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India's Escalating Water Crisis and the Expanding Role of Rainwater Harvesting in Sustainable Resource Management

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Abstract: ***The text outlines India's rapidly intensifying water crisis by tracing the combined pressures of groundwater depletion, erratic monsoons, urbanization, climate change, and weak governance structures. It explains how widespread over-extraction, contamination, and inadequate infrastructure have accelerated water scarcity, creating risks for agriculture, industry, and public health. The discussion highlights the growing strain on rural and urban systems, the retreat of Himalayan glaciers, and the economic vulnerabilities linked to declining water availability. Within this context, rainwater harvesting is presented as a practical and scalable option for strengthening water security, relieving pressure on groundwater reserves, reducing flood and drought damage, and providing cost effective support for agricultural, industrial, and urban needs. The text also acknowledges the technical, financial, spatial, and quality related challenges that constrain adoption, emphasizing the need for more adaptive and community-oriented water management practices.***

Keywords: Water crisis, groundwater depletion, climate change, rainwater harvesting, urban water stress, pollution.

1. Introduction

India is heading towards a grave water crisis that could have far reaching impact on its social and economic progress. India's principal government planning agency, the NITI Aayog has gone on record to raise concern in this regard. According to NITI Aayog's Composite Water Management Index (CWMI) report, India is experiencing the worst water crisis in its history, with nearly 600 million people facing high to extreme water stress with over 200,000 deaths being reported annually due to inadequate access to safe drinking water, with over 75% of its population unable to access it in their local areas. The situation is likely to worsen very soon, and it forewarns that by 2030, 40% of India's population may have no access to drinking water as its water demand will be twice the available supply by 2030 (NITI Aayog). This paper examines how India could go back to its cost-effective traditional water management traditions to salvage the situation **(1,2,3).**

This situation has not emerged overnight. Years of neglect and over exploitation of the country's water resources and its increasing population has brought the country to this situation. India is the largest consumer of groundwater in the world, consuming more than 25% of global groundwater — more than China and the United States combined. Yet, millions of Indians still struggle to access safe and reliable water. Groundwater serves as the backbone of India's agricultural and drinking water supply. Around 85% of rural drinking water and nearly 60% of irrigation needs come from underground aquifers. With erratic monsoons and inadequate surface water infrastructure, farmers have increasingly relied on borewells and tube wells to irrigate their fields. This unregulated extraction has led to a crisis with groundwater levels plummeting at alarming rates. According to a 2023 report by the Central Ground Water Board, more than 60% of India's districts have critical or overexploited groundwater levels **(4).** A major driver of this crisis is India's agricultural policy. Subsidies on electricity encourage the over-pumping of groundwater. Water-intensive crops like paddy and sugarcane are grown in arid regions, creating an unsustainable demand. Moreover, groundwater usage remains unregulated with millions of private wells operating without oversight or limits **(4).**

Unplanned Urbanization has further worsened the situation. Rapid urban growth, erosion of green cover, and encroachment of water bodies for construction and urban expansion have strained water availability. Urban areas have more paved surfaces and high deforestation to meet the needs of infrastructure. Hence, urban centres experience high surface runoff (have low permeability) which leads to decreased groundwater recharge. This condition, together with the unregulated nature of groundwater use has exacerbated the alarming groundwater depletion levels in cities and towns of the country **(5).**

Nearly 70% of wastewater generated in urban areas goes untreated. This sewage contaminates rivers, lakes, and groundwater. Furthermore, untreated effluents from industries release harmful chemicals, further degrading water quality. As a result of this more than 70% of groundwater in India is contaminated. it comes as no surprise that India ranks 120th among 122 countries on the Water Quality Index according to the World Bank Report on Global Water Crisis **(6,7,8,9).**

Climate and environmental challenges accompanied by topography limitations also make the situation very unfavourable. Climate change is impacting India's weather patterns making them more extreme, with more frequent and severe droughts in some regions and devastating floods in others. These extremes are having a profound impact on the country's water resources. During prolonged periods of drought, the availability of water for consumption also dwindles, making it hard for local communities to access clean water. On the other hand, parts of India are increasingly experiencing flooding, especially during the monsoon season. According to the National Disaster Management Authority (NDMA), India faced 1,106 flood incidents between 2000 and 2019, with some states like Kerala, Uttarakhand, and Assam being particularly vulnerable. The combination of heavy rainfall and poorly managed urban infrastructure leads to flash floods, which not only damage homes and roads but also contaminate water sources, making them undrinkable **(10,11).** In fact, the Central Water Commission (CWC) has reported that during the past three decades, the country has seen a 20% drop in rainfall in the northern and central parts, exacerbating the already existing water shortage in those areas.

India's water supply is also heavily dependent on the glaciers of the Himalayas, the water from which feeds some of the country's most important rivers, such as the Ganges, Indus, and Brahmaputra. Approximately five hundred million people depend upon water from these three rivers. According to a study published by the Indian Institute of Technology (IIT), the glaciers in the Himalayan region are retreating at an alarming rate, with some glaciers shrinking by over 30% in the past century. The loss of glacial mass means less snowmelt, which in turn leads to reduced river flow, particularly during the dry summer months. This reduction in glacial mass will lead to droughts and water shortages leading to widespread water scarcity which will have a devastating effect on agriculture and drinking water supplies **(12).**

Limited resources available for government agencies coupled with corruption had resulted in poor water infrastructure, inadequate supply networks, treatment plants, and storage facilities leading to high wastage and leakage. Fragmented water governance, with separate bodies for surface and groundwater, and politicised inter-state disputes and lack of Public Awareness and Involvement are serious bottlenecks in accountability and more effective management (**13).**

India cannot afford to ignore these warnings as it will have huge social and economic repercussions. According to the World Bank, water scarcity could reduce India's GDP by 6% by 2050, severely affecting economic growth **(14).** For India it also has huge repercussions in International Relations since it shares its water resources with China and Pakistan.

This could be the opportune time to go back and review the traditional Indian systems of water management that are both cost effective and can be managed by the consumers themselves. This will give some relief to the government in this area and allow them to focus on streamlining the infrastructure and other more capital-intensive water management mechanisms including using AI for effective management to avoid wastage and ensure more efficient usage. This paper examines the efficacy of large-scale adoption of Rainwater harvesting to mitigate India's water woes and make it more water secure.

2. Benefits of Rainwater Harvesting

2.1 Reduces India's Dependence on Monsoons

India is a significant example of an economy that still depends on the cyclicality of rains for its economic growth **(15).** This dependence is structurally critical as it impacts agriculture, drinking water, and energy, all of which have a huge impact on India's economic stability. The highest vulnerability comes from the dependence of agriculture as it has a direct impact on the rural economy and India's food security. While agriculture's share in India's economy has progressively declined to less than 15% due to the high growth rates of the industrial and services sectors, the sector's importance in India's economic and social fabric goes well beyond this indicator. First, nearly three-quarters of India's families depend on rural incomes. Second, the majority of India's poor (some 770 million people or about 70 percent) are found in rural areas. And third, India's food security depends on meeting the food demands of its growing population **(16).**

Agriculture is the backbone of India's rural economy. With over 45% of the workforce employed in agriculture, the sector underpins rural livelihoods and drives the development of allied industries such as dairy, poultry, and fisheries. Prosperity in agriculture translates directly into enhanced rural infrastructure, better income levels, and improved quality of life in villages **(17).** Approximately 60% of the country's farmland is rain-fed, which makes agricultural productivity highly susceptible to the erratic nature of monsoon rains. This dependence poses significant challenges, including droughts, flooding, and inconsistent crop yields **(18).** Climate change is expected to further exacerbate monsoon variability, potentially leading to more frequent and intense droughts and floods **(19).** Since India has a predominantly agrarian economy in terms of employment, inconsistencies in rainfall have a direct bearing on its economy, more specially in the rural economy. This happens as 65 -70 per cent (2021 data) of the country's population lives in the rural areas and 47 per cent of the population is dependent on agriculture for livelihood. Consequently, a good monsoon improves rural incomes, leading to higher spending on goods and services. This increased spending supports local businesses and stimulates economic growth. The opposite happens when the monsoon is below par or when there are floods and droughts.

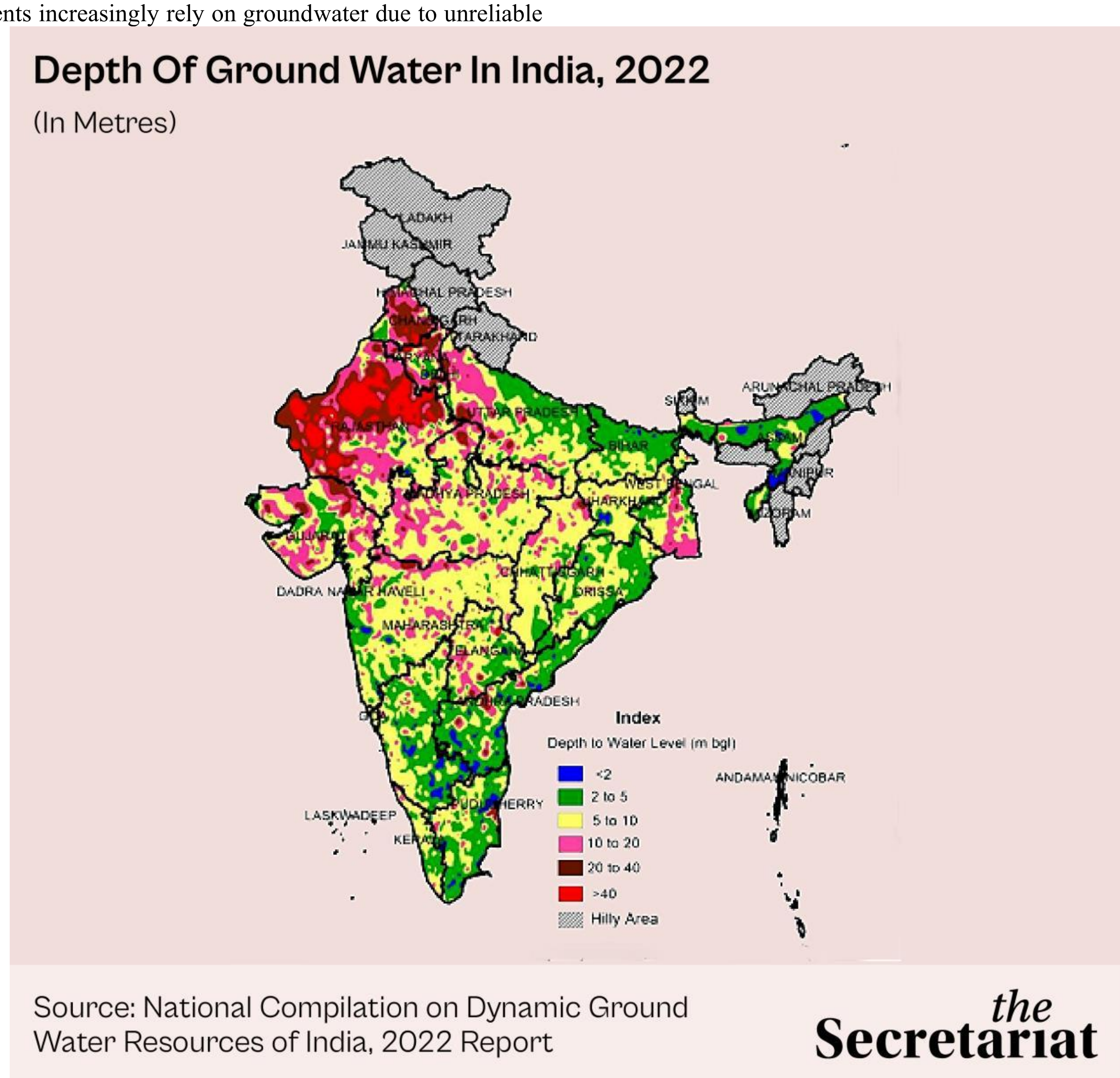
Monsoons also directly impact industries that rely on agricultural products, such as food processing, textiles, and beverages and their supply chains and profits. Poor monsoons can disrupt supply chains and increase costs. Since majority of the population is affected, the responsibility of the government goes up and it must step in to support farmers during bad monsoon years through subsidies and relief packages. This additional spending can strain the government's budget and increase public debt. High inflation from a poor monsoon might force central banks to raise interest rates to control prices, making borrowing more expensive and potentially slowing down economic growth. Given the dependency, a good monsoon boosts investor confidence, leading to higher stock prices across various sectors **(20).**

The extent of this over dependence can be gauged form the fact that more than 75% of fresh water of India is sourced through the monsoons **(21).** With monsoons becoming increasingly unpredictable, on account of climate change, India's water supplies are getting affected (22). It is reported that the majority of India faces critical drought conditions and water shortage (NASA, 2019), and approximately, 65% of India's reservoirs are running dry as a result of low rainfall and inadequate water management **(23)** Erratic monsoon patterns can create high rates of runoff leading to flood events and high short-term availability during wet seasons, followed by severe water stress during dry periods **(24).** Increasing dependence on ground water is lowering the levels to a dangerous low. For millennia, however, India has met the demand for seasonal water storage and increased water availability at the local level via the building of village-scale rainwater harvesting (RWH) structures, often referred to as tanks (25). These structures in various proportions can be used effectively to store water during the rainy season for use during dry spells and thus reduce the pressure on ground water that is becoming a matter of concern for everyone **(26,27).** These manmade tanks can capture and store intense rainfall that would otherwise flood or evaporate and provide a sustained water source during water shortage and for regular use putting less pressure on other sources.

2.2 Restoring and maintaining ground water levels which in turn is essential for ecological conservation

India is the largest user of groundwater in the world. It uses an estimated 230 cubic kilometers of groundwater per year - over a quarter of the global total which is more India is the world's top consumer of groundwater. It consumes more groundwater than the United States and China combined. More than 60% of irrigated agriculture and 85% of drinking water supplies are dependent on groundwater. Urban residents increasingly rely on groundwater due to unreliable and inadequate municipal water supplies. Due to this, an increasing number of aquifers are reaching unsustainable levels of exploitation. If current trends continue, in 20 years about 60% of all India's aquifers will be in a critical condition says a World Bank report, Deep Wells and Prudence. This will have serious implications for the sustainability of agriculture, long-term food security, livelihoods, and economic growth. It is estimated that over a quarter of the country's harvest will be at risk. There is an urgent need to change the status quo **(28).**

If the ground water falls consistently, it will worsen water shortages for households and industries, particularly in regions heavily reliant on groundwater for their daily needs. This is primarily the urban areas which are heavily populated. Despite a slight increase in rainfall over the past four decades, groundwater levels in India continue to decline. This is because the consumption of groundwater far exceeds replenishment from rainfall. Secondly, construction on catchment areas and ground surfaces, once available for groundwater recharge, has cut the natural process of replenishment **(29).** A UN study predicts India will hit an all-time low in groundwater levels by 2025. Reservoirs are working at 35 per cent capacity; the figure drops further to 16 per cent in some cities **(30).**



As the water table drops, it requires more energy and resources to pump water from deeper underground, increasing operational costs for farmers, municipalities, and industries. As the depth to water increases, the water must be lifted higher to reach the land surface. If pumps are used to lift the water (as opposed to **artesian** wells), more energy is required to drive the pump, making the extraction prohibitively expensive **(31),** which can be a huge challenge in India which is amongst the lowest per capita incomes. Excessive depletion of ground water leads to loss of biodiversity and disruption of ecosystems. Wetland ecosystems, which rely on ground water and regarded as the lungs of the earth, are important elements of landscapes, which provide shelter and supplies for aquatic and terrestrial species **(32, 33).**

When a large amount of water is withdrawn from the ground, void spaces in rock or soil collapse, the soil is compacted, and the ground subsides leading to structural damage to buildings, roads, and other infrastructure **(34).** Lowering water levels means the nitrates and other heavy metals are more concentrated in the remaining water, increasing the risk of methemoglobinemia (blue baby syndrome) in infants and other health issues, according to the MN Department of Health **(35)** making water unsafe for consumption without treatment. In coastal areas, over-extraction of groundwater can lead to saltwater intrusion, rendering freshwater aquifers unusable **(36).** Moreover, excessive groundwater use can reduce streamflow by reducing groundwater flows into streams and/or increasing losses from the stream into the aquifer ('streamflow depletion'). Streamflow depletion can impact aquatic ecosystems through changes in the availability and temperature of surface water adversely impacting aquatic habitats and species **(37).** Regions with decreasing ground water levels are more sensitive to droughts as they lack emergency water supplies to fall back on during dry periods and this is where rainwater harvesting is extremely useful **(38).**

Rainwater harvesting structures are highly effective for raising groundwater levels by collecting and directing rainwater into the ground and replenishing aquifers. This can occur naturally, through precipitation and infiltration, or artificially, by directing water into aquifer systems through recharge structures **(39, 40).**Structures such as infiltration pits, trenches, and recharge shafts are designed to collect rainwater and allow it to seep directly into the ground. This process increases the percolation rate of water into aquifers, enhancing groundwater recharge **(41).** Percolation Tanks, large shallow ponds designed to hold rainwater also allow substantial amounts of water to soak into the groundwater system **(42).** Collecting rainwater from rooftops and channelling it to recharge wells or infiltration structures in urban settings helps manage stormwater and contributes to groundwater restoration. In many parts of India, groundwater resources are being depleted at an unsustainable rate due to excessive extraction for agricultural, industrial, and domestic use. Rainwater harvesting helps mitigate this issue by reducing the dependency on groundwater for immediate needs. By supplementing groundwater supplies, rainwater harvesting increases ready availability that can benefit agricultural activities, which are heavily dependent on groundwater thereby allowing the levels to restore gradually **(43).**

2.3 Minimizing both flood and drought damage:

India is already experiencing the impact of climate change. Millions of people in Indian sub- continent are affected by floods, which have increased during the past decades and likely to increase further in response to warming climate **(44).** The precipitation patterns have changed and there is greater risk of floods and droughts. Studies show that regions like Rajasthan, Gujarat, central Maharashtra, and Karnataka have seen rainfall increase by up to 30% over the last decade compared to the previous 30-year average. This rise is not spread evenly across the season; instead, it is marked by short, intense downpours, such as those seen recently in Mumbai—an outcome of increasingly erratic monsoon behaviour. Saumya Swaminathan, environmentalist and Chairperson of M.S. Swaminathan Research Foundation for Sustainable development warned that Urban flooding is rising due to multiple factors—partly climate change, and partly poor planning. While total rainfall has not changed much over the decade, it's now falling in fewer hours, making it harder for cities to cope **(45).**

Flash droughts and flash floods are two interconnected phenomena that have become increasingly common in recent years due to climate change. After a flash drought, the soil may become hardened and less porous, reducing its ability to absorb water. If extreme rainfall follows, water is more likely to run off the surface rather than be absorbed, increasing the likelihood of flash floods. Both can occur rapidly, with flash droughts caused by intense heat and dry conditions and flash floods resulting from extreme rainfall. Climate change increases the frequency and intensity of both events. Rising temperatures lead to faster evaporation, contributing to flash droughts, while warmer air can hold more moisture, increasing the risk of flash floods **(46,47,48).**

Rainwater harvesting plays a crucial role in minimizing both flood and drought damage by managing water resources more effectively. Rainwater harvesting (RWH) is principally based on collecting, storing, and using rainfall which would otherwise be lost as surface runoff. Runoff threatens in several ways: accelerating erosion, intensifying flooding, and reducing groundwater recharge **(49)**. When diverted and stored purposefully, it reduces the risk of flooding and ensures that there is a supply option during droughts. Constructing detention basins or ponds allows excess rainwater to be stored temporarily, slowing down its flow into rivers and drainage systems. By capturing large volumes of rainfall, rainwater harvesting systems alleviate pressure on urban drainage systems during heavy rains, preventing overflow and associated flood risks that are becoming increasingly evident. Harvested rainwater provides an alternative source of water that can be used during dry spells, ensuring a continuous supply for domestic, agricultural, and industrial uses. needs **(50,51).**

2.4 Cost effective supply for Industrial and agricultural use:

It is important to note that while India is home to almost 18% of world population, it has only 4% of global freshwater resources. And much of this water is used in agriculture. While FAO puts this figure at 90%, Indian Central Water Commission says it is 78 -80% **(52).** Much of which is lost to inefficient and unsustainable use. In states like Punjab for example which are agriculture led economies, groundwater levels are falling by more than one meter every year, driven by the expansion of paddy cultivation and free electricity. According to the Central Ground Water Board, 78 per cent of Punjab's administrative blocks are now over-exploited, up from 50 per cent in 2004. India is, quite literally, eating its way into a groundwater emergency **(53)**. Climate change is exacerbating the issue by affecting rainfall patterns and increasing the frequency of droughts, making farmers more reliant on ground water resources which is not sustainable **(54).**

The World Bank estimates show that the current industrial water use in India is about 13 percent of the total freshwater withdrawal in the country and the water demand for industrial use and energy production will grow at a rate of 4.2 percent per year, rising from 67 billion cubic metres in 1999 to 228 billion cubic metres by 2025. All these estimates indicate that the industrial water demand is bound to grow in the coming years. The growth in some of the water intensive industries like coal based Thermal Power Plants, Pulp & Paper, Textile industries, Steel, etc. has been quite significant, adding further pressure on the industrial water demand. Many of the Thermal Power Plants in India are located in the water scarce regions Despite an increasing and competing water demand amongst various sectors, the water use in different sectors in India remains inefficient. Indian industries consume relatively higher amount of water for production as compared to international standards, while their water productivity in terms of ratio of water consumption to economic value creation is low, as compared to many developed nations. It is estimated that without water efficiency improvements, global water demand will exceed available supplies by 40% by the year 2030 (2030 Water Resources Group, 2009; UNEP, 2014). It is thus imperative for all the sectors including industries to integrate the strategies on water demand management, enhancing water use efficiency, water conservation, recycle and reuse, etc., to address water scarcity and water demand -supply gap **(55, 56, 57, 58).**

Rainwater harvesting (RWH) offers significant benefits to both farmers and industry owners, by ensuring a cost-effective sustainable year-round supply. It provides a critical backup source during dry spells, monsoon delays, or droughts, reducing dependence on erratic rainfall and depleting groundwater. The farmers benefit through extended growing seasons and better maintenance of their crops without having to rely on precious ground water and mitigates the devastating impact of water scarcity on yields and farm income. It also has the added benefit of capturing rainwater thereby reducing surface runoff, which prevents the loss of fertile topsoil and nutrient leaching **(59).**

Rain contains sulphur—important in the formation of plant amino acids, and it contains beneficial microorganisms and mineral nutrients collected from dust in the air— important for plant growth. Rainwater also contains nitrogen, which triggers the greening of plants. During storms, lightning strikes enable atmospheric nitrogen to combine with hydrogen or oxygen to form ammonium and nitrate, two forms of nitrogen that go into solution in atmospheric moisture and can be used by plants. Besides, rainwater has the lowest salt content of natural fresh water sources, so it is a superior water source for plants. Calcium, magnesium, potassium, and sodium salts are abundant in the earth's crust. Soils with high salt concentrations inhibit plant growth by reducing vegetation's ability to take up water and conduct photosynthesis. Soils high in sodium tend to disperse—or lose their structure— resulting in poor water infiltration, and soil crusting, which restricts root penetration and impedes seedling emergence **(60).**

It has similar benefits for industrial use. It is a cost-effective way of ensuring adequate water supply for industrial use. It is believed that installing a rainwater harvesting system leads to 80% direct cost saving on lengthy water bills **(61).** Besides cutting down on one's carbon footprints which are high in ground water extraction, harvested rainwater is naturally soft and is found in its purest form if stored properly **(62, 63).** Since commercial centres have bigger built catchment areas, they have high potential to receive a larger amount of rainwater that can be stored cleanly with proper maintenance.

A 2023 vulnerability assessment by the Ministry of Power's Central Electricity Authority showed India's major power grids were dependent on 14 major river basins — all of which are under 'high water stress'. Companies including Tata and JSW Steel, have led the way in building new water reservoirs in their plants and investing in water treatment plants and rainwater harvesting systems to ensure uninterrupted water supply **(64).**

2.5 Cost effective water source

Rainwater harvesting will help individuals and corporations save on their water bills and cut costs for entire communities. The cost to supply mains and overall water services can be substantially reduced when many people in one community use rainwater. The financial benefit associated with a rainwater harvesting system is solely connected with cost. The associated costs of a rainwater harvesting system are for installation, operation, and maintenance. Of the costs for installation, the storage tank represents the largest investment, which can vary between 30% and 45% of the total cost of the system depending on system size. A pump, pressure controller, and fittings in addition to the plumber's labor represent other major costs of the investment. A practical survey showed that (in Dhaka) the total cost related to construction and yearly maintenance of a rainwater harvesting system for 20 years' economic life is about 30000 BDT. This cost includes construction cost of tanks, gutters, flushing devices and labour cost. In the present case study, about 313.80 thousand Liters of water can be harvested from rain over one year. This amount of water could be collected within 1850 sq. ft catchment area and considering monthly rainfall data. The yearly consumption of this selected building stands at 2916 thousand Liters. Therefore, utilizing harvested rainwater for this building can save up to 11% of the public water supply annually. This volume of rainwater can serve a building with 60 members for about 1.5 months in a year without the help of traditional water supply. Cost comparison and associated benefits between a rainwater harvesting system and traditional water supply system encountered and revealed a rainwater harvesting system as a cost-effective technology **(65,66,67).**

2.6 Reducing urban water stress

India is urbanising rapidly. The World Bank says that by 2036, towns and cities of India will collectively have 600 million people, which would be roughly 40 per cent of its population. It is expected to breach the level of 50 per cent in 2047 (68). To accommodate the demands of this fast-paced urbanisation, India needs to devise better, smarter and sustainable ways of improving the present water-stressed situation. At present, the status of water in urban areas of India is not at all assured. For example, nearly 42 per cent of households in urban areas didn't have access to piped water connections inside their premises as per the 78th round of the National Sample Survey Organisation (NSSO) of 2020-21 and 24 per cent urban households were without access to an 'improved source of drinking water' that provided enough water throughout the year (69) . By 2050, thirty cities in India will be facing 'severe water risk' as per an assessment by the World Wide Fund for Nature (WWF) published in 2020 which included Bengaluru, Bhopal, Delhi, Mumbai, Rajkot and Vadodara (70). A study on global urban water scarcity projects that India could emerge as the most severely affected country in terms of growth in water-scarce urban population by 2050 (71).

Excessive urbanisation is marked by more paved surfaces and high deforestation to meet the needs of infrastructure. Hence, urban centres generally experience high surface runoff (have low permeability) which leads to decreased groundwater recharge. Excessive drawing of this groundwater for its increasing urban needs means that the ground water levels are falling to dangerous low.

As climate change concerns grow in the face of increasing occurrences of flooding and rising temperatures, that are posing grave challenges to the existing stormwater management capacity in cities, it is time for greater emphasis on sustainable practices like Rainwater harvesting. Limited green spaces and poor drainage systems are the main cause for the excessive flooding in urban areas. The rainwater harvesting system helps to reduce surface runoff and collection and storage of this water can help cities in not only managing the flooding, but this water can be useful for use.

By collecting and storing rainwater the cities can manage excess rainfall more efficiently and avoid the flooding of their surroundings and homes. The water collected by this system can also be used for the ground water recharge and for urban use, both at the individual and the local government levels. This water is relatively clean and free from pollutants as compared to other water sources like lakes and rivers **(72).**

By capturing rainwater, cities can reduce their reliance on traditional water sources, such as rivers, lakes, and groundwater. This alternative supply can be crucial during periods of drought or when conventional sources are contaminated or depleted or when there is shortage of regular supply. Additionally, Rainwater harvesting offers several environmental benefits. It reduces the strain on existing water sources, conserves energy by decreasing the need for water pumping and treatment and lessens the impact of stormwater runoff on urban waterways. Moreover, it can help create green spaces by providing a reliable water source for landscaping and urban agriculture **(73).**

3. Challenges of Rainwater harvesting

Rainwater harvesting comes with its fair share of challenges that need to be studied to be able to make a practical feasibility study:

3.1 Contamination and microbial overgrowth:

Rain war harvesting entails collection of surface run off or direct rainwater accumulation. Surface run off rainwater meets hard surfaces which are often covered with contaminants from dry (e.g., dust and particulates) and wet precipitation (e.g., rain and fog), animal urine and feces, and plant (e.g., debris). These contaminations will then be accumulated in the collected rainwater **(74).** A broad range of waterborne pathogens and microbial indicators have been found in urban roof runoff, such as bacterial indicators (e.g., total coliform, E. Coli, and fecal coliform), pathogenic bacterium, virus (e.g., adenovirus, protozoan pathogens and fungi. Meanwhile, runoff can flush fecal dropping of wild animals, insects, litter, and fungus on the roof. Another pathway is undesirable microbial growth in a RWH storage tank in the absence of sufficient secondary disinfection **(75, 76, 77, 78,79).** Exposure to sunlight can increase the temperature in the tank which encourages the growth of algae **(80).**

Collection of rainwater directly is also not secure anymore, particularly in urban areas where the air pollution is very high. Air pollution is turning rain acidic. Acid rain refers to rain with a high-level toxic caused by pollutants present in the air. Moreover, high AQI levels with increased concentrations of SO_2 (sulphur dioxide) and NOx (nitrogen oxides) in the atmosphere, coupled with industrial and vehicular emissions and Biomass burning makes rain acidic and sometimes unfit for drinking (**81).** Harvested rainwater can also be contaminated with microbial pathogens via roof runoff that contacted with faeces of birds, insects, reptiles or mammals that have access to the roof, as well as other organic debris deposited on the roof and gutter **(82, 83).**

3.2 Installation and Maintenance costs

Numerous studies have revealed that cost is the major prohibiting factor hindering adoption of rainwater harvesting technologies. This includes cost pf purchase, cost of installation and cost of maintenance. In the absence of active government support in terms of expertise, tax subsidies and other financial incentives to support rainwater-harvesting technologies, people are not very motivated to take on the added pressure **(84, 85).**

3.3 Lack of space in urban clusters:

Lack of urban space significantly hinders the adoption of rainwater harvesting by limiting the availability of suitable areas for both collection and storage of rainwater. Cities, with their high density and extensive built-up areas, often lack the open spaces required for larger-scale harvesting systems. the clustered housing has design and accessibility issues. Safety concerns related to installation and maintenance also deter people in crowded areas **(86,87,88)**

3.4 Design and technical issues:

Unless it is built to technical specifications that are compatible with the topographical features, it will not be effective. It is these details that prohibit people from making the investment as the slightest miscalculation in the slope gradient or even in the catchment area, can render the installation as ineffective. Inability to adapt to local conditions makes installation ineffective. Common issues include insufficient storage capacity for the collected rainwater, improper design of collection surfaces and conveyance systems, and a failure to address water quality concerns. Absence of planning for long-term maintenance and potential contamination risks can also lead to system failure or reduced effectiveness **(89,90)**

3.5 Public apathy and lack of awareness:

In India, the ones who can afford it are either sometimes not aware of its potential benefits **(91)** or do not understand the social obligation to contribute to the conservation of water. For instance, people do not trust the quality of harvested water resulting in the usage being limited to cleaning and washing purposes **(92).** Often due to poor operating conditions, the harvested water quality is below par which is one of the major setbacks for its widespread adoption **(93).** As RWH has yet to become popular, the lack of a skilled workforce for installation, maintenance, and service creates further roadblocks to its adoption **(94).** The lack of one-stop shops that can provide all the essential components required to set up RWH technology is also a vital challenge in many regions, especially rural areas **(95).** Lack of government pressure or incentives also does not motivate people to make a difference.

4. Conclusion

India has the planet's second largest population at 1.3 billion, expected to grow to 1.7 billion by 2050, which amounts to 16% of the world's inhabitants, while it possesses only 4% of the world's fresh water. Moreover, severe lack of regulation, over privatization, general neglect and rampant government corruption have led to multiple generations thirsting for more than just a few drops of hazard free water. The situation has grown to the point that regional disputes, both national and international, have risen over access to rivers in the country's interior. These disputes have assumed global proportions over the Indus waters with Pakistan and the River Brahmaputra with China **(96).**

To make matters worse, Over the past 50 years, policies have allowed rampant extraction of ground water leading to a dangerous ground water situation in most states. Estimates put India's groundwater use at roughly one-quarter of the global usage with total usage surpassing that of China and the United States combined. With farmers granted electricity subsidies to help power the groundwater pumping, the water table has seen a drop of up to 4 meters in some parts of the country. This unfettered draining of groundwater sources has accelerated over the past two decades. A survey in one of the worst hit states, Haryana, showed that Districts where subsidized electricity used for agriculture is the highest are among the most water-stressed, and among the top ten districts growing paddy and wheat. If this water use is not regulated, the state could soon run out of groundwater to meet the basic needs of the farmers **(97).**

Another study highlighting the flaws in government policy came from the state of Madhya Pradesh, where the government procurement of wheat was minimal until 2008, even when market prices dropped below the MSP. However, in 2008, the state introduced a bonus on top of the national MSP and significantly increased wheat procurement, especially in key wheat- producing districts. This change saw wheat procurement rise from 0.057 million tons in 2007 to 2.4 million tons in 2008, a 40-fold increase. This increased wheat cultivation created additional demand for irrigation, leading to an uptick in groundwater use, mainly from wells and tubewells. It was apparent that the shift towards wheat over less water-intensive pulses post-2008 heightened groundwater dependence **(98).** These policy flaws plague most states. While agriculture is the main water guzzler, increased urbanization in water stressed areas has also put more pressure on the country's resources. Excessive construction on catchment areas and ground surfaces, once available for groundwater recharge, has cut the natural process of replenishment.

Despite a slight increase in rainfall over the past four decades, groundwater levels in India continue to decline. This is because the consumption of groundwater far exceeds replenishment from rainfall. A UN study predicts India will hit an all-time low in groundwater levels by 2025 **(99, 100).** Climate change and fluctuating rainfall will only make matters worse.

In a country like India where both the government and most of its population is starved for funds, Rainwater harvesting is a cost-effective method to bring change. The challenge lies in how the government enforces the measure through a change in policy. Government policies are a decisive element for the adoption of sustainable practices in society **(101).** However, one of the main barriers for attracting new users' initiative in rainwater harvesting is the artificially low cost of drinking water tariffs **(102).** This does not give incentives to citizens to make a change in their water sources. Incentivizing those who do and penalizing those who use excess beyond a certain threshold could go a long way in pushing people to be more conscious of their consumption and the source of it.

There are numerous examples around the world of legislation that seek to regulate and encourage rainwater harvesting. Countries such as the United States, Germany, Spain, and Australia have implemented rainwater harvesting policies, at different governmental levels, that include economic incentives **(103).**

Partzsch (2009) identified three policies as the main causes for Germany becoming a world reference in the use of rainwater. These include the investment subsidies for decentralized technologies, the imposition of water extraction rates and the separate charging of drinking water and drainage bills. Hans Huber, shareholder and board of the Huber Group, which is among the worldwide leading suppliers in the field of wastewater/sludge treatment and process engineering, states that his company's success results from the strict German legislation and environmental requirements **(104).** More than 300 German companies specialize in water saving and recycling technologies and have created 60,000 jobs (12). Three policy instruments could be identified which are designed for particular support of decentralized technologies: investment grants for decentralized technologies, water extraction fees and separate water and effluent fees. This policy encourages water conservation by making it more expensive to use potable water for non-potable purposes like toilet flushing or garden irrigation These instruments may be ''smart'' and contribute to Germany's lead-market position **(105, 106, 107).**

Indian states have also made several attempts in this direction. Tamil Nadu became the first state to make rooftop harvesting mandatory for all buildings. Rajasthan revived its traditional structures like kunds and johads to harvest water. Others took various steps in encouraging larger plots of construction and commercial buildings to adopt rainwater harvesting, but lack of a concrete national policy and a central monitoring agency has not led to the expected results. Politicisation of schemes like the Atal Bhujal Yojana which excluded Punjab among many other states has not been desirable. According to new data released by the Jal Shakti Ministry, the Atal Bhujal Yojana, a central sector scheme identified water-stressed areas of 8,203 gram panchayats under 229 blocks in 80 districts of seven states, has only used Rs 71.24 crore of Rs 1,778 crore up until November 25 of the current fiscal year, which shows that the scheme did not have the desired impact nor did it have the vision to use the allocation effectively **(108,109,110).** The scheme's water budgeting process came under severe criticism for its hurried procedures. For example, the gram panchayat of Karnataka's Nonavinakere village, failed to account for imported surface water, which is water that flows into the region through canals. When formulating water security plans for groundwater management in gram panchayats, it is crucial to adopt an integrated approach that considers the interdependence between surface water and groundwater sources, without which the policy would lack the efficiency needed to repair the system. Robust mechanisms for monitoring the scheme's progress and evaluating its impact are crucial for long-term success. And those were mostly missing mostly **(111).** It is apparent that the government cannot hope to achieve much without a more scientific approach that factors in all possible water resources and their interconnectivity between states, active community participation, and accurate data. The absence of basin-wise rainfall data and runoff analysis hinders effective water budgeting and management. India is visibly running out of time.

The problem of maintenance of the existing ones can also be resolved by investing in developing an in-situ technology that can monitor the harvested water quality on a real-time basis with no human intervention can help behavioural change in the users **(112).** A lot can clearly be done if there is honest intent.

Rainwater harvesting, though not without its challenges, presents a compelling and sustainable strategy for addressing India's escalating water crisis. From revitalizing groundwater reserves and reducing monsoon dependency to offering a cost-effective solution for urban and industrial water demands, its multifaceted benefits extend across rural and urban landscapes. The systemic failures over-extraction, policy gaps, urban mismanagement, and climatic volatility require immediate redressal through decentralized, locally adapted solutions that empower communities. Traditional water wisdom, when fused with modern innovations and supported by policy and infrastructure, can transform the current vulnerability into long-term resilience. Moving forward, integrating rainwater harvesting into mainstream water governance is not simply a technical necessity; it is a socio-economic imperative with the potential to safeguard livelihoods, ecosystems, and national stability.

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