Indian J. of Agroforestry Vol. 16 No. 2 : 47-52 (2014)

Impact of rainwater harvesting structures on water table behavior and groundwater recharge in Parasai-Sindh watershed of Central India

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ABSTRACT: The open shallow dug wells, situated in unconfined aquifer, are the major source of irrigation throughout Bundelkhand region of Central India. These wells, due to dependence on perched water, are characterized by very low specific yield and unable to support for continuous operation of pumps to irrigate the agricultural fields in a single stretch. This warrants water harvesting to ensure quick recharge in wells and thereby facilitate irrigation and in turn crop productivity. Therefore, to improve the water resources in Parasai-Sindh watershed (1246 ha) about 1,00,000 cum, rainwater harvesting facility was created through 10 cost-effective structures during 2012 and 2013. Ensuing study is an attempt to analyze the impact of these rainwater harvesting structures on water table and groundwater recharge. Water table fluctuation (WTF) method was applied during pre and post intervention phases to quantify groundwater recharge and to analyze the fluctuation of water table in open shallow dug wells. The average increase in water column, during monsoon for pre and post intervention, was recorded as 3.54 and 5.98 m, respectively. Average water column has increased by 69 per cent during 2013 due to watershed interventions. Net groundwater recharge, during monsoon season for pre and post interventions scenario, was estimated at 53.7 and 92.3 mm, respectively, which is 71.8 per cent higher than pre intervention phase. Improved yield of open wells reduced *rabi* fallow by about 70 ha besides, ensuring irrigation water through dug wells to rabi crops predominantly wheat in entire treated area of the watershed. The study has proved the efficacy of rainwater harvesting for groundwater recharge in Bundelkhand region.

Key words: Groundwater recharge, rainwater harvesting structures, specific yield, watershed, water table fluctuation

Received on: 02.05.2014 Accepted on: 26.06.2014

1. INTRODUCTION

Groundwater is one of the important sources of potable water. This accounts for a significant water resource in India for domestic, irrigation and industrial needs. Over 80% of the rural domestic water supply and 45% of the irrigation water supply in the country are met from this valuable resource. Rainfall is the principal means for replenishment of moisture in the soil water system and recharge to ground water. Decreasing mean annual rainy days, rainfall and the increasing rainfall intensity, temperature and evaporation, particularly in semi-arid tropics (SAT), will require storage capacity to be increased or more stable resources to be harnessed to maintain security of water supplies at current levels.

The amount of moisture that will eventually reach the water table is defined as natural ground water recharge. The amount of this recharge depends upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type. In many arid and semi-arid regions, surface water resources are limited and ground water is the major source for agricultural, industrial and domestic water supplies. Therefore, augmentation of groundwater recharge in SAT regions is necessary for livelihood security.

Determination of rate of groundwater recharge is an inherently difficult task because of uncertainties and assumptions associated with different methods of analysis. Moreover, various quantifying methods differ in the type of recharge, and the space and time scales represented (Scanlon *et al.,* 2002). Groundwater recharge rates can be estimated through physical, chemical and isotopic techniques (Allison, 1988; Foster, 1988). These methods produce estimates over various time and space scales and encompass a wide range of complexity and expense. Among the physical methods, the water table fluctuation technique (WTF) links the change in groundwater storage with resulting water table fluctuation through the storage parameter (specific yield in unconfined aquifer). A combination of soil moisture and water table fluctuation method had been used by several researchers (Sophocleous, 1991, Singh *et al.*, 2014). This method is mostly applied due to simplicity of estimating recharge rates from temporal fluctuations and spatial patterns of groundwater levels. The primary advantage of this method is ease of use and low cost of application in semi-arid areas (Beekman and Xu, 2003).

In Bundelkhand region of Central India, open shallow dug wells are situated in unconfined aquifer which rest over massive granite rock. The irrigation is very difficult as these wells do not support continuous pumping and in turn, cost of watering is too high. Here, we present the results from a study of Parasai-Sindh watershed of Sindh basin representing drought prone semi-arid sub-tropics of Central India. The water availability has improved due to construction of 10 cost-effective rainwater harvesting structures on ephemeral drains in series including one *haveli,* traditional water harvesting system, which harvest maximum runoff during rainy season. This paper focuses on impacts of rainwater harvesting structures on water level fluctuations and groundwater recharge.

2. MATERIALS AND METHODS

The Parasai-Sindh watershed, as part of Sindh river catchment, is located at 25 º 23' 47.6" - 25 º 27' 05.1" N and 78º 20' 06.5" - 78º 22' 33.0" E, and about 270-315 m above mean sea level in Jhansi district of Uttar Pradesh (Fig. 1). The geographical area of watershed is 1246 ha, comprising three villages and has independent hydrology. The rainfall is highly erratic and uncertain. Long term weather data show that the average rainfall in study region is 877 mm (standard deviation, σ = 251 mm), about 85% falling from June to September (Singh *et al.*, 2014). The watershed experiences semi-arid sub-tropical climate and characterized by dry and hot summer, warm and moist rainy season and cool winter with occasional rain showers. Mean annual temperature ranges from 24 to 25 ^{0}C. The mean summer (April-May-June) temperature is 34 ^{0}C which may rise to a maximum of 46 to 49 ^{0}C during the month of May and June. The mean winter temperature (December-January-February) is 16 ^{0}C. Further, the diurnal variation in temperature is quite high.

Bundelkhand is an old landmass, composed of horizontal rock beds, resting on a stable foundation. The landscape is rugged, featuring undulating terrain with low rocky outcrops, narrow valleys, and plains. Surface rocks are predominantly granite of the Lower Pre Cambrian / Archaen period. Some Dharwarian and Vindhayan rocks present in the region contain minerals of economic value. Sandstone, shales and limestone of high quality, along with Dyhes, Sills and the famous pink Archaean gneiss rocks, are also found in places. Total area of the watershed is 1246 hectares which comprises three villages namely Parasai, Chhatpur and Bachhauni.

Rainwater Harvesting Structures (RWHS)

To augment groundwater recharge, 10 cost-effective rainwater harvesting structures were constructed before April, 2013 on ephemeral drains (Fig. 2). Surface storage of about one lakh cubic meter was created in the watershed. In the upper most reach, an old *Haveli* (traditional rainwater harvesting system in Bundelkhand region) near Parasai village alone has created 73 thousand cubic meter water storage through construction of its outlet and minor repair of its embankment.

Monitoring groundwater table and cropping pattern

Groundwater levels of the 200 open wells, located at Parasai-Sindh watershed, were monitored at monthly interval since its inception i.e. May, 2011. Average depth of wells varied from 2.95 to 17.8 m with the average value of 9.69 m. Water in these wells is being used for agricultural and domestic purpose. All the fields were digitized in GIS environment using Arc GIS ver. 10 and areal extent under different land uses was worked out.

Estimation of Groundwater Recharge

The groundwater recharge potential in the area was estimated using water table fluctuation method. Specific

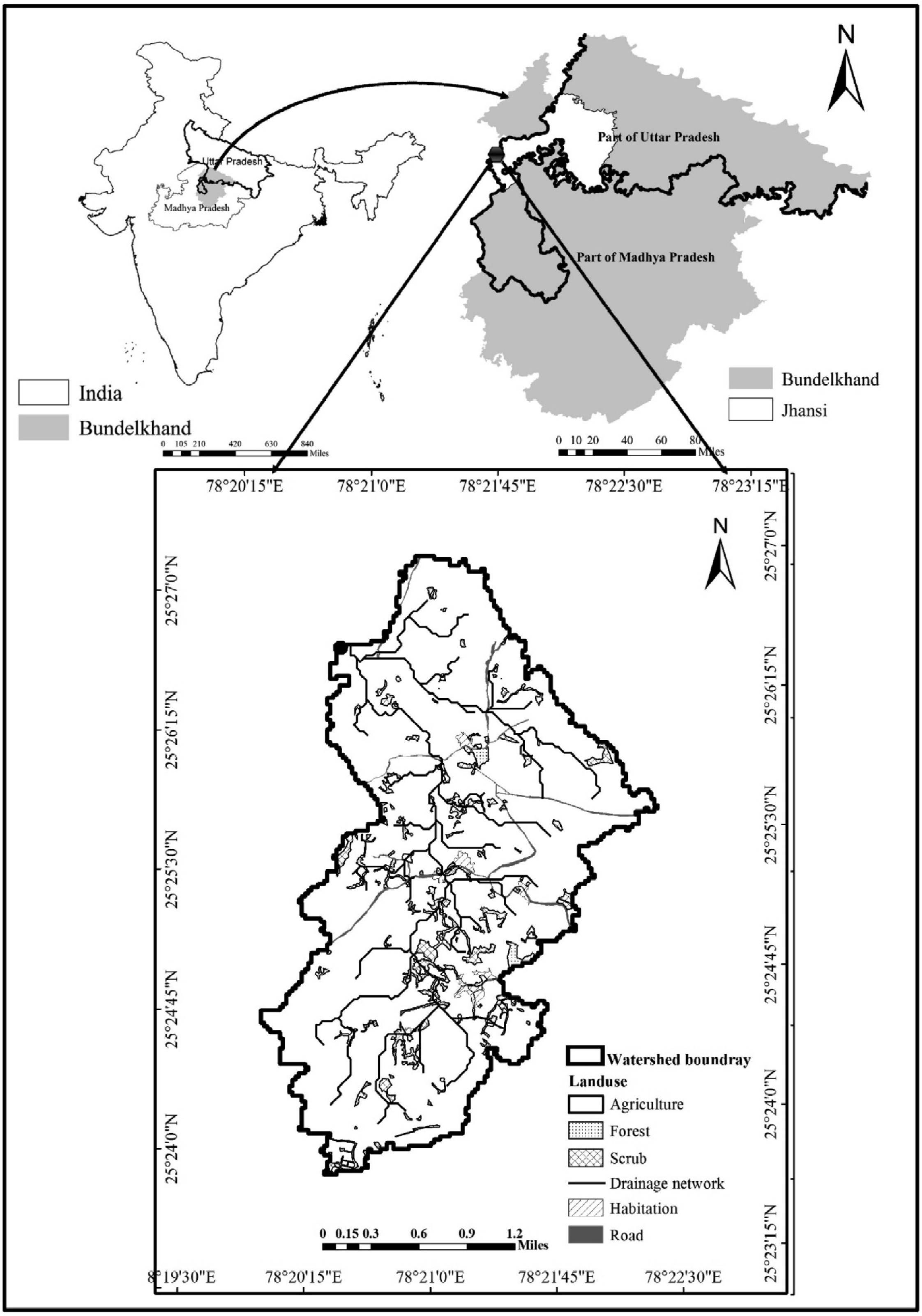

Figure 1. Location map of study site: Parasai – Sindh watershed

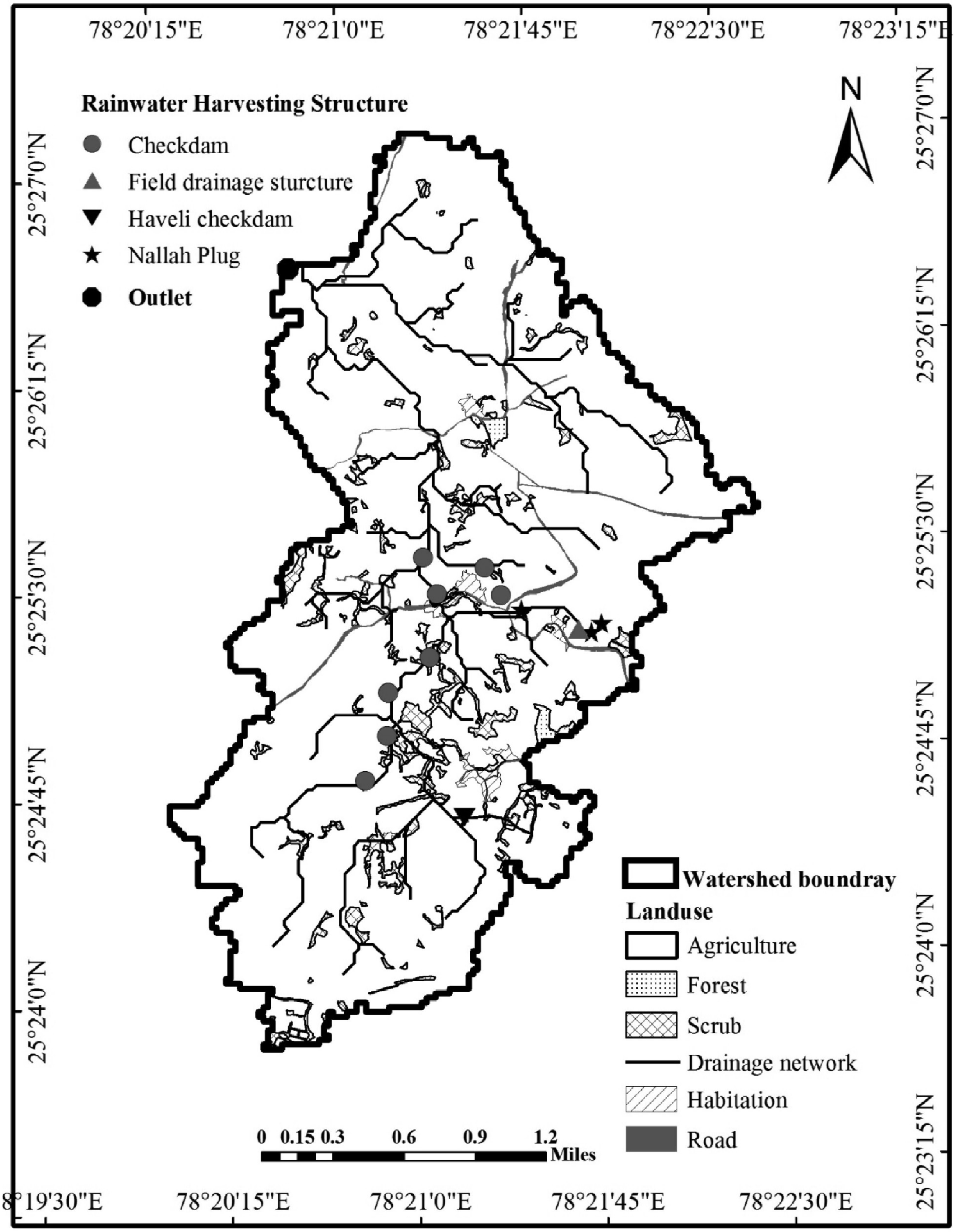

Figure 2. Location of rainwater harvesting structures on ephemeral drains of Parasai – Sindh watershed

yield was estimated in the range between 0.5 and 1.5% with average value of 1.0% for Bundelkhand hard rock region (Singh *et al.*, 2014). Central Ground Water Board (CGWB, 2000) also reported specific yield of Bundelkhand hard rock region in the same range. Water table fluctuation (WTF) method is a well accepted and convenient technique for estimating groundwater recharge in hard-rock regions (Sharda *et al.,* 2006; Dewandel *et al.,* 2010; Glendenning and Vervoort 2010; Garg and Wani, 2012; Singh *et al.,* 2014). This method was based on the hypothesis that the rise in groundwater level in unconfined aquifers is due to recharging water arriving up to the water table. Water balance captured by WTF method is defined by mass balance equation such as:

Net groundwater recharge during monsoon = change in hydraulic head before and after monsoon) × specific yield + water withdrawal during monsoon period + underlying deep drainage + evaporation losses from water table.

Hydraulic head in open wells at different time periods was obtained from water table data. Underlying deep percolation is assumed negligible due to presence of impervious granite layers. Evaporation losses from the groundwater aquifer were calculated as 5-10 mm year^{-1} for the study area using Coudrain-Ribstein *et al.* (1998) depth–evaporation relationship. Due to less availability of ground water only 5 mm year^{-1} evaporation was assumed in pre intervention phase. After watershed management and rainwater harvesting, evaporation was assumed as 10 mm year^{-1}. During monsoon season, groundnut is the only crop in watershed which requires one irrigation to get better yield. Irrigated areas were also recorded since inception of the project. Groundwater recharge during pre and post monsoon period (May - October) was estimated for the watershed for two years (2011 and 2013).

3. RESULTS AND DISCUSSION

Land use of Parasai-Sindh watershed was categorized in six types. Maximum area is under agriculture (88.7%) followed by scrub land, drainage network, habitat, road and forest (Table 1). It is observed that Groundnut is most preferred crop during kharif as it is remunerative over other crops. Area covered by groundnut (1029 ha in 2013) was 93.08% followed by sesamum 1.91%.

Table 1. Areal extent of different landuse in the Parasai-Sindh watershed

Sl. No.	Landuse	Area (ha)	Per cent of total Area
1	Agricultural	1105.5	88.7
2	Drainage Network	43.4	3.6
3	Forest	5.6	0.45
4	Habitat	11.1	0.89
5	Road	14.3	1.15
6	Scrub land	66	5.29
	Total	1245.9	100

The average depth of open wells was 9.69 m. Average water level and water column in shallow open wells during May, 2011 were 8.63 and 1.06 m, respectively. During pre interventions phase, average water column for the months of May and October was recorded as 1.06 and 4.60 m, respectively. However, it was 2.04 and 7.04 m, respectively, for post-interventions phase. The net groundwater recharge during monsoon was 3.54 and 5.98 m during pre and post-interventions, respectively. Considering 1% specific yield for the region, recharge of 35.4 and 59.8 mm rainfall is required to get respective water column during pre and post scenario. During monsoon season 2011, life saving irrigation was given in 828 ha. However, watering was done in 979 ha (18.2 per cent higher than pre intervention scenario) during 2013 due to enhanced availability of water in the watershed. During estimation it was assumed that irrigation was done at the rate of 70 per cent of required amount during pre-interventions, however, full amount of required irrigation was supplied during post scenario. Total groundwater recharge including irrigation, evaporation and water table buildup during pre and post interventions was estimated as 53.7 and 92.3 mm, respectively. It was 6.12 and 10.52 per cent of average rainfall (877 mm) during respective scenario.

The water column fluctuated between 1.05 to 5.64 m and 1.86 to 7.13 m during pre and post-interventions, respectively, with rainfall of 1289 and 1396 mm during 2011 (pre) and 2013 (post), respectively (Fig. 3). It was observed that there was significant build up in water column due to rainwater harvesting structures during post-interventions scenario for similar rainfall amount. Water column buildup was 0.31 and 2.61 m for the months of July and August, 2011 (pre), respectively, however, it was 3.22 and 1.91 m for post scenario.

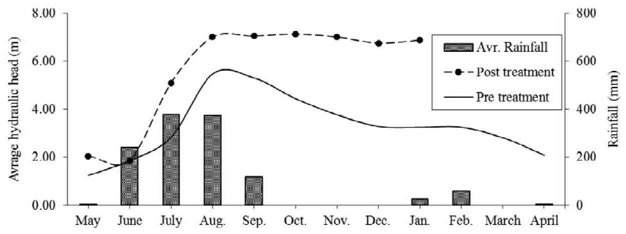

Figure 3. Fluctuation of hydraulic head with relation to rainfall in pre and post interventions in Parasai – Sindh watershed

Rainfall was hovering about 400 mm during July and August in both scenarios. It clearly indicates that deficit soil moisture quickly replenished during post-intervention. Increase in groundwater recharge in the Parasai–Sindh watershed was 38.6 mm representing 71.8 per cent increase in post intervention over pre intervention. The difference in the recharge values for the two study years could be attributed to the enhanced water availability through suitable RWHS. Singh *et. al.* (2014) also reported similar recharge in Garhkundar-Dabar watershed of Bundelkhand region, Central India.

4. CONCLUSION

In the present study groundwater recharge has been estimated by water table fluctuation method during pre and post watershed interventions. RWHS have significant and quick impact on groundwater recharge in Bundelkhand region. In addition, it improved productivity of eco-system due to sustainable impact on water table.

ACKNOWLEDGEMENT

Authors gratefully acknowledge ICRISAT, Hyderabad for providing financial support to develop Parasai-Sindh watershed. Authors also extend their sincere thanks to the other team members who have contributed in the project from time to time.

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