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TECHNICAL NOTE

Feasibility of Rooftop Rain Water Harvesting at Grey Iron Foundry, Jabalpur, Madhya Pradesh, India

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Abstract

As a supply-side option to manage the depleting groundwater resources in India, the Central Government has made it mandatory to install rain water harvesting system in any building with a plot size of 100 m^2 (MoUD (Ministry of Urban Development), Model Building Bye-Laws, Town and Country Organization, Government of India, 2016). An attempt has been made in this contribution to carry out feasibility study for rooftop rain water harvesting at the Grey Iron Foundry (GIF), Jabalpur, Madhya Pradesh, India. Since the post-monsoon groundwater levels in the area are in the order of about 2–3 m, scope for gravity recharge is limited and there is not much natural subsurface space available for storage of the harvested rain water. However, underground and on-the-ground artificial tanks can be constructed to store the water for further use. The three buildings examined have a combined roof area of 21,927 m^2 with a rain water availability of 21,784 m^3 giving a recharge potential of about one m^3 of rain water for every m^2 of roof area. Groundwater in the area contains high amount of fluoride and cannot be used for drinking purposes without adequate treatment. It is also not advisable even to drink the harvested rain water since it is slightly acidic in nature. It can, however, be used for other useful purposes, such as for gardening, horticulture and industrial cooling. It is estimated that about 85% of the cooling water requirements of the GIF can be met by harvested rain water. India consists of innumerable buildings across the country, and this foundry serves as a case study to harvest rain water in small scale industrial complexes even if post-monsoon groundwater levels are shallower to save the country from an impending danger.

Keywords Groundwater · Aquifer recharge · Water demand · Water scarcity · Water supply

1 Introduction

The world is going through the largest wave of urban growth in history (UNFPA, 2024). With 56% of the world's population living now in cities, this trend is expected to continue unabated, and by 2050, urban population shall be more than double of the current size of 4.4 billion people (TWB, 2024a). Therefore, urbanization is indeed a growing trend, and it is predicted that 7 out to 10 people (68%) shall live in cities in few decades from now (UN-DESA, 2019).

Certainly, urban living brings a myriad of opportunities (UN-Habitat 2024), but it also brings many baffling challenges, such as undue pressure on land and natural resources among many others (Marcial et al., 2024). With infrastructural growth not in conformity with the population growth in cities, especially in global south, including in Asia and Africa, access to water and sanitation could be a life and death situation for the poor urban dwellers (UN-Habitat 2022). In fact, urban water insecurity shall have many far-reaching consequences including increased rates of waterborne diseases and mental instability (Kimutai et al. 2023).

In India, 28.53% of people lived in urban areas in 2001 that grew to 36% in 2022 (TWB, 2024b). By 2030, about

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60 million people will reside in Indian cities and there will be addition of one Chicago every year (UN-Habitat 2024). By 2050, India will lead the world's urban population along with China and Nigeria by adding additional 416 million urban dwellers alone (UN-DESA, 2019). But with 18% of the world's population living in this country with only 4% of its water resources, it is listed as one among the most water-stressed countries in the world (TWB 2023).

As a consequence, there may arise "water emergency" in India in the coming decades from now as the population soars high at the rate of one child in every two seconds (WPR, 2024). With about 1.44 billion inhabitants at present, India's per capita distribution of water has gone down from 5,177 cubic metres per year in 1951 (CGWB, 2020) to 200 cubic metres less than the world standard of 1700 cubic metres per capita per year at present (PIB 2024). Thus, India is now a water deficit country (Naik 2017). Government of India is working constantly to counter the impending challenges, but this effort needs everybody's cooperation including that of the industries.

As per the Model Building Bye Laws (MBBL) (2016), the Government of India has made it mandatory to install rain water harvesting systems in any new building with a plot size of 100 m^2 (MoUD, 2016; PIB, 2023). In an effort to fulfil this mandatory requirement, on 26 July 2016, the Grey Iron Foundry (GIF) at Jabalpur, Madhya Pradesh (M.P.), India, a small defence establishment, approached the Rajiv Gandhi National Groundwater Training & Research Institute (RGNGWTRI), Raipur, India to carry out feasibility study for rooftop rain water harvesting (RWH) in its factory premises. This paper incorporates the findings of RGNGWTRI in this study.

Guidelines issued by the Government of India advise rooftop RWH where there is inadequate groundwater supply and surface sources are either lacking or insignificant (BIS, 2008). If augmentation of groundwater is envisaged, the minimum post-monsoon water level should be deeper than 3 m below the ground (CGWB, 2007). In case of GIF, none of these criteria actually fulfil the field conditions as the campus receives adequate volume of surface water supply and the post-monsoon water levels are shallower than 3 m. Generally, under such conditions, no further work is desired for any kind of recharge structure. But despite this, rooftop RWH was recommended at GIF so that the harvested rain water could be stored and used for some other purposes besides the reasons it receives the surface water supply. This makes this study unique unlike other studies in the literature where rooftop RWH have been conducted only because of lack of adequate groundwater/surface water supply.

2 Methods

2.1 Study Area

Grey Iron Foundry falls in Survey of India Toposheet No. 55 M/16 and lies within the North latitudes 23° 12′ 48″—23° 12′ 58″ N and East longitudes 79° 58′ 20″—79° 58′ 56″ E (Fig. 1). The entire GIF estate spreads over an area of 54.34 acres (0.22 km^2) and is located about 6 km North of the Gun Carriage Factory (GCF), Jabalpur, a large defence establishment, where also the RGNGWTRI team conducted a similar study in 2016 (Naik et al. 2023, 2024).

Grey Iron Foundry is a unit of Ordnance Factory Board under the Department of Defence Production, Ministry of Defence, Government of India.This foundry was founded in 1972 with collaboration from Skoda, Czechoslovakia. It has manufacturing capacity for production of various grades of grey iron automobile castings, S.G. iron, cast iron and medium carbon steel.

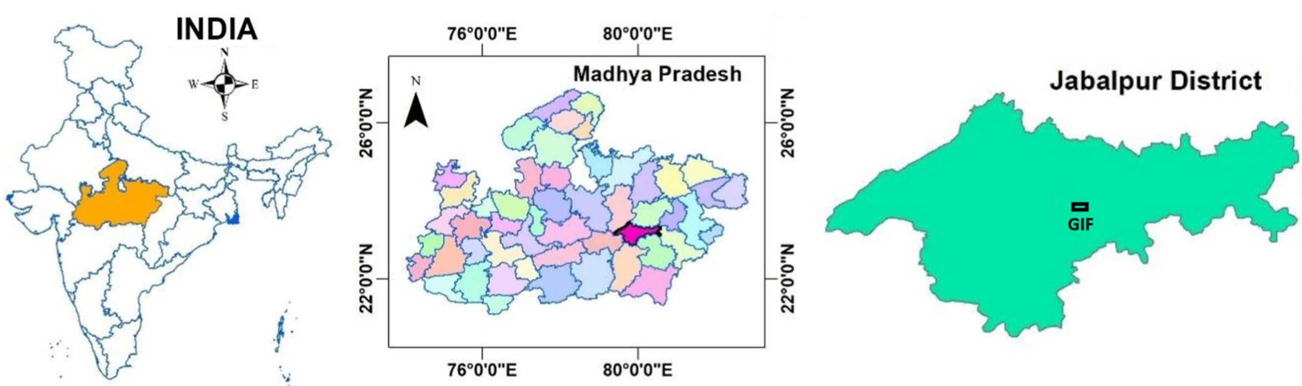

Fig. 1 Location map of the Grey Iron Foundry (GIF), Jabalpur District, Madhya Pradesh, India

2.2 Modus Operandi

Five distinct steps, as shown in a flowchart in Fig. 2, were adopted while studying the feasibility of rooftop rain water harvesting at the GIF. Technical meetings were held with GIF's management, other related officials and the people living around to understand their requirements and problems encountered, if any, in terms of water supply. All materials, such as total geographical area of the foundry, its layout, and building designs, were collected from various sections of the GIF. Meetings then were arranged with the local office of the Geological Survey of India to discuss the geology of the area and procure relevant maps and reports. Meetings also were held with the local India Meterological Department for collection of historical weather features. Regional hydrogeological and allied information were obtained from the published reports of the Central Ground Water Board. Field investigations were then conducted to understand the local physiography and geological set-up. Well inventory was carried out with the existing borewells to know the groundwater conditions. Geophysical surveys were not necessary. Two water samples were collected from the borewells for analysis of chemical parameters. Detailed surveys were then made in individual buildings to estimate roof areas, volume of rain water to be harnessed, site selection of the storage structures and for designing appropriate rooftop RWH structures. All calculations made at this step have been briefly mentioned below.

(i) Annual availability of rainfall per building = roof area of the building (m^2) × annual average rainfall (m).

(ii) Annual availability of rainfall that could be harvested per building (m^3) = roof area of the building (m^2) × annual average rainfall (m) × runoff coefficient

where runoff coefficient has two components: (i) runoff coefficient for the roof materials, i.e., galvalume sheets = 0.85 and (ii) coefficient for evaporation, spillage and first flush etc. = 0.80 (CPWD 2002). This means it is not possible to harvest 100% of available rainfall, since about 15% of the rain water is lost due to due to absorption, etc. by the roof materials and 20% of the remailing 85% is lost due to evaporation, spillage and first flush etc. Available water of the first rainfall event is generally not harvested and used as flushing/cleaning of the roofs since it contains lots of dust, leaves and other unwanted materials deposited on the roofs during the drier months. This calculation is based on the average annual rainfall. Therefore, 25% additional volume space is required for the years with higher rainfall, as often the case in this region.

(iii) Maximum water collected from roof in 15 min (m^3) = roof area (m^2) × maximum rainfall in 15 min (m) × runoff coefficient (0.85*0.80 = 0.68).

(iv) Capacity of settling tank (m^3) = roof area (m^2) × maximum rainfall in 15 min (m) × runoff coefficient for the galvalume sheets (0.85). Here runoff coefficient of the evaporation, spillage and first flush etc. is avoided since the purpose is to design the settling tank in such a way that it stores the maximum amount of rainfall for at least 15 min of intense rainfall period until the suspended materials settle down and the water moves to the collection/storage tank.

(v) Dimensions of the settling tank = length × breadth × height of the tank so that 15 min of maximum intensity rainfall could be stored.

(vi) Dimensions of the storage tank = length × breadth × height of the tank so that all harvested rain water in a year could be stored.

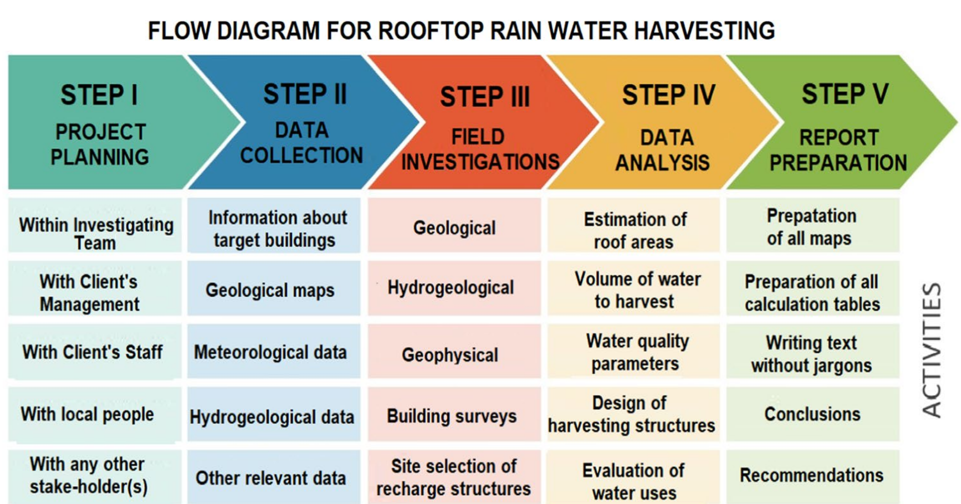

Fig. 2 Flow diagram for the procedures adopted for rooftop rain water harvesting at the Grey Iron Foundry, Jabalpur, India

All these calculations have been systematically discussed again in the sub-Sect. 3.4 and are shown in Table 1. The feasibility report was submitted to the GIF authority with all tables and figures explained in it in a simple language so that understanding of the contents does not require any special skill.

3 Results and Discussion

3.1 Physiography & Drainage

Jabalpur area is hilly and undulating in nature with elevations varying between 395 and 470 m above mean sea level (AMSL). The average elevation of GIF area is around 400 m AMSL. However, the study area is relatively plain with gentle undulations at places. It is a part of the Narmada River basin situated in its upper reaches.

3.2 Hydrometeorology

Jabalpur's climate is characterized by a hot summer and general dryness except during the South West monsoon period (June to September). October and November form the post monsoon period. As per the data provisionally collected from the observatory of the India Meteorological Department (IMD) at Jabalpur (August 17, 2016), the average annual rainfall around Jabalpur township is 1461 mm of which about 90% (1315 mm) falls during the monsoon season. While the maximum mean monthly rainfall is 467.50 mm (July), the minimum mean monthly rainfall is 4 mm (December) with number of rainy days in a year varying between 62 to 120 days. The cold season starts from December (min. 9.7 °C) to February and is followed by the hot season from March to about the middle of June (max. 42 °C).

3.3 Hydrogeology

Hydrogeology of GIF area is mainly controlled by the geomorphological and geological setup and also by climatic conditions. The area is underlain by a consolidated formation comprising of granites and granite gneisses of the Mahakausal Group of Precambrian age. The granites are coarse grained, hard, massive and pinkish in colour. The water yielding capacity of these rocks largely depends on the extent of weathering, fracturing, openness and size of fractures and extent of their interconnection with the near surface weathered zones. These interconnected joints and fractures in the underlying hard rocks facilitate circulation of groundwater and in turn form deeper aquifers.

A total of 6 borewells are constructed inside GIF premises. About half of them are production wells. Three

Table 1 Rain water available in three buildings of Grey Iron Foundry, Jabalpur, India for rooftop rain water harvesting

Sl. no.	Location	Roof area (m^2) (1)	Annual rainfall (m) (2)	Maximum rainfall in 15 min. (m) (3)	Runoff coefficient (0.8*0.85 = 0.68) (4)	Total water collected from roof in a year (m^3) (1*2*4)	Max. water collected from roof in 15 min. (m^3) (1*3*4)	Capacity of settling tank (m^3) (1*3* 0.85)	Dimensions of settling tank (m)	Dimensions of storage tank (m)
1	Building No. 1	9487	1.461	0.03	0.68	9425.1	193.5	241.9	12×6×3.5	5×50×50
2	Fetling Shop (Building No. 2)	9100	1.461	0.03	0.68	9040.7	185.6	232.1	12×6×3.5	5×50×50
3	Pattern Shop (Building No. 3)	3339.6	1.461	0.03	0.68	3317.8	68.1	85.2	7×4×3.5	5×30×28
	Total	21,926.6				21,783.6	447.2	559.2		

Runoff coefficient for the galvalume sheets = 0.85; Coefficient for evaporation, spillage and first flush etc. = 0.80 (CPWD 2002) borewells, as listed in Table 2, were selected to measure the depth to water levels (DTW). On 21 August 2016, the DTW ranged between 0.7 and 1.81 m below ground level (bgl) while on October 20, 2016, during postmonsson season, it was between 2.6 and 3.35 m bgl.

3.4 Feasibility of Rooftop Rain Water Harvesting

The DTW in GIF premises is found to be shallow for the injection of groundwater into the aquifers through rooftop rain water harvesting since there are chances that the injected recharge will be rejected by the aquifers during the monsoon season. Therefore, the rain water collected during the rainy season has to be stored either by an underground or on-the-ground cemented structure of adequate volume.

Grey Iron Foundry showed interest in installing water harvesting systems in Building Nos. 1, 2 and 3. It is estimated that approximately 21,784 m^3 of rain water harvesting capacity is available for storage in these buildings, as estimated in Table 1**.** Building Nos. 1 and 2 require a volume space of 10,000 m^3 individually for storing rain water when the annual rainfall is normal, i.e., 1461 mm. For higher rainfall extra volume shall be required since annual rainfall in the area often goes beyond 1500 mm (CWC 2014). Therefore, design is proposed to store up to 12,500 m^3 of rain water which has an additional 25% capacity up from the normal annual rainfall. The dimensions for the underground/on-the-ground storage tanks to hold this volume of water in individual buildings shall be $(5 \times 50 \times 50)$ m^3, if the height of the tanks shall be kept at 5 m. The proposed dimensions are flexible from construction point of view, and instead of one large storage tank for each building, two smaller tanks could be constructed depending on space availability.

For Building No. 3, a storage volume space of 3340 m^3 is required for the normal rainfall of 1461 m. For safety, provision may be kept for additional 25% volumetric space as discussed. So, the proposed volume of the tank, underground or on-the-ground, should be in the order of 4200 m^3 with dimensions of $(5 \times 30 \times 28)$ m^3 or $(4 \times 30 \times 35)$ m^3 or other suitable dimensions depending on availability of space. In this case too, the storage tank volume could be halved into two for two different tanks of the desired volumes if site conditions do not allow to construct one single tank.

Table 2 Depth to water level in Grey Iron Foundry premises, Jabalpur, India

S. no.	Location	Depth to water level (mbgl	
		21.08.2016	20.10.2016
1	BW–1 near Main Gate	1.81	3.2
2	BW–2 near Fetling Shop (Bld. No.2)	–	3.35
3	BW–3 near Pattern Shop (Bld. No.3)	0.7	2.6

The collected roof water is expected to have some amount of silt or other suspended materials in it (Gao et al. 2024). Therefore, settling tanks are required to settle down the silts, and a duration of 15 min is good enough for this purpose. Therefore, the size of these settling tanks should be such that they should be able to hold the collected rain water for a period of at least 15 min (CPWD 2019). Maximum rainfall intensity of 30 mm (0.03 m) in 15 min is assumed for Jabalpur while estimating the volume of the settling chambers (Naik et al. 2024). Accordingly, the dimensions of the settling tanks may be kept at $(12 \times 6 \times 3.5)$ m^3 for Building Nos. 1 and 2 and $(7 \times 4 \times 3.5)$ m^3 for Building No. 3. (Table 1).

If space is not available even for a settling tank, arrangements can be made for only one larger tank for both settling and storage purposes, but care has to be taken that no unwanted materials fall on this larger tank during the rainy days and the collected water is pumped out carefully so that only cleaner water is supplied to the user ends. If space is still limited, construction of an overhead storage tank of equivalent dimensions can also be explored in which case the collected water from the settling tank shall be pumped out continuously to this overhead tank and the stored water from this tank will be supplied through gravity at the time of need. But this option may be expensive due to continuous pumping from the settling tank during the rainy days and one has to keep a constant vigil on the whole procedure for smooth operation of the harvesting system. The pumping cost during the rainy days, however, shall be compensated accordingly during the drier seasons when the stored water from the overhead tank shall be supplied through gravity without use of electricity.

The current designs of the GIF buildings are such that down-take pipes (or down pipes) are already existing in all buildings, except the northern side of Building No. 2, where such down-take pipes could be installed. These down-take pipes play a crucial role in managing rain water from rooftops to the ground. Therefore, in each building, rooftop water through these down-take pipes must be collected in a larger channel (preferably closed) on the surface to connect it to the settling chamber. A rough design of the collection/settling and storage system is shown in Fig. 3a, b. The rain water thus stored could be used for multiple purposes, such as for gardening, horticulture or industrial cooling, by making suitable arrangements.

The GIF requires about 640 m^3 of drinking water and 70 m^3 of raw water for cooling purposes on daily basis (reported). Thus, the annual requirements for cooling purposes are estimated at 25,550 m^3, while total rain water that

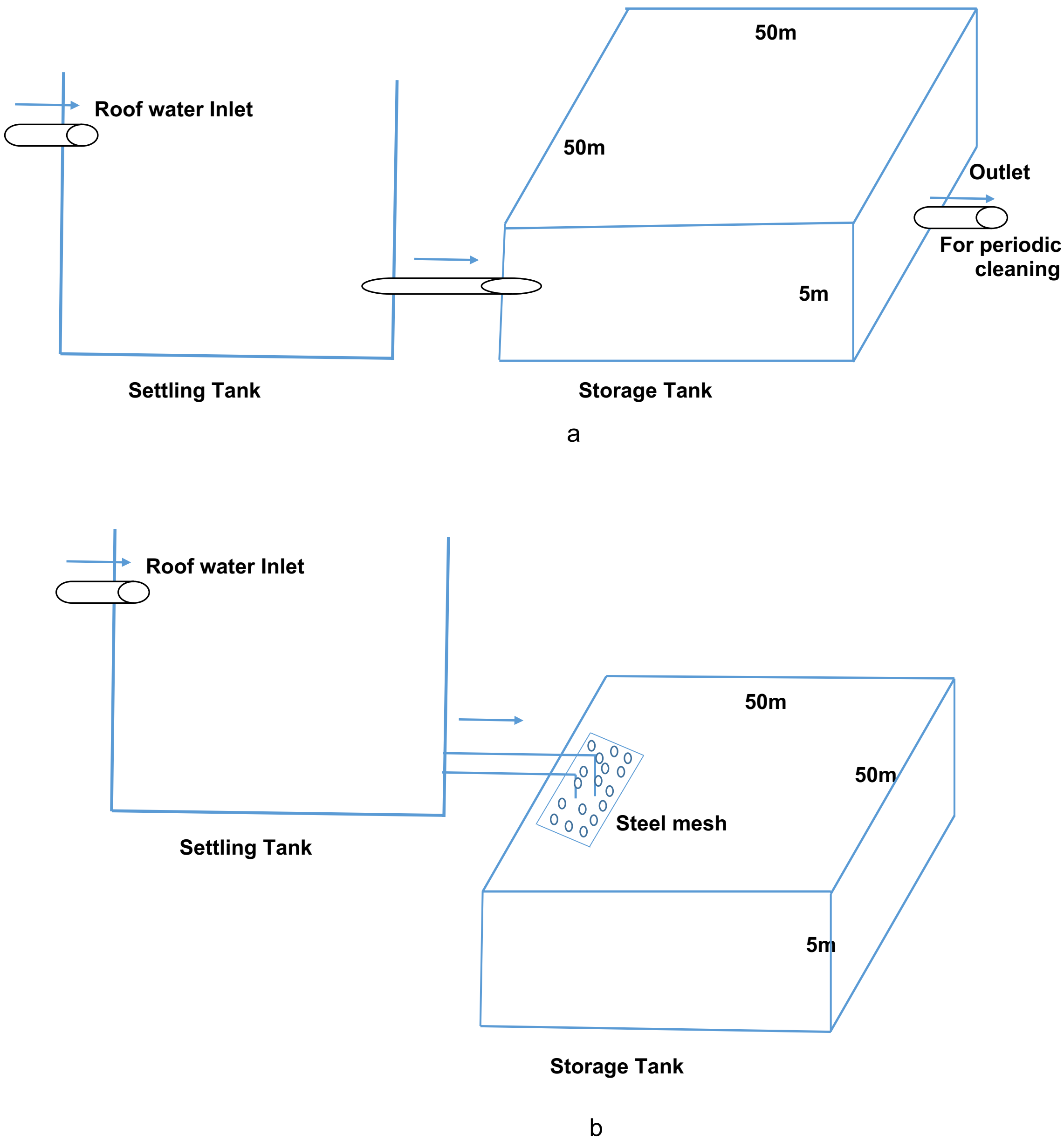

Fig. 3 **a** A storage system with settling tank and an on-the-ground storage tank, **b** A storage system with settling tank and an underground storage tank

Table 3 Chemical quality of groundwater in Grey Iron Foundry, Jabalpur, India

S. no.	Location	Source	pH	EC in µS /cm	CO_3	HCO_3	Cl	F	SO_4	Na	K	Ca	Mg	TH
					←Concentrations in mg/L→									
1	Inside GIF premises	Borewell	8.06	405	0	195	35	2.3	13	29.9	2.8	40	10.8	145
2	GIF Main Gate	Borewell	8.37	428	0	220	28	3.0	15	32.3	1.5	52	8.4	165

could be stored by these tanks is about 21,784 m^3, which is 85% of the cooling water requirements.

3.5 Chemical Quality of Groundwater

Chemically, as evident from Table 3, concentrations of the groundwater quality parameters, except that of Fluoride, lie within the drinking water standards prescribed by the Bureau of Indian Standards (BIS, 2012). The BIS acceptable limit for Fluoride is 1.0 mg/L, while the maximum permissible threshold in the absence of an alternative source is 1.5 mg/L. Its source in this area could be from the weathered granite formations. However, its persistence and seasonal variations need further investigation. Under the given circumstances, the groundwater is not suitable for drinking due excessive amount of Fluoride ions in it. The rain water collected at the Gun Carriage Factory, 6 km away from GIF, is slightly acidic in nature (Naik et al. 2023) and lacks all constituents desired of potable water. The harvested rain water is, therefore, not recommended for drinking purposes.

4 Conclusions

The city of Jabalpur receives heavy rainfall to the extent of about 1500 mm on annual basis (CWC 2014), but much of it goes a waste, untapped. It is a noble attempt by the GIF to harness the rain water falling in their premises. However, since the groundwater levels are very shallow (< 3 m), there is no sufficient natural space available underground for further groundwater recharge through gravity, but the harnessed rain water can be stored in an underground or on-the-ground storage tank for usage purposes. Until further investigations, the groundwater is not recommended for drinking due to the presence of high amount of fluoride in it. The rain water too is not suitable for drinking since it lacks all the constituents desired of human consumption. It can however be used for industrial purposes, such as for cooling of machinery, gardening and horticulture. It is estimated that about 85% of the cooling water requirements of the GIF can be met by the harvested rain water.

While the National Water Policy of the Government of India recommends water harvesting in areas showing declining trend of groundwater recharge (MoWR 2012), special policies have been framed for rooftop rain water harvesting in Model Building Bye Laws (MBBL), 2016 under which all buildings having a plot size of 100 m^2 or more must include the complete proposal of rain water harvesting (MoUD, 2016). This scheme was bolstered in 2019–2022 by a nationwide campaign, called "Jal Shakti Abhiyan" of the Government of India, under the banner "Catch the rain, where it falls, when it falls". The objective was to create mass awareness on rain water harvesting structures in urban and rural areas of all the administrative districts in the country, with people's active participation. PIB (2023) lists many other policy frameworks specific to rooftop rain water harvesting. Also, there are numerous literature available for efficient harvesting of rain water that people around the world in different terrains could adopt (Hofman-Caris et al. 2019; Chiu et al 2020; State of Green 2021).

Many published guidelines of the Government of India do not recommend rain water harvesting (RWH) in an area where groundwater levels are shallower than 5 m (CPCB, 2001; CGWB 2007). Central Ground Water Board (2020), however, recommends a minimum groundwater level of > 3 m bgl provided there is a declining trend in its level of more than 10 cm/year in plain areas. But Grey Iron Foundry (GIF) is an example where RWH could be implemented even in areas of shallow groundwater levels (< 3 m), although the water harvested will not be used for groundwater recharge but for some other meaningful purposes.

India consists innumerable building of different types in its 7935 towns and 475 urban agglomerates, 53 of which have more than a million population (CoI 2011). There are also about 242,395.000 manufacturing factories (CEIC 2022), 41 ordnance factories (DoO 2022), numerous military barracks and many other similar structures with large roof areas. If three of the buildings in a small foundry like GIF with a roof area of 21,927 m^2 could save about 21,784 m^3 of rain water at the rate of about one m^3 per one m^2 of roof area, what not to expect from tens of thousands of similar structures across the country?

Grey Iron Factory serves as a model example for rooftop rain water harvesting. All other establishments, whether smaller or larger, ought to follow this GIF model to save the country from an impending danger of water scarcity.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

References

BIS (Bureau of Indian Standards) (2008) Roof top rainwater harvesting–guidelines. IS 15797: 2008. https://nwm.gov.in/sites/default/files/IS-15797-Rainwater_Haresting_Roof_Top.pdf

BIS (Bureau of Indian Standards) (2012) Indian standard drinking water specification (second revision) IS10500:2012, https://www.bis.gov.in/wp-content/uploads/2020/10/PM-IS-10500.pdf.

CEIC (Computer and Enterprise Investigations Conference) (2022) India manufacturing industries: number of factories. https://www.ceicdata.com/en/india/manufacturing-industry-nic-2008-all-industries/manufacturing-industries-number-of-factories. Accessed 1 April 2022

CGWB (Central Ground Water Board) (2007) Manual on artificial recharge of groundwater. Ministry of Water Resources, Government of India. https://jsactr.mowr.gov.in/Public_Dash/download/Manual%20on%20Artificial%20Recharge%20of%20Ground%20Water.pdf

CGWB (Central Ground Water Board) (2020) Master plan for artificial recharge to groundwater in India-2020, Ministry of Water Resources, Govt. of India, 190 p

Chiu YR, Aghaloo K, Mohammadi B (2020) Incorporating rainwater harvesting systems in Iran's potable water-saving scheme by using a GIS-simulation based decision support system. Water 12(3):752. https://doi.org/10.3390/w12030752

CoI (Census of India) (2011) Provisional population totals: urban agglomerations and cities–data highlights, Government of India. https://docslib.org/doc/11622159/census-of-india-2011-urban-agglomerations-and-cities

CPCB (Central Pollution Control Board) (2001) Concepts and practices for rainwater harvesting, Resource Recycling Series: RERES/5/2001–02. Ministry of Environment and Forests, Government of India

CPWD (Central Public Works Department) (2002) Rain water harvesting and conservation. Consultancy Services Organization, Government of India

CPWD (Central Public Works Department) (2019) Rain water harvesting and conservation manual, Ministry of Housing and Urban Affairs, Government of India. https://cpwd.gov.in/Publication/Rain_Water_Harvesting_Conservation_Manual_2019.pdf

CWC (Central Water Commission) (2014) Narmada river basin. Ministry of Water Resources, Government of India, 149 p

DoO (Directorate of Ordnance) (2022). The Indian ordnance factories. http://ddpdoo.gov.in/

Gao Z, Zhang Q, Wang Y, Jv X, Dzakpasu M, Wang XC (2024) Evolution of water quality in rainwater harvesting systems during long-term storage in non-rainy seasons. Sci Total Environ 912:168784. https://doi.org/10.1016/j.scitotenv.2023.168784

Hofman-Caris R, Bertelkamp C, de Waal L, van den Brand T, Hofman J, van der Aa R, van der Hoek JP, der Hoek JP (2019) Rainwater harvesting for drinking water production: a sustainable and cost-effective solution in the Netherlands? Water 11(3):511. https://doi.org/10.3390/w11030511

Kimutai JJ, Lund C, Moturi WN, Shewangizaw S, Feyasa M, Hanlon C (2023) Evidence on the links between water insecurity, inadequate sanitation and mental health: a systematic review and meta-analysis. PLoS ONE 18(5):e0286146. https://doi.org/10.1371/journal.pone.0286146

Marcal J, Shen J, Antizar-Ladislao B, Butler D, Hofman J (2024) Assessing inequalities in urban water security through geospatial analysis. PLOS Water 3(2):e0000213. https://doi.org/10.1371/journal.pwat.0000213

MoUD (Ministry of Urban Development) (2016) Model building byelaws, 2016. Town and country organization, government of India. http://www.tcpo.gov.in/model-building-bye-laws-mbbl-2016

MoWR (Ministry of Water Resources) (2012) National Water Policy (2012), Government of India. https://www.nwm.gov.in/national-water-policy-2012

Naik PK (2017) Water crisis in Africa: myth or reality. Int J Water Res Develop 33(2):326–339. https://doi.org/10.1080/07900627.2016.1188266

Naik PK, Mondal KC, Naik PK, Prasad G, Gupta P (2023) Subsurface geophysics and hydrogeology at the gun carriage factory, Jabalpur, Madhya Pradesh, India. Jour of Geol Soc of India 99(11):1595–1603. https://doi.org/10.1007/s12594-023-2511-x

Naik PK, Naik PK, Prasad G, Mondal KC (2024) A design plan for roof top rain water harvesting in a defence establishment in central India. Desalin Water Treat 317:100252. https://doi.org/10.1016/j.dwt.2024.100252

PIB (Press Information Bureau) (2023) Rooftop rainwater harvesting. Release ID: 1897697. Posted on: 09 Feb 2023 4:41 PM by PIB, Government of India. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1897697

PIB (Press Information Bureau) (2024) Per capita water availability. Release ID: 2002726. Posted on: 05 Feb 2024 6:05 PM by PIB, Government of India. pib.gov.in/PressReleaseIframePage.aspx?PRID=2002726

State of Green (2021) Nature based solutions: using rainwater as a resource to create resilient and livable cities.https://stateofgreen.com/en/publications/sustainable-urban-drainage-systems-helps-increase-drinking-water/

TWB (The World Bank) (2023) How India is addressing its water needs? https://www.worldbank.org/en/country/india/brief/world-water-day-2022-how-india-is-addressing-its-water-needs. Retrieved 24 March 2024.

TWB (The World Bank) (2024a) Understanding Poverty: Urban Development. https://www.worldbank.org/en/topic/urbandevelopment/overview

TWB (The World Bank) (2024b). Urban population (% of total population) – India. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=IN

UN-DESA (United Nations-Department of Economic and Social Affairs) (2019) World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

UNFPA (United Nations Fund for Population Activities) (2024) Urbanization. https://www.unfpa.org/urbanization. Retrieved 24 March 2024

UN-Habitat (2022). Envisaging the future of cities. https://unhabitat.org/world-cities-report-2022-envisaging-the-future-of-cities

UN-Habitat (2024). Urbanization in India: building inclusive and sustainable cities. https://unhabitat.org/india. Retrieved 24 March 2024.

WPR (World population review) (2024). India population 2024 (Live) https://worldpopulationreview.com/countries/india-population.