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REVIEW ARTICLE

Urban Water Supply System of Prayagraj: Sources, Storage Capacity and Zonal Disparities in Well Distribution

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Abstract

The reliability of an urban water supply depends not only on how much water a city produces but also on where it is sourced, how much of it can be stored, and how evenly supporting infrastructure is distributed within the city. This paper examines the water supply system of Prayagraj, Uttar Pradesh, with emphasis on supply sources, storage capacity and zone-wise disparities in public wells. The analysis draws on records of the Jal Kal Vibhag (Prayagraj), the City Development Plan and the Census of India, supported by GIS mapping of the geo-tagged well inventory. Prayagraj is supplied with 308 million litres per day (MLD), of which 77% (238 MLD) comes from tube wells and 23% (70 MLD) from the Yamuna River. The reported per capita supply of 253 litres per day exceeds the urban norm of 135–150 lpcd, yet total storage is only 22.5 MLD, about 7% of daily supply (roughly 1.75 hours), and the Khushrobagh treatment plant runs at about half of its 135 MLD capacity. Of 184 public wells inventoried across eight zones, only 70 (38%) are operational. Functionality ranges from 87.5% in Zone 2 to nil in Zone 4, and Zones 1, 3 and 4 together hold about 66% of all closed wells ($\chi^2 = 67.2$, df = 7, $p < 0.001$). Projected demand of 347 MLD in 2031 and 418 MLD in 2041 would exceed present supply by 39 and 110 MLD respectively, while network losses reported at about 40% erode effective availability. The findings suggest that Prayagraj's water problem is one of storage, distribution and maintenance rather than raw availability, and the paper outlines priorities for well rehabilitation, storage augmentation, loss reduction and more equitable service.

KEYWORDS:
Arban water supply; groundwater dependence; storage capacity; public wells; spatial disparity; Prayagraj

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1. Introduction:

Water is central to human health, development and well-being, and global targets under the Sustainable Development Goals call for universal and sustainable access by 2030. Freshwater that is usable for people is limited and unevenly distributed, and it does not always coincide with where populations live (Bhat, 2014). India receives about 4,000 km³ of precipitation a year, roughly 3,000 km³ of it during the monsoon (Bhattacharyya et al., 2015; Hussain, 2018), and about 70% of surface water arrives within three to four months (Bhat, 2014). This temporal and spatial imbalance, combined with population growth and urbanisation, has steadily reduced per capita availability and produced scarcity that varies across river basins (Amarasinghe et al., 2005). Urban supply systems have also deteriorated under rural–urban migration and management problems (Bowonder & Chettri, 1984), and the fact that about 92% of Indians can reach an improved source does not by itself mean that the water is safe or reliably available (Cronin et al., 2016).

Prayagraj illustrates these tensions. The city lies at the confluence of the Ganga and the Yamuna and is bordered by the two rivers on three sides, which suggests abundant surface water. Yet most of its piped supply is pumped from tube wells, a large share of its older public wells is out of use, and storage and distribution infrastructure is old and unevenly provided. Aggregate indicators such as litres per capita per day can conceal such conditions, because they say nothing about storage,

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intra-city differences in infrastructure or the condition of decentralised sources on which poorer residents often depend.

This paper therefore looks beyond headline supply figures. Its objectives are: (i) to describe the sources, treatment, storage and distribution components of Prayagraj's water supply; (ii) to assess the adequacy of storage relative to supply; (iii) to quantify zone-wise disparities in the functionality of public wells; and (iv) to compare present supply with projected demand and identify the main challenges facing the system.

2. Study Area

The study covers the municipal area of Prayagraj (formerly Allahabad), which extends from 81°43′20″ to 81°53′30″ E and from 25°23′00″ to 25°32′00″ N, with an east–west extent of about 25.2 km, a north–south extent of about 30.5 km and a municipal area of about 75 km². The city is a major pilgrimage, administrative and educational centre. The 2011 Census recorded 1,112,544 persons in the city and 1,212,395 in the urban agglomeration. Residential use occupies about 77% of the city's area, while industrial water demand within the main city is low because most industry lies outside it or on the Naini fringe. Census-based analysis of the city uses seven zones (A–G), whereas the Jal Kal Vibhag records wells by eight administrative zones (Zone 1–8) and operates twelve water supply zones. These three zonal schemes are not interchangeable, and each is used here only for the data it was designed to organise.

3. Data and Methods

The study is based on secondary data. Information on sources, supply volumes, treatment, storage, distribution and the well inventory was obtained from the Jal Kal Vibhag, Prayagraj. The inventory lists each well by zone, ward, location, status (operational or closed) and geographic coordinates. Population and demand projections for 2021, 2031 and 2041 were taken from the City Development Plan, and demographic data from the Census of India (2011). Operational wells were mapped in QGIS from their recorded coordinates over the zonal boundaries.

Four indicators were derived. The *functionality rate* of zone z is $FR = (O/T) \times 100$, where O is the number of operational wells and T the total number of wells in the zone. The *share of operational wells* is each zone's operational wells divided by the city total. The *storage–supply ratio* is total storage capacity divided by daily supply. The *supply–demand balance* is present supply minus projected demand. Association between zone and well status was tested with a chi-square test of independence, with Cramér's V as the effect size. Because wells within a zone are not independent random draws and one expected cell count falls below 5 (4.57, Zone 8, operational), the test is treated as indicative rather than inferential. Qualitative remarks recorded against closed wells (for example disuse, debris, damaged walls) were summarised to interpret the quantitative pattern.

4. Results and Discussion

4.1 Supply sources and the dominance of groundwater

Prayagraj's piped system delivers 308 MLD: 70 MLD (22.7%) from the Yamuna River and 238 MLD (77.3%) from tube wells (Table 1). Surface water is lifted at the Kareli (Kerela Bagh) pumping station on the Yamuna and conveyed through mains to the Khushrobagh Water Treatment Plant, which uses rapid gravity filtration with disinfection and has a capacity of 135 MLD (settling tank capacity 177 MLD). Treated water passes to reservoirs and then to a distribution network of about 1,122 km serving more than 1.5 lakh connections and 1,700 public stand posts.

Table 1. Key characteristics of the piped water supply system of Prayagraj

Parameter	Value	Remark
Total supply	308 MLD	Surface + tube wells
Surface water (Yamuna River)	70 MLD (22.7%)	Via Khushrobagh WTP
Tube wells	238 MLD (77.3%)	Groundwater
Treatment plant capacity	135 MLD	Operating at about 50%
Per capita supply (reported)	253 lpcd	Norm: 135–150 lpcd
Total storage capacity	22.5 MLD	18 reservoirs
Distribution network length	1,122 km	Oldest pipes laid in 1890
Consumer connections	> 1.5 lakh	Partly metered
Public stand posts	1,700	Citywide
Hours of supply	6–10 h/day	Varies by area

Source: Jal Kal Vibhag, Prayagraj; percentages computed by the authors.

The twelve water supply zones differ sharply in their dependence on source (Table 2). Only three zones (Lukerganj, Khushroobagh, Atala) rely on surface water, two (Civil Lines, Kydganj) use both sources, and seven zones (58% of the total)

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depend entirely on tube wells. The system is therefore structurally tied to the aquifer even though the city sits beside two perennial rivers. An earlier Jal Sansthan estimate put supply at 220 MLD with 36.4% from river water and 63.6% from groundwater. The two sources are not strictly comparable, but the contrast hints at growing groundwater dependence.

Table 2. Water supply zones of Prayagraj by source

Source	Zones	No. of zones
Surface water	Lukerganj, Khushroobagh, Atala	3
Surface water and groundwater	Civil Lines, Kydganj	2
Tube wells (groundwater)	Colonelganj, Daraganj, Rasoolbad, Sulem Sarai, Naini, Phaphamau, Jhunsi	7

Source: Jal Kal Vibhag, Prayagraj.

Surface treatment capacity is under-used. With 70 MLD drawn from the Yamuna, the Khushrobagh plant operates at roughly half of its 135 MLD capacity (70/135 = 52%), leaving about 65 MLD idle. That idle capacity equals about 27% of present tube-well abstraction (238 MLD). If raw-water intake and river availability permit, using it would ease pressure on the aquifer.

4.2 Per capita supply and its limits

The reported supply of 253 lpcd is 1.7 to 1.9 times the 135–150 lpcd norm usually applied to urban areas, which might suggest comfortable availability. Dividing 308 MLD by 253 lpcd gives about 1.22 million people, which corresponds closely to the 2011 urban agglomeration population (1.21 million). The headline figure thus appears to rest on 2011 population rather than the present one. Against the projected 2021 population of 1.64 million, gross supply falls to about 188 lpcd, about 26% lower. If the loss of about 40% reported in a JNNURM pilot study still applies, net delivery would be around 185 MLD, or about 113 lpcd, below the norm. This last figure is illustrative, since it combines data from different years, but it shows how sensitive the apparent surplus is to its denominator and to network losses.

Averages also hide inequality. In slum areas, where direct household connections are lacking, supply relies on 1,273 public taps, 2,383 hand pumps and 207 tube wells, supplemented by 22 municipal water tankers. In parts of the old city, residents install booster pumps to draw water from the network. This shifts shortages to downstream users and can draw wastewater into the pipes where there are leaks, creating a contamination risk.

4.3 Storage capacity

The system has 18 storage reservoirs with a combined capacity of 22.5 MLD (Table 3). Three underground tanks (Mayo Hall, Daraganj, Bhardwaj) hold 5.85 MLD (26%), and 15 overhead tanks (OHT) hold 16.65 MLD (74%). The largest single facility is Mayo Hall (2.70 MLD, 12% of the total); Allapur and Kalindipuram hold 2.0 MLD each, while several tanks, such as Kareli-2 (0.40 MLD) and Rasulabad (0.45 MLD), are very small.

Table 3. Water storage reservoirs in Prayagraj

Location	Capacity (MLD)	Type
Mayo Hall	2.70	Underground
Daraganj	1.80	Underground
Bhardwaj	1.35	Underground
Govindpur	1.25	OHT
Rasulabad	0.45	OHT
Rajapur	1.35	OHT
Allapur	2.00	OHT
Bai ka Bagh	0.85	OHT
Naini	1.50	OHT
Kareli-1	0.80	OHT
Kareli-2	0.40	OHT
Rajrooppur	1.00	OHT
Transport Nagar	0.65	OHT
Sulem Sarai	0.75	OHT
Preetam Sarai	1.50	OHT

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Phaphamau	0.65	OHT
Avantika Colony (ADA), Naini	1.50	OHT
Kalindipuram	2.00	OHT
Total	**22.50**	**3 underground, 15 OHT**

Source: Jal Kal Vibhag, Prayagraj. OHT = overhead tank.

Against a daily supply of 308 MLD, total storage equals 7.3% of daily supply, or about 1.75 hours. Planning guidance in the CPHEEO manual commonly puts balancing storage at about one-third of the daily requirement, which would be about 103 MLD for the present supply; existing storage is therefore only about 22% of that benchmark. The shortfall matters because supply runs for only 6–10 hours a day, so storage is the buffer between intermittent pumping and continuous household demand. Its absence helps explain why residents resort to booster pumps and household storage.

4.4 Treatment, distribution and losses

Parts of the distribution network are more than a century old, with pipes laid as early as 1890, including a 500 mm main. The network is reported at 1,118.87 km in 2007 and 1,122 km in the latest records. If both figures are reliable, it has grown by only about 3 km while population and demand have risen substantially. Jal Sansthan reports shortages of maintenance and repair staff, illegal connections, unmaintained taps, poorly sited tube wells and low pressure in many areas. A JNNURM pilot found that about 40% of supplied water is lost within the system, and a significant share of production is non-revenue water, which also weakens the utility's finances. Summer shortfalls arise from groundwater depletion, lower river levels and electricity disruptions.

4.5 Zonal disparities in public wells

Beyond the piped system, the Jal Kal inventory records 184 public wells across eight zones, of which only 70 (38.0%) are operational and 114 (62.0%) are closed (Table 4; Figures 1 and 2). The distribution is highly uneven. Zone 2 has the highest functionality (87.5%) and holds 30% of all operational wells, while Zone 4 has none. Zones 1 and 3 have only 2 and 4 operational wells (6.7% and 12.5%). Zones 5 to 8 occupy an intermediate band, with 50–58% of wells in use. Zones 2 and 5 together contain 39 of the 70 operational wells (55.7%).

Table 4. Zone-wise status of public wells in Prayagraj

Zone	Operational	Closed	Total	Functionality (%)	Share of operational (%)	Share of closed (%)
Zone 1	2	28	30	6.7	2.9	24.6
Zone 2	21	3	24	87.5	30.0	2.6
Zone 3	4	28	32	12.5	5.7	24.6
Zone 4	0	19	19	0.0	0.0	16.7
Zone 5	18	15	33	54.5	25.7	13.2
Zone 6	11	9	20	55.0	15.7	7.9
Zone 7	7	7	14	50.0	10.0	6.1
Zone 8	7	5	12	58.3	10.0	4.4
City	**70**	**114**	**184**	**38.0**	**100.0**	**100.0**

Source: Jal Kal Vibhag, Prayagraj; derived indicators computed by the authors.

The concentration of closure is striking. Zones 1, 3 and 4 account for 81 wells (44% of the inventory) but only 6 operational wells (8.6% of the operational total), while holding 75 closed wells, or 65.8% of all closures. The association between zone and well status is strong ($\chi^2 = 67.16$, df = 7, $p < 0.001$; Cramér's V = 0.60), although the caveats in Section 3 apply.

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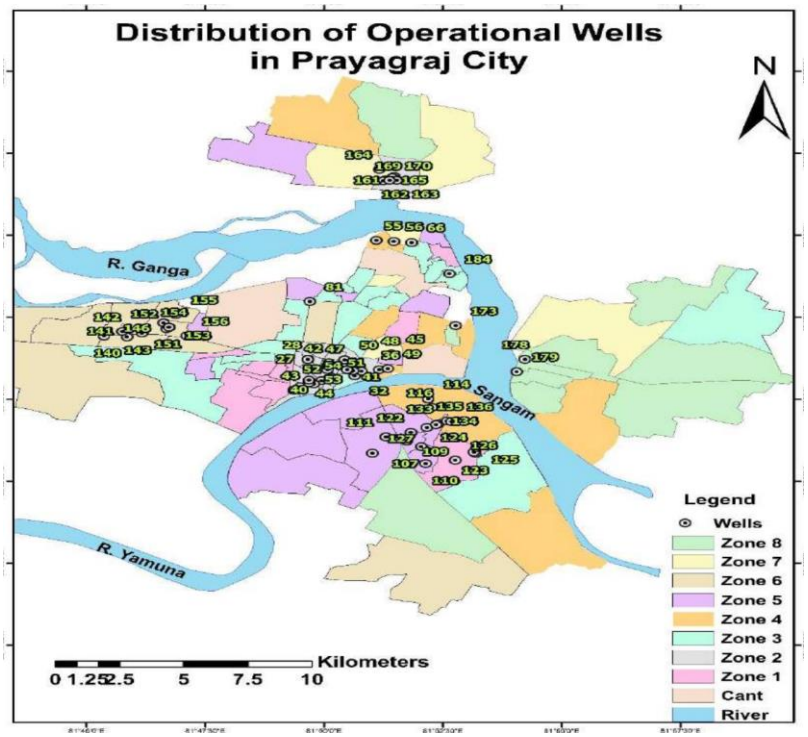

Figure 1. Operational well locations in Prayagraj city, shown over the zonal boundaries. Source: prepared by the authors from Jal Kal Vibhag, Prayagraj records.

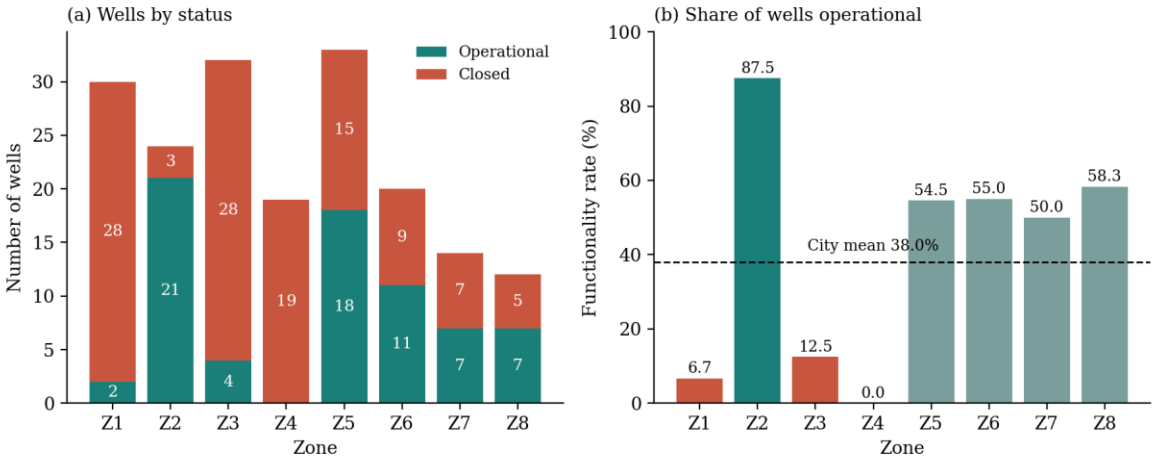

Figure 2. Zone-wise status of public wells: (a) number of operational and closed wells; (b) functionality rate, with the city mean of 38.0% shown as a dashed line. Source: computed from Jal Kal Vibhag data.

Ward-level remarks suggest why wells are closed, and the reasons differ by zone. In Zone 3 many wells await cleaning or maintenance. In Zone 4 all 19 wells are covered with iron gratings, so they are protected but not in use. Closures in Zone 5 are attributed mainly to disuse, security concerns and damaged walls, with Chakmarti (six closed against five open wells) and Chakdehi (four closed, one open) the clearest hotspots. In Zone 7 swampy ground and accumulated debris block access to some wells, and in Zone 8 debris and dirt affect both closed and open wells. Two readings of this pattern are possible: wells may have been abandoned as piped and tube-well supply replaced them, or they may have been lost through neglect. The recorded remarks, which refer repeatedly to cleaning, debris and damaged structures, point to maintenance neglect as a substantial factor, though the data cannot separate the two explanations.

The spatial pattern is also cultural. Many wells lie within or beside temples, mosques and ashrams, for instance near Hanuman Mandir, Harihar Nath Mandir, Lalita Devi Mandir, Shah Ghulam Ali Masjid and Tellyarganj Masjid. In Zone 2, which covers the high-density old-city wards of Muthiganj, Bahadurganj and Malviya Nagar, most functioning wells stand near such sites. Community custodianship probably helps keep these wells in use, whereas wells in Zones 5, 7 and 8 that remain in use are often at residential premises. Muthiganj and Bahadurganj are also among the high-density localities, along with Kydganj, Ranimandi and Rambagh, where water demand is highest, which suggests that functioning wells persist where dependence on them is strongest.

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4.6 Projected demand and the emerging gap

The City Development Plan projects the city's population to rise from 16.4 lakh in 2021 to 20.1 lakh in 2031 and 24.2 lakh in 2041, with water demand rising from 284 to 347 and 418 MLD (Table 5). The ratio of demand to population is almost constant at about 173 lpcd, so demand grows almost exactly in line with population (47% between 2021 and 2041).

Table 5. Projected population, water demand and balance against present supply (308 MLD)

Year	Projected population (lakh)	Demand (MLD)	Balance (MLD)	Balance (% of demand)
2021	16.4	284	+24	+8.5
2031	20.1	347	−39	−11.2
2041	24.2	418	−110	−26.3

Source: City Development Plan (demand and population); balance computed by the authors.

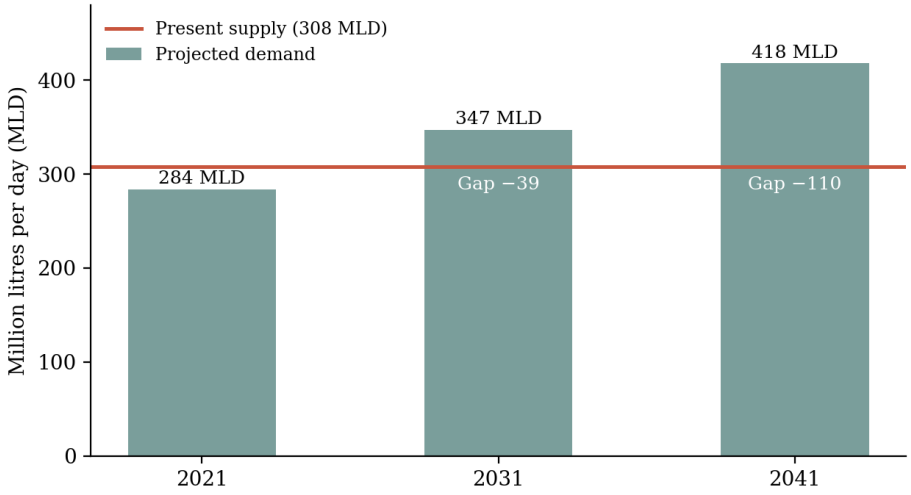

Figure 3. Projected water demand compared with present supply of 308 MLD.

Present supply exceeds the 2021 projection by 24 MLD, but it would fall short by 39 MLD in 2031 and 110 MLD in 2041. Closing the 2041 gap would require raising supply by about 36%. The idle capacity of the Khushrobagh plant (about 65 MLD) could in principle cover roughly 60% of that gap, though only if intake works and Yamuna flows allow. These figures are gross, so losses of the order of 40% would widen the effective shortfall. The projections also assume a fixed per capita requirement, whereas changing climate and unpredictable rainfall could reduce availability.

5. Policy Implications

The evidence points to a system that is adequate in volume on paper but fragile in storage, distribution and upkeep. The following priorities follow from the analysis.

1. **Rehabilitate wells where closure is concentrated.** Zones 1, 3 and 4 hold 75 of the 114 closed wells. Those closed for cleaning, debris or access problems can be restored at modest cost. Water quality should be tested before reuse, and revived wells can serve emergency, non-potable and recharge purposes.
2. **Expand storage.** Storage of 22.5 MLD is a small fraction of daily supply. Capacity should be added in stages, beginning with zones that depend entirely on tube wells.
3. **Raise the surface-water share.** Using more of the 135 MLD Khushrobagh capacity, subject to river availability, would reduce pressure on the aquifer and help meet projected demand.
4. **Reduce losses and illegal use.** Replacing century-old pipelines, metering connections, curbing illegal tapping and fixing faulty taps would recover water without new sources.
5. **Improve equity.** Slum households relying on public taps, hand pumps and tankers need piped connections or additional stand posts, and booster-pump use in the old city should be managed.
6. **Strengthen data.** A dated, GIS-based well inventory that records status and reason for closure, and per capita figures based on current population, would make future planning more reliable.

6. Limitations

The analysis relies on secondary records from a single point in time, and well status was not verified in the field. Some

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figures differ between sources and years (for example 220 versus 308 MLD of supply, and 15.15 versus 16.65 MLD of overhead storage); the most recent and internally consistent data were used. Zone totals follow the summary well inventory, and ward-level narrative records differ from it by a few wells in some zones, so the inventory should be reconciled with the department's register. Data on well depth, yield and water levels were not available, and the demand projections were taken from the City Development Plan without independent validation. The statistical test is indicative only.

7. Conclusion

Prayagraj has a large and apparently generous water supply, but this study shows that its strength is overstated by aggregate indicators. About 77% of supply comes from groundwater even though two major rivers flank the city, the surface-water treatment plant is used at about half its capacity, and storage covers only about 1.75 hours of supply. Public wells show sharp zonal contrasts: 38% are operational overall, ranging from 87.5% in Zone 2 to none in Zone 4, and three zones hold two-thirds of all closed wells. Projected demand will outstrip present supply by 2031, and by 110 MLD in 2041. Meeting this challenge will depend less on finding new sources than on rehabilitating existing wells, expanding storage, using treatment capacity fully, reducing losses and extending reliable service to underserved areas.

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