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Exploring the potential for rainwater use for the urban poor in Bangladesh

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ABSTRACT

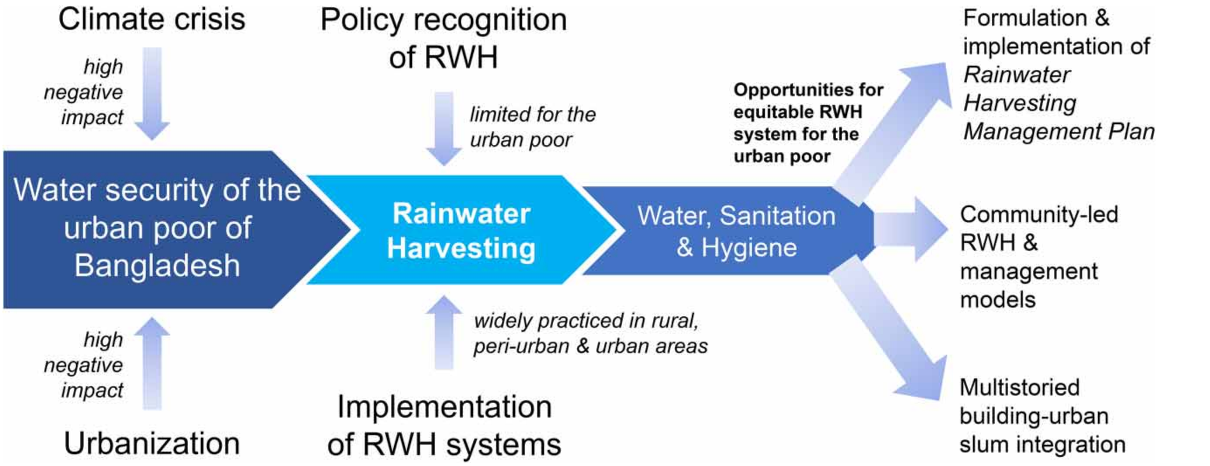
Under the climate crisis and rapid urbanisation, rainwater harvesting (RWH) is more pertinent than ever. In Bangladesh, the full potential of rainwater use, especially for the urban poor, has not been explored. This study reviewed the recently-executed national plans to assess the RWH provisions, explored literature to map RWH practice, showed the alignment between the plans and the practices, and assessed the provision of RWH in the currently-implemented plans, with a particular focus on the urban poor. Although the past plans recognised RWH, the study found that these did not emphasise the implementation process nor offer provisions for the urban poor. RWH was, however, widely practised in the urban, peri-urban, and rural parts of the country by utilising different catchment structures. Building on the experiences of other countries, the study assessed the feasibility of RWH for the urban poor to meet their sanitation and hygiene needs under the changing climate. The study concluded that a detailed 'Rainwater Harvesting and Management Plan' supporting the adoption and promotion of community-led models to mitigate RWH-related challenges in the urban slums and integrating multi-storied buildings to harvest rainwater for the poor neighbourhoods could ensure efficient and equitable rainwater management for the urban poor.

Key words: Rainwater harvesting, Slums, Sustainable water management, WASH

HIGHLIGHTS

- National planning documents emphasise utilising rainwater, but lack implementation mechanism.
- Rainwater harvesting identified as a feasible solution, especially for the areas that lack proper water supply.
- Rainwater harvesting has not been adequately adopted for urban slums.
- A context-specific rainwater management plan along with community-led compassionate model can ensure suitable water supply, especially under climate crisis.

GRAPHICAL ABSTRACT



INTRODUCTION

Rainwater harvesting, the cheapest alternative to the traditional water sources (Zavala *et al.*, 2018), is a simple process to preserve rainwater for further use by collecting, storing, and purifying if needed (Mays *et al.*, 2013). The practice of rainwater harvesting dates back to the Neolithic age (10,000–4,500 BC) (Mays *et al.*, 2013). From the Prehistoric era (3,200–1,100 BC) to this modern period, harvested rainwater has been part and parcel of human lives (Yannopoulos, *et al.*, 2017). In the technology-dominated 21st century, harvesting rainwater remains prevalent in almost every corner of the globe. Rainwater harvesting is being practised in Africa (Durodola *et al.*, 2020; Odhiambo *et al.*, 2021), Asia (Tran *et al.*, 2020; Zhang *et al.*, 2021), Europe (Velasco-Muñoz *et al.*, 2019), Latin America (Cardoso *et al.*, 2020), North America (Lloveras, 2019; Rovira *et al.*, 2020), and Oceania (Bint *et al.*, 2018). Rainwater can be used as both potable and non-potable water (Słyś & Stec, 2020). The use of the harvested rainwater entails drinking, non-drinking household uses (i.e., cooking, bathing, laundry, and flushing toilets), agriculture (includes livestock production or homestead gardening), water resource management (e.g., groundwater recharge), and other uses (e.g., washing vehicles and equipment, and water for fire protection) (Tolk *et al.*, 2014; Zdeb *et al.*, 2018; Pavolová *et al.*, 2019; Durodola *et al.*, 2020; Kazmi, 2020).

In recent times, rainwater harvesting has been gaining special attention as a form of sustainable practice, especially in the urban context (Lani *et al.*, 2018). Rooftop rainwater harvesting (RTRWH) is the most common technique that is practised in urban areas. Although RTRWH can be implemented anywhere, individually or at a community level (Shrestha, 2007), a monthly average of 50–300 mm rainfall is needed to make rainwater harvesting feasible in the urban areas (Behera *et al.*, 2016). Furthermore, it may cost USD 100–1,000 to install a rainwater harvesting system (RWHS) in any urban infrastructure (Lehmann *et al.*, 2010). However, the supply of harvested rainwater is limited by the amount of rainfall, the size of the catchment area, and the storage and other management facilities (Karim *et al.*, 2021).

Bangladesh enjoys an annual average rainfall of approximately 2,400 mm (BMD, 2021). Studies conducted both in rural and urban contexts (Alam *et al.*, 2011; Karim *et al.*, 2015; Islam & Afrin, 2020) indicated that up to 55% of the total water demand of a household could be met through proper rainwater management. Karim *et al.* (2015) also highlighted that, based on the catchment size (140 m^2–200 m^2), 250–550 kilolitre of rainwater could be harvested in a year. The payback period, a major concern of urban rainwater harvesting, was recently estimated to be 3–13 years, depending on the precipitation (Islam & Afrin, 2020). Molaei *et al.* (2019) noted that 500–800 m^3 of water could be saved annually by harvesting rainwater in different cities in Bangladesh.

The concept of rainwater harvesting is becoming popular gradually in Bangladesh, especially in the coastal areas, since they suffer from salinity, inadequate fresh water, and other climate change issues, making the water supply more difficult (Islam & Afrin, 2020). The technology of RWH is also prevalent in arsenic-affected rural areas (Bashar *et al.*, 2018). However, the urban areas show limited adoption of rainwater harvesting mainly because of a lack of confidence in potential water savings and payback period on the initial investment (Bashar *et al.*, 2018).

Until now, rainwater harvesting has been piloted in residential buildings (Sikder, 2020), educational institutions (Islam *et al.*, 2019), industrial establishments (Karim *et al.*, 2021), and other infrastructures (e.g., office buildings, and hospitals) (Kazmi, 2020) in most of the major cities in the country. Nevertheless, no significant initiatives have been taken for slum areas, the home of most urban poor. Moreover, no prior studies have been found that assess whether rainwater has been utilised in a planned way in Bangladesh.

Several studies have highlighted how slum dwellers and low-income communities suffer from a lack of water (Alam *et al.*, 2020; Baten *et al.*, 2021; Chowdhury, 2021). Harvesting rainwater, therefore, has significant potential for the poor in Bangladesh, especially in towns and cities (Imteaz *et al.*, 2021). Studies elsewhere showed (Chan *et al.*, 2020; Anayah *et al.*, 2021) that RWH has the potential to ensure improved sanitation and hygiene for the urban poor. To capitalise on the full potential of RWH for the urban poor of Bangladesh, we need to understand how the current government plans are considering rainwater management and how RWH is being practised in this country. While this combined understanding of plans and practices can help recognise the future scopes of RWH and the overall water sustainability issue of urban Bangladesh, such analysis is currently missing.

To fill in this knowledge gap, we focused on three interlinked issues: (i) the plans adopted by the Government of Bangladesh regarding RWH, (ii) the practices of RWH throughout the country since 2011, and (iii) RWH for the urban poor. The objective of our research was to explore whether the RWH is practised in a planned way in Bangladesh. Furthermore, we investigated the plans adopted by the government to apprehend if there is any scope for RWH for the urban poor, especially for sanitation and hygiene purposes.

Following were the research questions that guided our study:

1. How do the short-term and medium-term planning documents (2011–2021) of the Government of Bangladesh address RWH?
2. What are the rainwater management actions taken so far by different agencies in different regions essentially to implement the government plans?
3. What are the opportunities the current short-, medium-, and long-term plans (since 2018) offer, especially for the urban poor, regarding their sanitation and hygiene practices?

METHODS

This qualitative research is mainly driven by the textual narrative synthesis method (Popay *et al.*, 2006) that focuses on formatting the data into applicable sub-groups. This study was conducted from July 2021 to September 2021. The secondary literature considered in this research is six planning documents of the Government of Bangladesh labelled as short-term, medium-term, and long-term plans (Table 1). Textual narrative synthesis guided the analysis of these planning documents. To explore rainwater harvesting in these planning documents, keywords, namely 'rainwater harvesting', 'rain water harvesting', 'rainwater', 'rain water', 'water harvesting', and

Table 1 | Planning documents of the Government of Bangladesh analysed in this research following textual narrative synthesis method.

Time-frame	Short-term	Medium-term	Long-term
Plans those guided the RWH practices till 2021	Sixth Five-Year Plan (FY2011–FY2015) (Planning Commission, 2011) Seventh Five-Year Plan (FY2016–FY2020) (GED, 2015)	Perspective Plan of Bangladesh (2010–2021) (GED, 2012)	Not applicable
Plans those will steer the RWH practices beyond 2021	Eighth Five-Year Plan (FY2021–FY2025) (GED, 2020b)	Perspective Plan of Bangladesh (2021–2041) (GED, 2020a)	Bangladesh Delta Plan 2100 (GED, 2018)

Note: FY stands for the fiscal year. In Bangladesh, an FY covers from 1 July of a year to 30 June of the following year. For example, FY2011 means 1 July 2010-30 June 2011.

'water management' were used. These keywords were considered as the data search parameter based on the findings from the earlier literature review.

The five-year plans are the main short-term plans adopted by the Government of Bangladesh. Among the three FYPs considered in this study, the Sixth Five-Year Plan (6FYP) has been driven by the theme 'Accelerating Growth and Reducing Poverty' and acted as an implementation plan of the 'Vision 2021' (political manifesto of the then government) and the Perspective Plan of Bangladesh (2010–2021) (the plan that guided the 'Vision 2021') to graduate Bangladesh to the Lower Middle-Income Country status by 2021. The Seventh Five-Year Plan (7FYP) had a slogan similar to that of the 6FYP, 'Accelerating Growth, Empowering Citizens', which focused on continuing the 'Development Outlier' phenomenon towards sustainable development trajectory that Bangladesh achieved for its socio-economic transformation. Prepared during the first year of the COVID-19 pandemic, the Eighth Five-Year Plan (8FYP) complements the Perspective Plan of Bangladesh (2021–2041). Moreover, the 8FYP prioritises implementing the first phase of the Bangladesh Delta Plan 2100 (BDP2100). The 8FYP highlights inclusive growth, public investment, human development, social protection, infrastructure development, urban transition, and sustainable development, among other priorities.

The first-ever Perspective Plan of Bangladesh started its mission with the tagline 'Making Vision 2021 A Reality'. This plan (2010–2021) was the roadmap for accelerated growth while eradicating poverty, inequality, and deprivation. It has also taken into consideration the urban challenges that exist in the country. The backlog of unmet demands and the new demands for basic urban services were underlined in the plan. Next to it, the follow-up perspective plan for 2021–2041 was initiated with an aim to make the 'Vision 2041' a reality. This medium-term planning document highlights eliminating extreme poverty and reaching Upper Middle-Income Country (UMIC) status by 2031 and High-Income Country (HIC) status by 2041.

The Bangladesh Delta Plan 2100 is the long-term planning document of the Government of Bangladesh that focuses on challenges regarding sustainable management of water, ecology, environment, and land resources in the context of their interaction with natural disasters and climate change. The goals of the BDP 2100 are adaptive in nature. An integrated and holistic plan for water resources management is highlighted separately in this document.

This study is also guided by the scoping review method (Munn *et al.*, 2018). Scoping review guides the in-depth analysis of the data acquired. The scoping review approach was mainly followed to analyse academic and practitioner-level studies to scrutinise the practices regarding rainwater. We collected practices and implementation activities of RWH through a thorough online search. We first explored relevant organisations' websites, then used search engines, namely Google and Google Scholar, to collect relevant literature for analysis. Moreover, a few articles published in the reputed national dailies of Bangladesh were also taken into consideration.

The rainwater management practices were categorised into three contexts: urban, peri-urban (e.g., municipalities, and Upazila (sub-district)), and rural. Moreover, to understand the catchment area, infrastructures were divided into (i) multi-storied residential building, (ii) residential structure other than multi-storied building, (iii) commercial establishments, (iv) educational buildings, and (v) other establishments (e.g., community buildings, government/NGO offices, and hotels). Practices of RWH in Bangladesh were analysed for the past 12 years (2010–2021). This timeline was considered because it covers the implementation period (2010–2021) of the country's first perspective plan when the 6FYP (FY2011–FY2015) and the 7FYP (FY2016–FY2020) were implemented and includes both the completion of the Millennium Development Goal (MDG) period and beginning of the Sustainable Development Goal (SDG) era.

RESULTS AND DISCUSSION

RWH in the short- and medium-term plans (2010–2021)

In the Sixth Five-Year Plan (FY2011-FY2015) (6FYP), RWH is first mentioned under the theme managing climate change. Regarding adaptation to climate change, flood protection and drainage schemes are encouraged to protect urban areas from rainwater-induced waterlogging during the monsoon. In the policies and strategies for the development of water supply and sanitation (WSS), urban water supply, urban sanitation, and urban environmental sanitation (includes solid waste management and stormwater and sullage drainage), RWH is underlined as well. It also refers to the National Policy for Safe Water Supply & Sanitation 1998 as it includes the provision for proper use of surface water and rainwater. As the Government of Bangladesh alone has the ownership of the water sources, their protection, development, extraction, treatment, transmission, and service, its Department of Public Health Engineering (DPHE) is assigned as the responsible agency to manage the water sources in rural areas. Furthermore, the concerned local government institutions (LGIs) are put in charge of the operation and management of the WSS services. To explore the technological options for sustainable water and sanitation services, recognising the needs of specific areas and socio-economic groups of people are also highlighted in the 6FYP. RWH is pointed out as one of the appropriate technologies for arsenic mitigation. In the development aspects of this plan, to increase the coverage of safe drinking water (both in rural and urban areas) and ensure access to hygienic sanitary latrines for all, including densely populated poor communities, storage and use of rainwater is recognised as one of the mechanisms. The strategy for poverty reduction in the 6FYP emphasises promoting sustainable water and sanitation services by ensuring storage and use of rainwater.

In the Seventh Five-Year Plan (FY2016-FY2020) (7FYP), RWH is first mentioned to reduce groundwater dependency. The plan mentions that, although the Water Act 2013 promotes rainwater as an important source of safe potable water, it is yet to be elaborated in different policies, strategies, and action plans. The 7FYP especially emphasises making RWH mandatory for all government buildings that will benefit the people in the coastal regions and also secure the level of groundwater in the urban areas. The plan also emphasises exploring options for RWH. Regarding agriculture, to address the challenges of decreasing water resources and ensuring water conservation, mandatory RWH and efficient use of rainwater is prioritised. Agricultural research is also encouraged that will safeguard sustainable natural resources management, including RWH for agricultural production. To highlight the needs and scope of a well-planned irrigation management system, RWH in rain-fed, coastal, and hilly areas are encouraged.

Although the Perspective Plan of Bangladesh (2010–2021) is the guiding document of the 6FYP and the 7FYP, this document is not much detailed. In this medium-term strategic planning document, RWH is mentioned once under the long-term water resource management strategies and is encouraged in the dry season.

Rainwater management in practice

RWH is practised both in the rural and urban areas of Bangladesh. A wide range of rainwater usages covers both potable and non-potable usages. However, RWH for potable use in the urban context was almost absent (Table 2). RWH was being practised through government and non-government initiatives. Along with that, RWH for commercial purposes has also started in the country.

Initiatives regarding rainwater management adopted by the Government of Bangladesh date back to 2000 (Haq, 2013). In 2002, the Public Works Department (PWD) and the Department of Architecture (DoA) jointly published a manual on RWH in Bangla language (*Brishtir Pani Shangrakkhan o Baybohar Proshonge Nirdeshaboli*; translated into A Guideline to Preserve and Use Rainwater) (Haq, 2013). In recent times, the Government of Bangladesh considered RWH systems an alternative water supply option to be implemented in hilly and coastal areas (Al Amin, 2019). Rajdhani Unnayan Kartripakkha (RAJUK) constructed 69 buildings in Uttara, Dhaka, with RWH facilities. Moreover, the government initiated the building of 12,000 and 60,000 apartments with RWH facilities in the Jhilmil and Purbachal projects in Dhaka, respectively, which are supposed to be completed by 2021 (Abdullah, 2019). The DPHE, the mandated representative of the government regarding water supply, has also adopted RWH as a mitigation mechanism to ensure water supply in rural areas of the country (DPHE, 2015).

In the capital city, Dhaka Water Supply & Sewerage Authority (DWASA) is working to utilise rainwater as an alternative source of water supply (Ahmed *et al.*, 2013). Among the development organisations working in Bangladesh, WaterAid has installed more than 7,000 RWHSs since 2010 (Al Amin, 2019). The organisation has been encouraging harvesting rainwater for watering gardens, washing cars, and toilet flush, rather than drinking it. They have also assisted two national NGOs (Population Services and Training Centre, PSTC and Village Education Resource Centre, VERC) to install RWHS to find out the knowledge gaps and opportunities for urban areas (Ahmed *et al.*, 2013). UNICEF in Bangladesh was practising and advocating for the Managed Aquifer Recharge (MAR) concept for a long time, and under this initiative, they were practising rainwater harvesting (Tolk *et al.*, 2014). In the coastal villages of Bangladesh, another UN agency, UNDP, established RWHSs in household, community, and institution levels and attempted to secure at least two litres of freshwater per person every day (UNDP, 2020). The United Nations Capital Development Fund (UNCDF) is also doing the same, in rural parts of the country, as a part of their 'Local Government Initiative on Climate Change (LoGIC)' project supported by the Local Government Division (LGD) (Hasan & Ariba, 2021). UN-HABITAT (2005) reported that the NGO Forum for Public Health promoted rainwater harvesting in Bangladesh, mainly rural. As per that report, during 1997–2005, they installed around 1,000 rainwater harvesting plants. Since then, the NGO Forum has been endorsing rainwater harvesting in the urban areas as well. Dushtha Shasthya Kendra (DSK) also worked on rainwater previously (The Daily Star, 2013), but no recent initiatives have been noticed, although they rigorously work in several WASH projects.

Rainwater harvesting for commercial purposes is a comparatively new concept in Bangladesh. Skywater Bangladesh (SB) Ltd, established in April 2013, is a specialised sky water harvesting company that focuses on solving the drinking water crisis. AMAMIZU (1,000-Litre jar) is one of their unique products made of sand and cement by a specially trained mason using Thai technology. This is suitable for the household level use of low-income people (Skywater Bangladesh, 2021). ABM Water Company is another private entity focused on rainwater harvesting. Established in 2000, they have been providing several other water-related services as well. A national daily

Table 2 | The following table analysed different types of rainwater harvesting (RWH) initiatives iterated, piloted, and adopted in Bangladesh.

Context	Residential Area (multi-storied building)	Residential Area (other than multi-storied building)	Commercial/ Industrial Establishment	Academic Institute (including students' residential halls/hostels)	Others
Urban	*For Flood reduction/management* in Chittagong (Akter *et al.*, 2020) In Dhaka (Uttara, Mirpur, Merul Badda, and Gulshan) and Gazipur (Tongi), recommended for *non-potable use* (Haque & Rinkey, 2019) In Chittagong, Rajshahi, Khulna, Sylhet, and Barishal, *for multiple usages in daily lives and to alleviate urban flooding/waterlogging* (Bashar *et al.*, 2018) In Dhaka, *for household usage* (Karim *et al.*, 2015) In South Agrabad, Chittagong (Akter & Ahmed, 2015) *For toilet flushing and cleaning purpose* in Kazipara, Dhaka (Tabassum, 2013) In Niketan (Dhaka), *for household usage* (Nahian *et al.*, 2013)	In Bashundhara (Dhaka), tin rooftop *recommended for non-potable use* (Haque & Rinkey, 2019) In Maleker slum (Tilpapara), Bhuiyapara slum (Meradiya), and Lalasarai slum (Mirpur) (all in Dhaka), *for sanitation purpose* (Nusrat, 2014) In duplex buildings in Banani and Baridhara (Dhaka), *for multiple non-drinking purposes* (Dakua *et al.*, 2013)	In five commercial buildings in Dhaka, *mainly non-potable purposes (used for cleaning of floors and parking lots, toilet flushing, etc.)* (Karim *et al.*, 2021) In Midas Centre in Dhanmondi (Dhaka), *as a secondary water source for daily toilet use* (Niloy, 2020) In Dhaka, Chittagong, Rajshahi, Khulna, Sylhet, and Barishal, *for various usage* (Bashar *et al.*, 2018) In Northern Tausrafi Industry (Dhaka), *for nine months of toilet flushing for 2,000 persons* (Alum, 2013)	In Khulna University of Engineering & Technology (KUET), *as an alternative non-potable water source* (Zakir & Ekram, 2020) In the University of Information Technology and Sciences (UITS) (Dhaka) *for multiple purposes like toilet flushing, ablution for prayer, mopping, and gardening* (Islam *et al.*, 2013) In the Military Institute of Science and Technology (MIST) (Dhaka) *for washing purposes and recharging the aquifer* through Aquifer Recharge System (Faruk & Arifuzzaman, 2013) In Ahsanullah University of Science and Technology (AUST) (Dhaka), *for multiple non-drinking purposes* (Dakua *et al.*, 2013) In Bangladesh University of Engineering & Technology (BUET) *for toilet flushing* and Independent University of Bangladesh (IUB) *for different purposes except drinking* (both in Dhaka) (Ahmed *et al.*, 2013)	In hotels, government office buildings, hospitals, and mosques in Cox's Bazar (Kazmi, 2020) *for toilet and shower usage (in hotels)* In the head office of the Public Works Department (PWD) (Dhaka) for toilet flushing (Ahmed *et al.*, 2013) In the office of two NGOs in Dhaka – Village Education Resource Centre (VERC) *(for supplying water to the training centre and head office)* and Population Service and Training Centre (PSTC) (Ahmed *et al.*, 2013)
Peri-urban	Did not find any case regarding RWH in multi-storied residential buildings in the peri-urban areas	In residential buildings in Paikgacha Municipality (Khulna) *for various usage* (Islam & Afrin, 2020) In Mongla (Bagerhat) *for domestic water supply* (Islam *et al.*, 2015) *For household-level drinking water*, in Dacope (Khulna) and Mongla (Bagerhat) (Ghosh *et al.*, 2015)	In commercial buildings in Paikgacha Municipality *for various usage* (Islam & Afrin, 2020) In a four-storied commercial building with 1,000 employees at municipality level, *to assess the life cycle of a commercial rainwater harvesting system* (Ghimire *et al.*, 2017)	In education institutes in Paikgacha Municipality *for various usage* (Islam & Afrin, 2020) In Pabna University of Science and Technology (PUST), *as a supplementary water source* (Atauzzaman *et al.*, 2020)	In community buildings in Paikgacha Municipality *for various usage* (Islam & Afrin, 2020) In the Barind region – Godagari (Masum *et al.*, 2013) and Tanore Upazila (Rajshahi) (Hasan *et al.*, 2019) and Nachole and Gomastapur Upazila (Chapai-Nawabganj) (Rahaman *et al.*, 2019) *for agriculture (irrigation) purpose*

(*Continued.*)

Table 2 | Continued

Context	Residential Area (multi-storied building)	Residential Area (other than multi-storied building)	Commercial/ Industrial Establishment	Academic Institute (including students' residential halls/hostels)	Others
					To address the scarcity of drinking water, in Paikgacha Municipality (Khulna) in Abasan (a low-cost housing settlement) community (Sake, 2013)
Rural	Not Applicable	In multiple locations, *for drinking water* at rural household level (Alim *et al*., 2020) In rural households, *for drinking water*, especially for underprivileged people (UNDP, 2020) *For cooking water*, at the household level in the coastal area (Karim *et al*., 2014) In Khulna, *for domestic use* (Biswas & Mandal, 2014) In Mymensingh and Sylhet, large-scale storages are used (Ahmed *et al*., 2013) In Kaptai, Bandarban, and other hill tracts areas, *for household use* (Ahmed *et al*., 2013) In Sylhet, for drinking purposes (Alam *et al*., 2011)	Not Applicable	In 23 primary schools of Mongla (Bagerhat), *as a source of drinking water* (Islam *et al*., 2019)	In Sutarkhali Union (Khulna), mainly *for drinking purposes* (Hasan & Ariba, 2021) In Deluti Union (Khulna) *for providing drinking water* at the community level and in institutions (UNDP, 2020) In the Chittagong Hill Tracts, *for agricultural purposes* (Islam *et al*., 2016) In Narail that aimed at *arsenic reduction* (Tolk *et al*., 2014) 52 indigenous harvesting methods by coastal people (Ahmed *et al*., 2013) In Rangamati (Kaptai), Bandarban, and other hill tract areas, *for irrigation and navigation purposes* (Ahmed *et al*., 2013) Community-based southwest coastal and arsenic-affected areas in the country, *to mitigate the drinking water problem* (Karim, 2010)

In each case, use is given in italics.

(Chandan, 2018) mentioned that ABM Water Company harvests rainwater to convert it into fresh drinking water, especially in the remote villages of Bangladesh.

A few key points gathered from the analysis (Table 2) are that rainwater harvesting for drinking purposes is almost absent in the urban areas, rainwater is used more for cleaning and sanitation in the urban context, and in most cases, rainwater is harvested using the run-off and catchment of the rooftops of multi-storied buildings.

Alignment of national plans and practices (2010–2021)

Building on the preceding two sections, we aligned the RWH practices with the relevant plans. Table 3 shows that these plans have so far been implemented broadly. As the table highlights, the plans have underscored a few issues, like waterlogging, urban water supply dynamics, drinking water scarcity (in a few special cases), WASH, and agriculture. On the other hand, rainwater harvesting practices portray that rainwater has been utilised to address most of these issues.

RWH in the short- and medium-term plans beyond 2021

In the Eighth Five-Year Plan (FY2021-FY2025, 8FYP), rainwater utilisation is mentioned from several standpoints. RWH is highlighted to promote sustainable agriculture and green growth, in agricultural research, regarding improved management of water pollution and to focus on sustainable water resources management. The objectives and targets of the water sector for the 8FYP were set out in conformity with the Perspective Plan of Bangladesh (2021–2041) (PP2041) and the Bangladesh Delta Plan 2100 (BDP2100), where rainwater harvesting is mentioned as a strategic objective. RWH is mentioned explicitly for sanitation purposes in the coastal areas, *char* (riverine island) areas, and hill tracts. Community water points and sanitation blocks to be maintained by community-based organisations are marked as appropriate solutions in the hill tracts and the coastal areas. Community water points have also been encouraged for the urban slums. However, in the urban slums, where

Table 3 | Rainwater management in Bangladesh in the 2010s by translating plans into practice.

Key sectors that have been associated with rainwater harvesting in the planning documents	Recorded practices of rainwater harvesting that show alignment between the plans and practices
Rainwater harvesting for urban flood/ waterlogging management	Such practices were found in Chittagong, Rajshahi, Khulna, Sylhet, and Barishal districts
Proper utilisation of rainwater for urban water supply	Various cases were identified. However, all of those were initiated by individuals or private entities
Rainwater harvesting in the rural area, especially for arsenic mitigation	Multiple cases were marked where RWH was practised to collect drinking water in the places that were arsenic-prone and faced salinity intrusion challenges *[although the latter was not highlighted in the plans]*
Rainwater for WASH (urban poor have been mentioned particularly in the 6FYP)	Just one case was found where rainwater harvesting was practised in the slums; most of the cases found were based in multi-storied urban structures *[which did not include the urban poor]*
Rainwater harvesting for water resource management in the dry season	In the dried Barind region, harvested rainwater was used for irrigation purposes during the dry season
Mandatory provision of rainwater harvesting in all government buildings	RAJUK has been implementing this in its two ongoing projects in Dhaka
Rainwater for agriculture	This is practised mainly in the Barind region and the Chittagong Hill Tracts

Some discrepancies are noted in italics within square parentheses.

there is deprivation of basic WASH facilities, waterlogging, and lack of water supply, rainwater was not mentioned at all. Regarding the strategies for the development of infrastructure and services, basic urban services (although it does not focus on the urban poor), including water supply, rainwater harvesting, are encouraged to be explored, which might have the added benefit of reducing run-off.

The PP2041 does not discuss RWH in detail. Still, it includes the scarcity of surface water for irrigation and decline in the groundwater level, use of digital technology and sound water management systems, and use of water resources. In all these aspects, rainwater harvesting is mentioned. RWH is also mentioned regarding agricultural research and sustainable water resource management, especially for the problem areas, such as hills, coastal, *haor* wetland, and drier Barind areas, with proportionately higher populations of poor and vulnerable people. However, in this category, the urban poor is not included.

In the BDP2100, RWH is considered an innovative alternative for water supply that may reduce demand on the existing water supply. In this strategic plan, rainwater harvesting is mentioned regarding ensuring water availability by balancing supply and demand for sustainable and inclusive growth, especially during the dry season and in the Barind and drought-prone areas; providing safe water to sustainable drinking water and sanitation, especially in the *haor* wetland and flash-flood areas; ensuring water for irrigation; and ensuring optimised water control in the Chittagong Hill Tracts. RWH is also highlighted as a local water-saving technique in urban areas. To improve sanitation, drainage congestion, and flood control for Chattogram City Corporation area, necessary measures are adopted to store and use rainwater. Concerning the rapid urbanisation and urban poverty, it is mentioned that urban poor people are forced to settle on marginal lands, which usually serve as storage areas for rainwater. If squatter settlements are developed on public open spaces or green areas, that may increase rainwater run-off and hinder groundwater recharge. However, no mechanism is mentioned that might help the urban poor to utilise rainwater.

To summarise, there is almost no provision of rainwater harvesting for the urban poor in the above three short-, medium-, and long-term planning documents. Moreover, rainwater harvesting for sanitation and hygiene gained moderate attention, although no significant focus is put on the urban poor.

Recognition of rainwater harvesting in national policies and plans and its translation into action

It is alleged that the potential for rainwater harvesting has largely been neglected in the modern era due to both local context and policy and institutional barriers (Corneliussen, 2018). However, many countries in the world have also been trying to promote rainwater harvesting. Japan and Uganda provide subsidies and low-interest loans for RWHS installation, while Australia, the USA, and Germany provide rebates and tax exemptions to foster rainwater use (Lani *et al*., 2018). Some other countries (e.g., Taiwan, Jordan, Spain, and Belgium) are trying to utilise rainwater in a planned way, which is reflected in their national planning and policy documents (Lani *et al*., 2018).

In South Asian countries, RWH has always been a priority, reflected by the South Asia Rainwater Network (SARN). Among its member countries, India harvests at least 10–20% of the total available rainwater in a year (Verma, 2021). Here, most of the states have separate plans regarding rainwater harvesting (Shrinivasan, 2021). For the last two decades, the Central Ground Water Board (CGWB) had a Rain Water Harvesting Guide that emphasised RWH in urban areas (MoWR, 2003). One of the best practices in India is that the Indian Railways install rooftop RWH systems at more than 2,400 different locations, including station buildings (Outlook, 2017). Rainwater harvesting for the urban poor has been noticed in India as well. West Bengal implemented a rainwater harvesting project in Darjeeling, especially for the poor (IANS, 2017). In Sangam Vihar, an unauthorised colony in Delhi, rainwater harvesting was utilised to mitigate flooding and water scarcity as an initiative by a USAID-funded project (Roller, 2016). Such plans and practices regarding RWH for the urban poor can also be adopted in Bangladesh by both the government and the development partners. However, the feasibility and sustainability of those projects need to be ensured first.

Another South Asian country, Sri Lanka, receives an abundance of rain, making it one of its primary sources of water (Ariyananda, 2020). Although RWH in Sri Lanka started in 1995, the National Rainwater Policy and Strategy (NRPS) was adopted in 2005 to bring RWH under a systematic approach (Ariyananda, 2020). Since 2009, legislation has also been prevailing that made the rainwater harvesting system mandatory in new buildings in the urban area (Strand, 2013). According to the Lanka Rain Water Harvesting Forum (LRWHF), more than 50,000 RWHS were installed throughout the country during the last 25 years (LRWHF, 2020). However, there are very few rainwater harvesting systems in the urban areas, mostly in commercial and industrial buildings (Strand, 2013). In Sri Lanka, no recent projects and practices of RWH in the urban areas are found; instead, RWH in rural areas, especially the flood- and drought-prone areas, are marked (LRWHF, 2021). Such dynamics might be due to a challenge assessed by Strand (2013) that RWH requires ample space, which is inadequate in urban areas compared to rural ones. This is also true for Bangladesh's cities; however, RWH for the urban poor should not be ignored since there are no cheaper, eco-friendly alternatives.

In Myanmar, harvested rainwater is used for agricultural production and safe water supply in rural areas, sanitation, and water-related hazard mitigation (Castelli *et al.*, 2020). However, there are no specific rainwater harvesting policies or plans that have been noticed. A case study on integrated water resource management highlighted the importance of rainwater harvesting as a tool for strategic planning for water resources (Oo, 2015). In the National Water Policy 2015, rainwater harvesting has been promoted throughout the country as a part of fair water allocation. In urban and industrial areas, rainwater harvesting has been incredibly encouraged to increase the availability of usable water (NWRC, 2014). In the urban area, central urban supply is highly inadequate, making the people rely on individual initiatives (ADB, 2013). Nevertheless, RWH in urban areas seems almost absent since no such cases could have been found.

In Malaysia, rainwater harvesting was proposed by the government as part of the solutions to mitigate the water scarcity problem (Lee *et al.*, 2016). Following this, a guideline on installing a rainwater collection and utilisation system was issued in 1999, and a few other policies and guidelines have been adopted recently (Lani *et al.*, 2018). Among those, an RWHS Guidebook on Planning and Design and an Urban Stormwater Management manual are notable. Despite having such policies, RWH is still not well received in Malaysia (Ayob & Rahmat, 2017), although urban rainwater harvesting has significant opportunities in Malaysia (Woon *et al.*, 2019). Cases from both Myanmar and Malaysia make it clear that only the presence of policy without its proper implementation will not add any value. Another vital issue that needs to be underlined is that while developing any policy or plan, the regulatory body is required to assess the practicality and acceptability. Otherwise, it would be difficult to translate the plans into action.

Recently, rainwater harvesting has gained wider attention from the government in Vietnam (Thuy *et al.*, 2019). While the Vietnamese Law of Water Resources (2012) has encouraged RWH, this document does not provide detailed rainwater harvesting guidelines. Moreover, there is a common lack of awareness and knowledge about RWH among the urban residents in Vietnam (Thuy *et al.*, 2019). However, lately, Ho Chi Minh City has planned to build more than 100 reservoirs to store rainwater (Viet Nam News, 2019). Thailand mostly follows traditional mechanisms to harvest rainwater, i.e., individual household jars and community-oriented tanks (Visvanathan *et al.*, 2015), which can be an example for the Bangladeshi urban poor. In 1985, the National Jar Program was launched in Thailand, which significantly supported rainwater harvesting (Luong & Luckmuang, 2002). The temporary households with inadequate spaces can follow the 'Jar Model', and the permanent structures can utilise the community model. The Jar Model can be efficient for the urban slums in Bangladesh as they do not require much space. Although it is not systemized, similar models are followed in

Bangladesh, especially in the rural areas. Since waterlogging is a concern at the present time, if the Jar Model is adopted in a resilient manner, that would help the urban poor to access rainwater. Flood-resilient jars made of eco-friendly materials, such as cane, bamboo, etc. can also play an active role to eliminate waterlogging in congested urban settlements. Another unique practice in Thailand that can be replicated for the urban poor is using bamboo instead of steel to prepare the reservoir tanks, which is a poor-friendly initiative as it can save more than 50% of the installation cost (Visvanathan *et al.*, 2015).

Scope of rainwater harvesting for sanitation and hygiene of urban poor

The unplanned urbanisation and congested infrastructure made the low-lying urban structures, primarily the settlements in slum areas, almost unable to harvest and utilise rainwater. In Mumbai, for example, the middle-class cohort of the city was practising rainwater harvesting technology by utilising their buildings. In contrast, the urban poor, who consist of almost 60% of the city, were neglected even though they had low access to safe water and low reliance on water scarcity (Button, 2017). One probable reason behind such dynamics might be that RWH is not cost-effective for small holdings (Al Amin, 2019).

Research in Africa (Cowden *et al.*, 2006) showed that domestic rainwater harvesting could be a cost-effective solution to provide improved water supply to the urban slums since almost 70% of the slum dwellers might be able to use rainwater for two to three months. Based on the evidence from Brazil, Egypt, India, Indonesia, Kenya, Nepal, and the Philippines, Elrayies (2016) suggested rainwater harvesting should be explored as a sustainable solution for the urban poor. In Bangladesh, rainwater harvesting could be a means of building resilience in the urban slums (Ahmed, 2016).

The Productive End Walls in Manila, the Philippines, is a good example of an integrated solution for poor neighbourhoods to achieve sustainable water use, ensuring economic and social sustainability that can be replicated in slums (ASLA, 2010). The Sustainable Tower in Florianópolis, Brazil, is another example of promoting rainwater harvesting for the urban poor (Bustler, 2008). In recent times, a few studies regarding RWHS in the low-income communities in the developing countries were adopted by the IDRC, the UNEP, and the USAID. However, not enough government policies were found that could support this approach (Hindiyeh *et al.*, 2020). Privately owned RWHS also need to be promoted for the poor, and this proper policy formulation and financial incentives as required should be emphasised.

A study conducted on a few slums in Dhaka, Bangladesh, showed high potential for the use of rainwater for sanitation (Nusrat, 2014). While WASH is one of the everyday basic needs to maintain the living standard, the slums and low-income communities all over the world do not have proper access to WASH facilities most of the time as studies in Africa (Akoteyon *et al.*, 2020) and South Asia (Saroj *et al.*, 2020) showed. Elrayies (2016) indicated that properly managed rainwater could provide a significant additional source of water that can be used for toilet flushing and drinking, although purification is recommended. In Bangladesh, rainwater harvesting has been emphasised, but not for the urban poor. However, these worldwide practices and concerns portray the potential of rainwater harvesting for the urban poor that may be an effective tool in ensuring proper WASH facilities among the low-income communities.

Rainwater harvesting amidst climate change

Unavailability and instability in the source of fresh water are just some of the many impacts of climate change (IPCC, 2018). The issue of climate change cannot be ignored at all while discussing rainwater harvesting for two major reasons. First of all, rainwater is an alternative source of clean water in many places that have been (and will be) affected by climate change. Second, the reliability and feasibility of harvesting rainwater are highly dependent on climate change.

In Indonesia, it has been noted that rainwater harvesting can be an effective tool to tackle drought and manage floods (Mukaromah, 2020). The study shows that if rainwater is harvested during the rainy season, harvested rainwater can be utilised in the dry season when there is a shortage of clean water. Bangladesh, already a victim of climate change, faces water scarcity in the dry season but is flooded during the rainy season (Islam, 2019). The major cities of Bangladesh are already threatened with the challenge of water scarcity (Islam, 2019; Dhaka Tribune, 2020; The Financial Express, 2021a). Rainwater can be an additional source of water that will tackle this scarcity problem. Since most urban slum dwellers in Bangladesh do not have reliable and sufficient access to water supply (Cooper, 2020; Shuaib & Rana, 2020), rainwater harvesting can be considered a practical approach. Malaysia has also been considering rainwater as an effective tool to mitigate the water scarcity problem (Lee *et al*., 2016). Rainwater harvesting can also be a tool to tackle waterlogging and flash floods that have already been practised in Bangladesh (Bashar *et al*., 2018), Sri Lanka (Strand, 2013), and Vietnam (Viet Nam News, 2019), for example.

Several studies showed that climate change will have little impact on rainwater harvesting and that rainwater harvesting can reduce domestic water insecurity (Musayev *et al*., 2018; Santos *et al*., 2020). However, another study highlighted that globally rainwater harvesting would be impacted negatively due to climate change since rainfall patterns might be changed in the future, which may, in turn, affect the amount of rainwater being harvested and reliability on rainwater, although on a limited scale (Haque *et al*., 2016). Irregularity in the rainfall already exists in Bangladesh (Hossain *et al*., 2015). In this situation, rainwater can be a blessing if properly utilised and might become a curse otherwise. Urban slums in Bangladesh are already occupied with climate migrants, the worst victims of climate change (Castellano *et al*., 2021). If the government fails to protect the already suffering people, the overall sustainability of the country's development journey might be jeopardised.

Undoubtedly, poor people are the most vulnerable to climate change impacts. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) stated that global warming would likely cause abrupt shifts in the weather patterns and the water cycle (IPCC, 2021). The report also mentioned climate change would affect water availability and quality. In a country like Bangladesh, which is already vulnerable to climate change and where the urban poor has weaker access to safe water, rainwater harvesting cannot be neglected at any cost. Moreover, rainwater harvesting plans must be adopted in a way that will be able to cope with the adverse effects of climate change, and harvested rainwater will be a potent mechanism to ensure the water rights of the urban poor.

Feasibility of RWH in unplanned urbanization

Since the previous discussion highlights that the feasibility of rainwater harvesting is crucially dependent on climate change and its impacts, the authors consider the feasibility of RWH that ensures reliance on this source of water as a key factor to establish RWH for the urban poor. A study conducted in Egypt assessed the feasibility of rainwater of 22 cities and discovered that approximately 142.5 million m^3 of rainwater can be secured annually (Gado & El-Agha, 2020). They have also indicated that in the North Coast of the country the potential of RWH can be up to 12%, which means 12% of water demand can be met through harvested rainwater. A Jordanian study investigated the feasibility of rooftop rainwater harvesting and underlined two main factors, such as the number of establishments that practice RWH and the amount of average rainfall (Al-Qawasmi, 2021). In a country like Bangladesh where the average annual rainfall is about 2,200 mm (The World Bank Group, 2021), if the area of rainwater harvesting can be increased that would definitely ensure higher feasibility of RWH.

Akter & Ahmed (2015) already showed that rainwater harvesting is more popular in the rural parts of Bangladesh rather than the urban areas due to cost-effectiveness. The study also revealed that in Chattogram (average annual rainfall is 3,000 mm) rainwater can save up to 26% of city water supply by providing 20 litres of water per day per person for a year. In this context, preserving the harvested rainwater is a concern. Public authorities like DPHE, WASA, and other local government institutes may come forward. To preserve harvested rainwater establishments like, flyovers, metro rail, rapid bus transit, etc. can be utilized.

A recent study conducted in India declared rooftop rainwater harvesting (RTRWH) to be the most economical and environmentally-friendly method (Anchan & Prasad, 2021). The study also highlighted fluctuations in rainfall and the higher potential of RWH during the monsoon period. A study concentrated on building information modelling (BIM) portrayed that the number of household members (living in the building), rooftop area, and the quality of materials used for RWH determine the amount of harvested rainwater (Maqsoom *et al.*, 2021). The study also found that a 90 m^2 area of rooftop would be required to ensure the potential use of RWH for five people. In the congested low-income settlements/slum areas where the urban poor live, such conditions would be the biggest barrier to ensure access of RWH to the poor community.

Beirne *et al.* (2021) have rightly reflected that the quality and quantity of harvested rainwater depends on multiple factors like the geographical location, land use of the area, seasonality, rainfall intensity, and the material of the catchment surface. In the context of rainwater harvesting systems in urban areas, the authors suggested integrating community engagement along with adequate policy formulation and implementation. Furthermore, the quality of the harvested rainwater can also not be ignored. Previous studies showed the level of pH remains within the WHO standard in the country (Rahman *et al.*, 2021). However, the turbidity of rainwater exceeds the WHO standard during the monsoon period, and the faecal coliform level exceeds the WHO standard in both monsoon and post-monsoon periods (Rahman *et al.*, 2021). Low-cost anti-microbial water filters available in Bangladesh (The Financial Express, 2021b) can be used to ensure the quality of harvested rainwater. To store harvested rainwater for the long term, storage facilities can be set up centrally. Government bodies can take the initiative to reduce inequality in the water supply.

Almost two decades ago, Kumar (2004) mentioned rooftop rainwater harvesting cannot be an alternative to mainstream water supply both in an urban and a rural setup, especially in the regions that get a low amount of rainfall. The study also highlighted RTRWH can offer limited scope in ensuring water security for the urban low- and middle-income cohorts. In a recent article, Kumar (2018) again highlighted this earlier notion of his with an added perspective of urban floods. In Bangladesh, urban waterlogging is seriously affecting the poor community but can be tackled through a planned rainwater management system. Furthermore, taking climate change into account, a study projected that rainfall will increase up to 200 mm in general (will decrease in December and January) in the future (2045–2075) in Bangladesh (Karim *et al.*, 2020). At this stage, additional focus on rainwater harvesting must be integrated into all water-related policies and interventions.

CONCLUSION

Safe drinking water is a fundamental human right and an essential step toward improving universal living standards. Therefore, a lack of proper water services for the urban poor cannot be ignored. Rainwater is generally accepted as a sustainable source of water. Like many countries, Bangladesh has been using rainwater for WASH purposes. Our research has identified some hindrances because such a cost-effective, compatible, and ingenious solution is overlooked in the urban context, especially for the urban poor. Our focus needs to be shifted from harvesting the rainwater as an infrastructure issue to efficient management of this natural resource as a means of maintaining social equity. To do it, an integration among relevant stakeholders and suitable policies and plans will be crucial. Since the existing more comprehensive development plans of the Government of Bangladesh do not emphasise rainwater harvesting, in the urban context, especially for the poor, the concept of rainwater management can be designed to ensure that no one is left behind. Such an initiative will also help

Bangladesh to remain on track in achieving the UN Sustainable Development Goals (SDGs), particularly SDGs 6 and 11. We, therefore, propose the following three recommendations.

First, a detailed 'Rainwater Harvesting and Management Plan' (RWHMP) should be developed to provide guidelines for proper rainwater management considering all the possible obstacles, such as climate change issues, urban infrastructures. The existing short-, medium-, and long-term plans adopted by the Government of Bangladesh address rainwater harvesting in several capacities, and they have also passed the Bangladesh National Building Code 2020 (BNBC, 2020) that has made instalment of RWHS mandatory in all the proposed new buildings (MoHPW, 2021). The National Water Policy of Bangladesh (MoWR, 1999) and Bangladesh Water Act (MoLJPA, 2013) also put in place the provision of rainwater management to ensure the people's water rights. Through the proposed RWHMP, the abundance of rainfall will be fully utilised, and rainwater management will become the basis of maintaining water justice.

Second, a community-led approach should be adopted and promoted to mitigate the challenges around harvesting rainwater in the unplanned, temporary urban settlements lacking sufficient space for water storage. A central RWHS can be established in a nearby government-owned place. From that source, water can be supplied to slums' toilets and cleaning/bathing spaces. Slum-dwellers can also collect water for cleaning purposes from the central RWHS, which water ATM booths might accompany following a pay-as-you-go model. The government can also build RWH structures utilising the flyovers as catchment areas. A public-private partnership model can also be followed by engaging the private entities which are utilising rainwater for commercial purposes.

Third, the multi-storied residential and commercial buildings of urban areas with direct water supply connections can harvest rainwater for the neighbouring slum dwellers. Such an arrangement can help overcome the catchment problem since slum houses are not always suitable for rainwater harvesting as they are temporary, made of weaker materials (e.g., iron sheet, cardboard, wood, and plastic sheet), do not have uniform heights as some are one-storied, some are two- or three-storied, and congested arrangement makes the catchment area much smaller. This will decrease the dependency on underground water, which will benefit both the poor and rich. Besides, this would also improve compassion and social cohesion in urban life.

In this era of sustainable development, when the assurance of leaving no one behind is already mandated, a certain community, the low-income community in the urban area, cannot be unheeded. Since rainwater harvesting is a sustainable solution towards achieving water justice for low-income communities, proper management, adequate planning, and feasible guidelines for RWH practices must be ensured.

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DATA AVAILABILITY STATEMENT

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

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