'first batch' of Sponge City construction pilot cities in 2015. The same year, Changde set a goal: 'Repair water ecology, better water environment, improve water safety, protect water resources, and revitalise water culture' - to attain a more holistic approach that focuses on a coherent water system. Changde since then implemented a Sponge City plan consisting of 148 projects focusing on improvement of water environment, water ecology and water safety (flood risk).

2.3. Copenhagen

Copenhagen, the capital city of Denmark, is a coastal city located mostly on flat low-lying land. In the mid 1800s open gutters were replaced with a combined sewer system. Today the Copenhagen Municipality has approximately 1300 km of combined sewer lines; separated sewers serve less than 10% of the city. In 2011, Copenhagen adopted a Climate Adaptation Plan, targeting extreme rain events, but also the increased risk of droughts. To match the predicted increase in annual precipitation, the discharge capacity of the drainage system should be increased by 30% over 100 years, using BGI and conventional sewer enlargement. Later that year, on July 7, Copenhagen was hit by the largest ever recorded rain event in the region, 135 mm during 24 h, triggering the adoption in 2012 of the Copenhagen Cloudburst Plan (CCP), which calls for water in excess of what can be managed by the existing sewer system during events up to $T = 100$ y to be discharged to the harbour via re-profiled streets, supplied with a number of pipes, tunnels and pumping stations. While the Climate Adaptation Plan called for the use of BGI and the city does have a growing number of examples, BGI plays a minor role in the CCP. The CCP is currently on hold due to a national executive order prescribing a standardized method for how municipalities may define SWM service levels (Ministry of Environment and Gender Equality, 2020), which in case of Copenhagen may result in an economically feasible service level of T=10 y in most of the city and T=30 y in central parts, rather than T=100 y (Municipality of Copenhagen, 2023).

2.4. Amsterdam

Amsterdam, capital of the Netherlands, is surrounded by historical dikes to protect the city against storms from the former shallow bay, the Zuiderzee. In the center of the city, wastewater and stormwater are collected in a combined sewer system and conveyed to a treatment plant. Underground reservoirs prevent most combined sewer overflow from discharging into the canals. Outside the city centre, about 75% of the stormwater is discharged directly via the storm drains of a separate system to the local surface water. During the past 15 years, there has been an increase in heavy rain events. On the 28th of July 2014, between 50 and 90 mm of rain fell, mostly within 2 h, causing extensive flooding of the city and inundations of critical infrastructure and historical buildings. Similar extreme events, at a smaller scale, have occurred since then. The current trend in Amsterdam is a shift towards active management of BGI, taking climate change into account in the new SWM design criteria and to identify and utilise synergistic adaptation.

2.5. Turku

The City of Turku is located on the Southwestern coast of Finland where shallow bedrock is overlain by mostly clay soils, creating challenging conditions for stormwater infiltration and belowground storage. During the winter months the soil and surface stormwater structures are usually frozen or covered by ice and snow, causing rain and melt water in spring to be converted almost entirely to surface runoff. The oldest sewer structures date back to 1896 and the oldest separated sewers to 1957, coinciding with the establishment of the first wastewater treatment plant. Today, Turku has 563 km of separated sewers and 39 km of combined sewers, with combined sewer overflows rarely occurring. New storm sewers are designed for $T = 2–5$ y, including a climate factor and a contingency for predicted climate change. Space reservations for BGI are a relatively recent development in urban planning and currently require a reservation of 1 m^3 retention capacity per 100 m^2 impermeable surface. Turku city has no distinct plans or contingencies for extreme events, but in known risk areas located mostly near the shallow harbour area, extra drainage infrastructure has been added. In some newly developed areas, flood routes are included in the detailed plans. The master plans drawn for the year 2029 include large area reservations for BGI and green space corridors.

2.6. Gothenburg

Gothenburg, Sweden's second largest city, is located in the western part of Sweden, with an area of 447 km^2 of which about 15.5 km^2 is water. The central areas of Gothenburg are dominated by a combined sewer system. This combined system corresponds to 40% of the entire sewage grid and consists of more than 2000 km of pipes. The city of Gothenburg is listed as one of the 18 Swedish cities at risk of flooding by Swedish Civil Contingencies Agency. Three types of flooding threaten Gothenburg, namely fluvial, coastal and pluvial flooding. Gothenburg has several plans such as Oversiktsplan (Developing master plan), Skyfallsmodellering (Cloudburst modelling), Strukturplan (Structure Plan), and Rain Gothenburg, which expresses the aim to mitigate flooding in a sustainable way, implement BGI, and also to turn stormwater and the drainage system into an asset.

3. Methodology

3.1. The 3PA as a framework for SWM

The three domains of the 3PA are presented in Figure 1. This figure is inspired by 3PA diagrams presented in Fratini et al. (2012), as well as more recent representations of the framework as it is being adopted in planning documents from the City of Oslo, Norway (Oslo Municipality 2023). Like in other figures illustrating the 3PA, the x-axis represents the event return period. The y-axis of 3PA figures sometimes describe costs (Fratini et al. 2012) or impact (Gersonius et al. 2016), sometimes event depth (Lerer et al. 2017; Lindholm et al. 2008) and

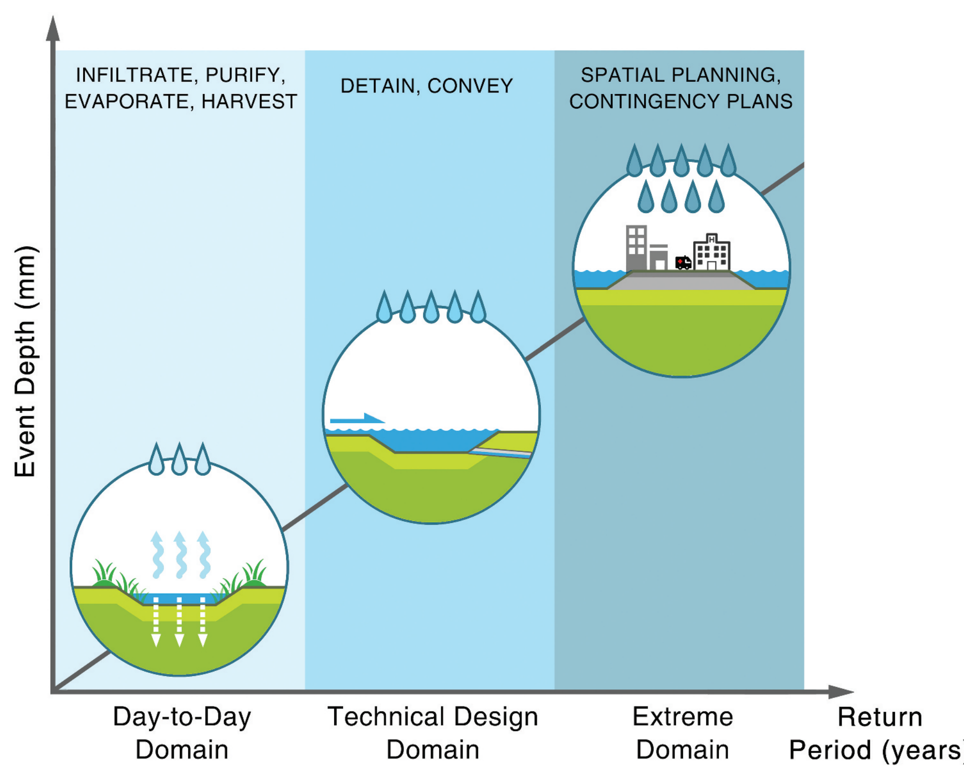

Figure 1. The three domains of 3PA and how they relate to return periods (the x-axis) and event depths (circles' position on the y-axis). The pictograms in the circles indicate the prioritized water management mechanisms within each domain.

percentage of annual rainfall handled (Sørup et al. 2016). In this study, the event depth (in mm) has been opted for, as it is an intuitive and simple physical metric that is understood to be the same globally and easier to communicate across disciplines than return periods. Figure 1 also illustrates the types of interventions to be considered when implementing the 3 PA in SWM. This includes resource-related interventions in the DDD, control interventions in the TDD, and urban planning and building regulation measures for protecting critical infrastructure, combined with contingency planning to mitigate the effects of the ED. Boundaries between the three domains are typically defined by return periods between DDD and TDD and between TDD and ED. The domains, represented in Figure 1 as shaded columns are subject to economic and political decisions made by cities or catchment authorities. When adopting the 3PA, the ultimate goal is for the selected interventions to collectively align with the targeted values of each domain.

3.2. Stormwater targets and the 3PA domains

Ideally, cities should have well-defined targets and an integrated SWM strategy for all of the three domains. In the DDD, the target may be to retain a certain fraction of the annual precipitation, e.g. 85%, and further link that target to ecological and social services. A typical target in the TDD may be to manage rainfall up to a 5 y event (i.e. return period, T = 5 years), but values from T = 2 y to T= 10 y are also often seen. Recently, cities have begun to target significantly larger storms, like T = 100 y, for the technical systems, e.g. using bigger pipes or reprofiling streets to allow them to be turned into flood routes (Copenhagen 2012). Even though T = 100 y represents a severe storm, this is still considered to belong to the TDD in this context since the water is controlled in human-made structures. However, even such large structures can reach capacity, in which case the surcharged water will pond on the terrain and flow in an uncontrolled manner through the city, filling up depressions and entering any low-lying areas (C. Zhang et al. 2023). This situation belongs to the ED, where the spatial planning and recovery capacity, combined with contingency plans are the keys to minimize damage.

To operationalize the 3PA, it is necessary to define the two boundaries that separate the DDD from the TDD and the TDD from the ED. In this paper, the return period defining the DDD-TDD boundary was calculated for all six cities using the Volume Capture Ratio of Annual Rainfall (VCR_a) with a target of 85%, as defined in the Sponge City program (see section 3.3 below). This choice was made due to a lack of defined DDD-TDD boundaries for the four European cities. For the TDD-ED boundary, the individual return periods targeted by the cities were used. However, to allow for a homogeneous description, the corresponding event depths were calculated using the global IDF-formula by Courty et al. (2019) (see section 3.4 below).

Table 1 also contains descriptions of the climate types of all six cities, including their annual rainfall averages and Köppen-Geiger climate classifications (Kottek et al. 2006). To assess the extent to which the SWM of the six case cities comply with the 3 PA, local guidelines and plans were compiled by the city representatives participating in CECoSC.

3.3. The DDD-TDD boundary based on 85% VCR_a

The annual Volume Capture Ratio (VCR_a) is used in China to define the fraction of runoff that must be targeted in SWM of individual sponge cities and is stipulated from the central government (MoHURD 2014). It is defined as a percentage of the total annual rainfall that is not directly discharged but controlled by means of natural and artificial measures, such as infiltration, evaporation and detention. The VCR_a is not focused on flood prevention but is an ecological metric, meant to improve the overall water balance and provide a minimum amount of water in the 'sponge' to sustain periods of drought (Chen et al. 2021).

The VCR_a for all six partner cities was calculated following the procedure outlined the Sponge City Guidelines (MoHURD 2014, in Chinese) and also described in K. Zhang et al. (2016). Thus, the daily 24 h precipitation data from 1983 to 2012 were downloaded from the National Oceanic and Atmospheric Administration's Climate Data Online Service (NOAA 2018)

Table 1. Basic information for case cities on drainage systems, climate and calculated rain depths for selected return periods.

Precipitation[2]	Mean temp.[b]	Climate Class[b,c]	Rain depth[d] at *T*= 2 y	10 Y	100 y	VCRa[e] 85%
mm/y	°C		mm	mm	mm	mm
Beijing, CN: *Combined sewer within the second-ring road; manage T = 1 y. Separated system outwards; most parts designed for T = 1–3 y, since 2016 for T = 3–5 y.*[1]						
566	12.7	Dwa	70	128	220	34
Changde, CN: *>70% separated system (Jiangbei district 80%). 1/3 designed for T<1 y, 54% T = 1–2 y, rest T>2 y*						
1526	17.8	Cfa	78	127	205	32
Turku, FI: *>95% separated system, designed for T=2 y.*[1]						
720	6.1	Dfb	26	40	64	11
Gothenburg, SE: *ca. 40% combined system, designed for T=10 y; 60% separated system, designed for T = 2–10 y.*[1]						
998	8.1	Cfb	31	45	66	13
Copenhagen, DK: *ca. 90% combined, designed for T = 10 y. Cloudburst routes designed for T = 100 y.*[1]						
728	8.9	Cfb	33	54	88	11
Amsterdam, NL: *ca. 30% combined, designed for T = 2 y.*[1]						
844	10.7	Cfb	28	40	59	12

Superscripts a–d indicate sources: a) City representatives; b) https://en.climate-data.org/; c) Köppen-Geiger climate classification; d) Calculated using the generalized global IDF-curve suggested by Courty et al. (2019), assuming a duration of 24 h; e) 85% Volume Capture Ratio of annual precipitation, see details in Section 3.3.

and sorted in ascending order after excluding rainfall events smaller than 2 mm (considered wetting loss). The rain depth corresponding to 85% of the total was then calculated.

It should be noted that VCR_a is based on rainfall, making this approach less suitable for cities where snowfall makes up a significant fraction of annual precipitation, as is the case in some of the partner cities (especially Turku and Gothenburg).

3.4. The TDD-ED boundary based on universal IDF curves

All precipitation events can be described in terms of their intensity (I) and duration (D). Based on historical precipitation records, the probable time between the return of events with different combinations of intensity and duration can be presented as IDF curves, where F is the frequency, also referred to as the return period, expressed in years. If a city has a return period of 5 y for their SWM systems, local IDF curves are used to size the pipes and basins needed to be able to cope with the worst combination of intensity and duration that occurs on average once in 5 years. Although most major cities in China and Europe do have IDF curves calculated from local data, comparison of the IDF curves between cities may still be challenging as they are not always easily accessible or updated and may not be generated based on equivalent data or methods.

In this study, the universal IDF formula and the open global data set of location and scaling factors suggested by Courty et al. (2019) were applied. Based on city coordinates, the location and scale factors of each of the six cities for durations ranging from 1 to 48 h were extracted and entered into the formula to calculate intensities for events with return periods of 2, 10 and 100 years to plot the IDF curves. Only the 24-h event duration values were used for inter-city comparison for simplification and because the 24 hour durations are more directly comparable to the VCR_a values based on 24-h rainfall.

4. Results and discussion

4.1. City hydrological characteristics

Table 1 provides an overview of the basic climate conditions of all six cities, along with a short description of their current SWM (in italics). It also contains the results of DDD and TDD boundary calculations.

In all six cities, the SWM consists of a mix of combined and separated sewer systems designed to accommodate events ranging in size from a 1 to 10 year return period (Table 1). This information reflects that all six cities are old and traditionally embedded in the TDD of the 3PA. It also reflects that the cities have comparable flood safety levels (TDD).

As seen in Figure 2, the similarity in flood safety levels overs distinct differences in rain depths based on the uniformly generated IDF curves. Beijing's and Changde's curves are at

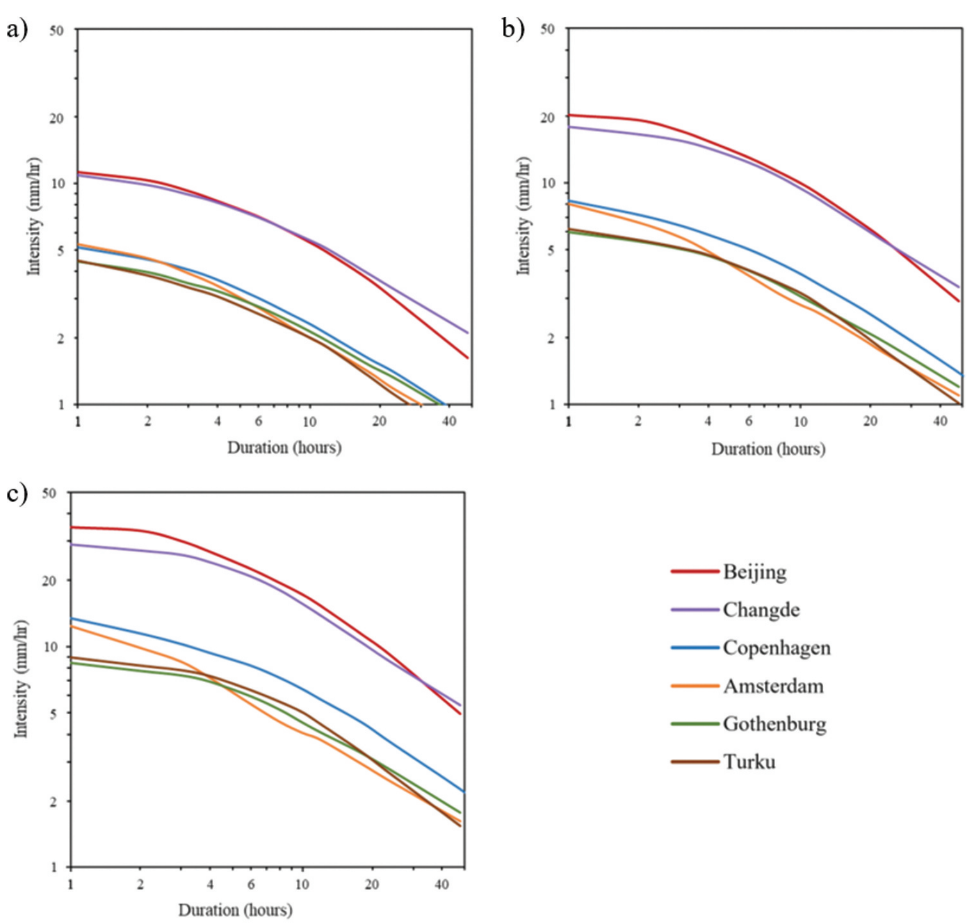

Figure 2. Six cities' IDF curves for return periods of: 2 years (a), 10 years (b) and 100 years (c). All curves generated based on formula and data presented by Courty et al. (2019).

a distinctly higher level than the curves for the four European cities, and the corresponding rain depths are much larger (Table 1): While a 10 y 24 h rain event corresponds to rain depths of 40–54 mm in Turku, Gothenburg, Copenhagen and Amsterdam, the depths are 127 and 128 mm for Changde and Beijing, i.e. approximately two to three times more.

In general, the official 24-h design storm values from cities based on local data were comparable in terms of relative magnitude to values calculated from the Courty et al. method, however tended to be higher. For example, the 24-h duration 2 y and 100 y storm calculated for Copenhagen based on local data via the *Regionalregnrække* are 40 and 94 mm, respectively (Madsen, Arnbjerg-Nielsen, and Mikkelsen 2009), as compared to 33 and 88 mm determined using the Courty et al. formula. For Beijing, the official 24 h 100 y storm is 299 mm (MoHURD 2024), significantly higher than the 220 mm found based on Courty et al.

The tendency of the two Chinese cities to have larger event depths is also seen when a VCR_a of 85% is calculated for all cities (Table 1). To capture 85% of the annual precipitation the Chinese cities have to deal with rain depths of 32–33 mm, while the European cities can reach a similar target by capturing 1/3 of that, i.e. rains with depths of 11–13 mm. Differences in local climate are the driver for these differences (Table 1). Both Chinese cities have monsoonal tendencies giving rise to large rain events. This is despite the very different seasonal distributions of rainfall, where Beijing's hot-summer humid continental climate (*Dwa)* exhibits much higher precipitation in summer than in winter, and the humid subtropical (*Cfa)* climate of Changde lacks any predictably dry months. All the four European cities are located in the Northwest of Europe and have similar climate classes – Turku (*Dfb*), Amsterdam, Copenhagen and Gothenburg (*Cfb*). Rainfall is relatively well

Table 2. Summary of the six case cities' stormwater strategies (pluvial water only) within the three domains. Sources in foot notes, otherwise based on CECoSC partner information.

	Day-to-Day Domain	Technical Design Domain	Extreme Domain*
Beijing	VCR_a goal of 85% (33.6 mm) for new construction areas. Other areas have other targets; average is 70% corresponding to 19 mm; must be 80% implemented by 2035	In the future the capacity of the combined sewered areas will be increased to $T = 3–5$ y; By 2025, key roads in central urban areas and urban sub-centers can cope with hourly rainfall of 65 mm without inundations. Other roads in the central city and key roads in the new city centre can cope with hourly rainfall of 54 mm without inundations. Sewage will not enter the river at the overflow points and crossing points in the central urban area when the depth of rainfall event is less than 33 mm. (Office of Beijing Municipal Government 2021)	No information available
Changde	VCR_a goal of 78% (21 mm) and 45% reduction in Total Suspended Solids by 2025, with a further reduction to 50% by 2035 for new construction areas[a]	By 2025, $T = 2–3$ y in the central city, $T = 3–5$ y in important areas and $T = 10–20$ y in the underground passages and sunken squares. By 2035, the central city will extend to $T = 2–5$ y, important areas will enhance to $T = 5–10$ y, and underground passages and sunken squares will further expand to $T = 20–30$ y. Continuously, $T = 30$ y ensures no water at buildings' ground floors, and a maximum of 15–20 cm on roads remains consistent throughout the periods.[a b)]	No information available
Turku	No binding goal. There is a recommendation to detain 1 m^3 per 100 m^2 of impervious area[c]	Most of Turku has a separate sewer system, with the stormwater pipe dimensioned for $T = 2$ y. Designated flood routes designed for $T = 100$ y	No information available
Gothenburg	No binding goal. A national guideline[d] highlights capturing of the first 10 mm of each rainfall corresponds to 75% of annual precipitation (and 15 mm to 85%)	The target for the existing combined systems is to be able to handle $T = 10$ y (with climate factor 1.2)[d]. Cloudbursts must be handled on the ground, by use of designated routes for discharge and areas for detention[e]	New developments only allowed on adequate (high) ground, and buildings must have good plinth elevation[e]
Copenhagen	No binding goal. By 2100 the capacity of the combined sewer system must be enhanced with 30% compared to 2010, preferably by decoupling and retaining stormwater in naturebased solutions (NBS)[f]	To maintain the service level of $T = 10$ y for the combined sewer, despite a 30% expected increase in annual precipitation by 2100, a 30% enlargement of the drainage capacity is decided[f]. To curb the more frequent extreme events, an additional $T = 100$ y service level is to be met by 2050. Is being based on approx. 60 'cloudburst branches', for detention and discharge via streets[g]	No specific plan. Examples of spatial planning, e.g. new Metro stations are secured against the $T = 2000–10.000$ y events by means of raised entrances
Amsterdam	No binding goal	In addition to the $T = 2$ y service level (20 mm), 40 mm should be captured by vegetation in gardens and on roofs.[h] Since 2021, 60 mm must be detained for at least 60 h on own parcel for new or renovated buildings[i]	Minimum plinth height of 20 cm above street level required

*Only spatial measures (contingency plans are not listed) Superscripts indicate sources: a Changde (2021), b MoHURD Ministry of Housing and Urban-Rural Development (2021), c iWater (2020), d Swedish Water (2016), e Gothenburg (2021), f Copenhagen (2011), g Copenhagen (2012), h van Assenbergh et al. (2015), i Amsterdam (2021a), Amsterdam (2021b).

distributed throughout the year, and small precipitation events are frequent.

4.2. City stormwater targets

In Table 2 the six case cities' current SWM strategies are organized after the 3 PA domains. None of the cities have clear targets for all three domains.

For the DDD, Turku requires a detention or retention capacity of 10 mm for every impervious m^2, and Gothenburg emphasizes the resource aspect of small events, while Copenhagen prioritises BGI-based sewer capacity enhancement to maintain its 10 y flood safety service level despite increasing precipitation. Only the two Chinese cities have specific targets in the form of VCR_a of 78 and 85%, prompting a level of citywide capturing of the first 21 to 32 mm of all rainfalls.

In the TDD, the targeted return periods vary from $T = 2$ to 100 y, corresponding to event depths from 26 mm to 162 mm. Four cities target more than one return period; thus, Beijing, Changde, Copenhagen and Amsterdam all promise a certain degree of technical control over storm events with return periods from $T = 30$ to 100 y, with only Copenhagen having an implementation deadline. This may reflect a new trend prompted by climate change, and in a way introduce first steps towards a partial SWM strategy for the ED. In the case of Copenhagen, the service level added in 2012 allows water depths of 10 cm on terrain, in contrast to the 10 y service level provided by the combined sewer where no water on terrain is allowed. While 100 y, and even 30 y events are in many contexts considered 'extreme events', here they are placed in the TDD because the target refers to a specific service level that the city's infrastructure should provide. The Extreme Domain is reserved for those events that are beyond the service level and call for contingency planning and securing of critical infrastructure through urban planning.

Regarding the ED, none of the six cities have clear citywide spatial planning strategies, but Gothenburg, Amsterdam and Changde prescribe minimum difference between ground floor level (plinth; freeboard elevation) of a building and street level. In line with this, the new Metro in Copenhagen is secured to T >1000 y by raising entrances above the surrounding terrain. While Table 2 has been completed based on correspondence with city employees and review of city stormwater documentation, these targets continue to evolve and may quickly become outdated. Therefore, the websites of the cities should always be referred to directly for the most recent targets.

4.3. Targets in the context of the 3 PA

In Figure 3, the cities' SWM targets are expressed as event depths in a 3PA-inspired plot. Such visualizations can improve understanding between cities because volumes that may be considered relevant for TDD interventions in one region may be considered DDD interventions in other regions. For example, Beijing and Copenhagen have similar annual precipitations (Table 2), but when they exchange knowledge on SWM it is critical for stakeholders to be aware that a 33 mm rain event would be considered part of the TDD in Copenhagen since it

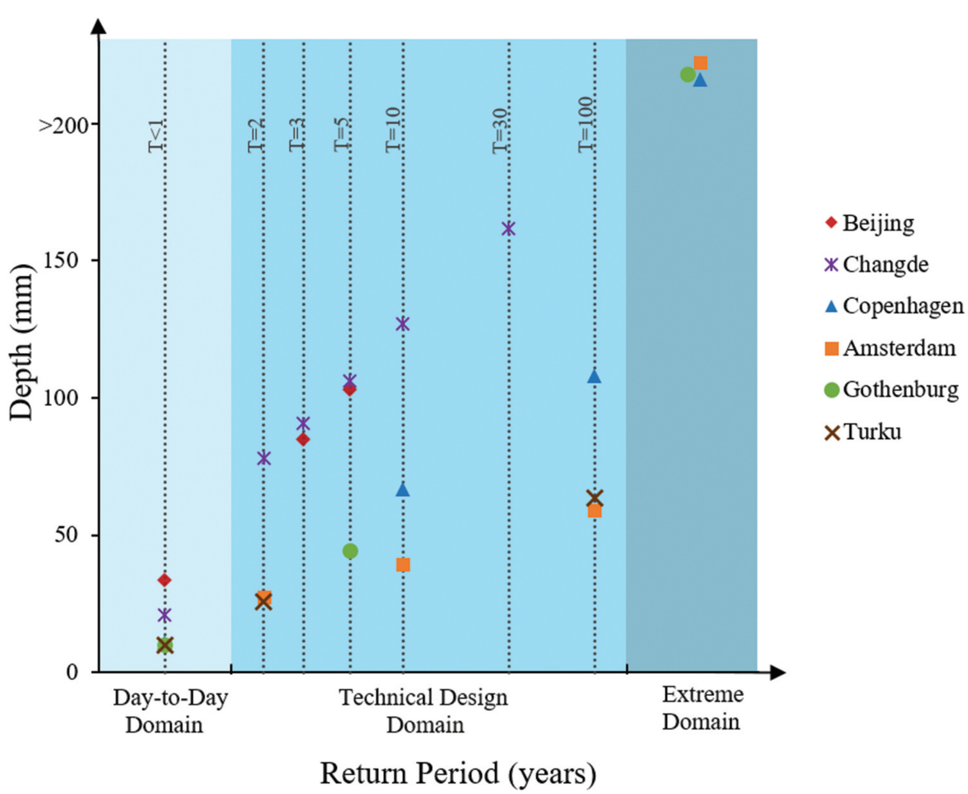

Figure 3. Stormwater targets as reported by the six CECoSC cities and organized after the three 3PA domains. In the DDD, the targeted rain depths (mm) are all shown on the same vertical line, since the corresponding return periods are all in the same low range – less than 1 y. For reasons of comparison rainfall depths in the TDD were uniformly calculated (Courty et al. 2019), assuming 24 hour durations. By definition the ED is not correlated with a specific rain depth or return period, so the marking for cities with a strategy for the extreme domains are arbitrarily positioned. There is no fixed range for the size of events the ED should cover.

corresponds to a 2 year event, but in Beijing it would be part of the DDD since the 85% VCR_a equivalent rain depth is 33.6 mm. Similarly, as seen from Figure 3, the rain depth that Copenhagen understands as a 100 y storm is actually most similar to a 5 y storm in Beijing, in terms of total rainfall volume within a 24-h period (Figure 3).

Furthermore, the event depths targeted in Beijing and Changde to meet ecological targets in the DDD, correspond to a significant fraction of the event depths managed by European cities' in the TDD (~20–60 mm). Expressing the targets as depths thus highlights absolute domain challenges as well as overlaps in domain management strategies between regions.

Figure 3 also shows that there are overlaps in the DDD and the TDD, representing opportunities for infiltration and evaporation (i.e. events up to 10–15 mm for the European cities and up to 35 mm for the Chinese cities). Thus, maximisation of benefits and minimisation of risks can intervention-wise represent two sides of the same coin.

A specific issue in target setting is snowfall and snowmelt, as seen especially in the Turku case where snowmelt can lead to serious flooding. This, however, is not the direct consequence of rainfall and has no relation with IDF curves. Moreover, the use of snowfall precipitation data for calculating the VCR_a can lead to misleading results.

4.4. Recommendations and future research

The 3PA, as applied in this paper using rain depths, is considered a strong framework for selecting and designing interventions targeting the DDD and ED and their adoption in existing city-specific approaches. By setting policies and targets for not only the TDD but also for the DDD and the ED, cities are encouraged to follow a holistic approach by addressing both the resource and disaster aspects of SWM in an integrative way. The 3PA framework also supports a dynamic policy-setting process, enabling cities to move beyond static design standards and to customize the design and engineering of the urban environment, including water services and infrastructure, to the local needs and context.

While the 3PA was found relevant as a framework in the current case which required a common language between different cities, it does not consider all complexities associated with setting stormwater targets, meaning individual cities would likely apply it as a supplement to other existing approaches when setting future targets. There are potential improvements to the 3PA, e.g. as noted by Huang and Wang (2024) the useful concept of 'design for failure' is not considered in the original description of 3PA, thereby leading to their proposed '4PA'. The current work has not made a comparative analysis of variations of 3PA and related frameworks, so this may be a useful endeavour in future work.

Whether the 3PA becomes a commonly applied framework in the future will in part depend on whether it can be effectively operationalized. A design-based process supported by evidence building (such as modelling) that synergistically integrates urban water management into the broader urban landscape will be required. To enhance operationalisation of the 3PA, future research and initiatives should focus on: (i) advancing the design methodology and guidance to accommodate the complexities arising from the intersection of water services and infrastructure delivery, and the enhancement of urban liveability and redevelopment; and (ii) harmonizing binding requirements and setting consistent targets across all three domains, potentially through regional directives or national legislation on SWM in both Europe and China. Establishing a level playing field could facilitate communication and learning among diverse professionals and stakeholders across various regions, fostering the development of new international policies.

Further, flood risk policy could be a strategic research theme for future collaborative research but will require stronger cooperation between numerous stakeholders including government, local authorities, industry, academia, and local citizens to identify common goals and reduce fragmentation of responsibilities (Rubinato et al. 2019).

5. Conclusion

This study revealed how the 3PA serves as a valuable framework for evaluating current SWM approaches in diverse urban settings. By contextualizing SWM objectives in terms of rainfall depths within the 3PA framework to create a level playing field, commonalities and disparities in SWM strategies were pinpointed across the six cities: Beijing, Changde, Turku, Gothenburg, Copenhagen, and Amsterdam. The analysis revealed that only the TDD was covered by all cities, while Amsterdam and Copenhagen displayed trends to close the gap towards more extreme events by targeting longer return periods, although with a lower service level, e.g. allowing some degree of water on the surface. Regarding the DDD, the Sponge City guidelines require some level of stormwater retention, expressed as VCR_a, presented as an ecological and drought resilience measure. Similar argumentations were found in the Swedish national guidelines.

By comparing cities using metrics such as IDF curves derived from global datasets, it was found that the rainfall depths targeted by Chinese cities to achieve VCR_a targets are closely aligned with those managed by European cities to achieve targets in the TDD. Expressing these targets as event depths reveals synergies in domain management strategies, providing valuable insights for future efforts to mitigate risks and maximize benefits through a shared SWM terminology that transcends geographical and disciplinary boundaries.

Although initially conceived as a qualitative framework, this paper demonstrates the practical application of the 3PA using quantitative metrics (i.e. IDF curves and VCR_a), and by framing challenges in terms of rainfall depths rather than return periods. An area ripe for further exploration involves striking a balance between discharge and storage capacity within urban drainage systems, where enhanced storage capacity for retention and detention throughout the city enables the integration of BGI capacities for both the DDD and the TDD. Future research could support detailed guidance in this regard, empowering cities to address their unique drainage challenges and devise tailored solutions that alleviate flooding, drought, water quality issues, and water resource constraints while optimizing societal, ecological, and economic benefits.

While the utility of the 3PA framework was evident in our study, challenges such as institutional complexity and inertia may hamper its widespread adoption in SWM practices. Overcoming these obstacles necessitates dismantling silos to create an environment where all disciplines recognize the imperative to address all three domains. This shift promises to streamline the adoption of comprehensive and resilient SWM strategies conducive to sustainable urban development

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Data availability statement

The 24-h rainfall records used to calculate Volume Capture Rations are openly available from the Climate Data Online Service of the National Oceanic and Atmospheric Administration at https://www.ncei.noaa.gov/cdo-web/. The Parametrized eXtreme Rain (PXR) published by Courty et al. (2019) used for producing IDF curves are available at https://zenodo.org/records/2616438#.XU6tW2R7mUk.

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