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Geospatial Approach to Water Supply Asset Management: Evidence from Damak Municipality, Nepal

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Abstract

This study evaluates the Damak Water Supply System using a GIS-based asset management approach to map and analyze key water supply infrastructure. Field surveys, institutional data, and spatial mapping identified 16 borewells, 20 treatment plants, 3 overhead tanks, 16 pump stations, 172 valves, and 392 km of pipelines, serving 13,075 households over 19.73 sq. km. GIS analysis revealed uneven service distribution, with full coverage in Wards 1, 5, 6, 7, and 8, and limited access in Wards 3 and 10. Findings highlight the need for targeted upgrades and demonstrate GIS as an essential tool for efficient, equitable water supply management.

Keyword: Urban water supply, GIS base data, community base water, management, water supply

Introduction

Water resources management refers to the coordinated strategies used to develop, distribute, and sustain water resources for human needs and ecosystem health (UN-WWAP, 2020). It encompasses planning, conservation, infrastructure operation, and policies that ensure water availability, quality, and resilience under changing environmental and socioeconomic conditions. As pressures from urbanization, population growth, and climate change increase, achieving efficient and equitable management of water systems has become a global priority (WWF, 2021). A core objective of modern water management is balancing supply and demand, maintaining safe drinking water quality, and addressing risks such as floods, droughts, and contamination (GWP, 2019). Geospatial technologies play a crucial role in this process by enabling real-time data collection, mapping, and analysis of water supply assets, including pipelines, reservoirs, and treatment facilities (Sharma et al., 2023). These tools support evidence-based decision-making and improve operational efficiency. Contemporary water supply management also focuses on identifying distribution network characteristics, forecasting future water demand, and implementing robust water security and safety measures (ADB, 2022). The advent of the Internet of Things (IoT) has revolutionized monitoring, allowing utilities to detect leaks, track pressure variations, and remotely manage system performance (Mukherjee et al., 2020). Asset management approaches further enhance long-term planning by assessing infrastructure condition, service life, and investment needs (World Bank, 2018). Sustainability and resilience form essential pillars of water resource management. A resilient water system must withstand climate extremes while ensuring uninterrupted service. Integrating geospatial analysis, digital monitoring systems, and adaptive governance is increasingly recognized as necessary to build climate-smart, efficient, and equitable water supply systems (UNICEF & WHO, 2022). This chapter provides a foundation for understanding modern water management practices, highlighting technological, environmental, and strategic dimensions essential for future water security.

Access to safe water is a fundamental human necessity and a critical determinant of public health and well-being. As an essential resource for sustaining life, water plays a pivotal role in ensuring human survival and promoting good health. In rural communities, reliable access to safe water significantly contributes to overall socio-economic development by enhancing livelihoods, reducing disease burdens, and supporting education and economic productivity (Smith et al., 2009).

The history of ancient water supply systems can be traced to early civilizations, particularly the Greeks and Romans, who developed sophisticated technologies that laid the foundation for modern water engineering and management (Angelakis & Zheng, 2015). Earlier forms of water control, however, emerged during the Neolithic Age (ca. 5700–2800 BC), when humans began constructing small-scale irrigation structures to support agricultural activities (Mays, 2010). The agricultural revolution, which took place approximately 6000 to 7000 years ago in Mesopotamia and Egypt, marked a major advancement in water management, with prehistoric irrigation canals some still visible today supporting early settlements and crop cultivation (Hassan, 2011; Garbrecht, 2014. And Wikander (2000)

These systems played a key role in the development of early societies. Over time, especially during the Bronze Age, many urban hydraulic systems became outdated (Jansen, 1989). Nonetheless, evidence of ancient wells and rainwater channels from around 3000 BC shows the early development of domestic and agricultural water management systems (Jansen, 1989).

The development of piped water supply systems in Nepal began with the commissioning of the Bir Dhara system between 1891 and 1893, marking the country's first modern water distribution network (Shrestha, 2012). Constructed during the Rana regime, the system laid the foundation for formal urban water management and led to the establishment of the *Pani Goshowara Adda*, the earliest government office responsible for water supply operations (Pradhan, 2019). Although the system introduced private and community standpipes, services were limited to selected urban neighborhoods and political elites within Kathmandu Valley (ADB, 2010). Early water management practices remained centralized and engineering-oriented, with gradual expansion occurring only in the mid-20th century as population growth and urbanization increased water demand (Udmale et al., 2016). The Bir Dhara system is therefore recognized as the starting point of Nepal's modern water supply history, shaping institutional reforms and technological upgrades that followed (Dixit & Upadhya, 2005). All of these have different consequences for safe water management, equity, and long-term access to safe water for community members. (Regmi et al., 1999). In Nepal, modern governmental efforts to develop the drinking water supply sector are relatively recent, emerging mainly during the 20th century as urban demand increased (Udmale, Ishidaira, & Pandey, 2016). Previously, the Ministry of Water Resources was responsible for all drinking water supply through the Department of Irrigation and Water Supply, which was founded in 1966. (Nepal IRC, 1988).

Nepal has made notable progress in the drinking water sector over recent decades; however, the impacts of climate change on drinking water systems remain poorly documented and insufficiently understood. Recent reviews indicate that while climate change effects on water resources are increasingly evident, limited policy attention has been given to climate-resilient WASH planning (Thapa et al., 2023). Analysis of secondary data from both published and gray literature shows that although several national policies acknowledge climate risks, integration of climate adaptation into the drinking water and sanitation sector is still weak. Therefore, urgent action-oriented research and eco-region-specific interventions are required to safeguard water services from climate-induced hazards and ensure long-term resilience (Thapa et al., 2023). Despite various laws addressing climate issues, integration with the WASH sector is limited. Urgent action-based research and eco-region-specific interventions are needed to adapt to and mitigate climate change impacts on water services. (Sharma et al., 2021).

Shakya et al. (2022) note that decentralized tap water systems serve as a primary source of drinking water worldwide. Although the preferred model is a continuous water supply (CWS) with adequate pressure and safe water quality, many urban regions—particularly in water-scarce and low-income countries still rely on intermittent water supply (IWS), which frequently leads to degraded water quality. A recent study examined tap water quality in intermittent water supply (IWS) systems in Kathmandu Valley, Nepal, by using nitrate-nitrogen (NO_3-N) as a contamination indicator and stable hydrogen isotopes (δD) as a source tracer (Shakya et al., 2022). Water samples were collected from nine reservoirs and ninety household taps during both the wet (June–September) and dry (November–February) seasons. Results showed that 10% of tap samples contained higher NO_3-N levels than their corresponding reservoirs during the wet season, increasing to 16% in the dry season. Likewise, δD enrichment was observed in 3% of samples in the wet season and 23% in the dry season. The combined NO_3-N and δD analysis indicates notable groundwater intrusion into the distribution system, identifying it as a major contributor to tap water quality deterioration under IWS conditions. According to the Udmale et al. (2016), are define to the United Nations Sustainable Development Goal 6 aims to ensure access to water and sanitation for all by 2030. Achieving this target is particularly challenging for developing countries like Nepal due to inadequate infrastructure and rapid population growth. To evaluate the water crisis in Nepal's most urbanized and densely populated region the Kathmandu Valley this study estimated both water availability and domestic demand. In 2016, even after the first phase of the Melamchi Water Supply Project (MWSP), a supply deficit of 102 million liters per day (MLD) remained. However, if the MWSP is fully completed on time and supported by adequate water treatment and distribution systems, the deficit is projected to be eliminated by 2023–2025. This highlights the potential of the MWSP to significantly enhance water security in the valley. Nonetheless, realizing this potential depends not only on completing the project but also on maximizing the use of available water through robust infrastructure. In addition, integrated strategies are essential—such as land use planning to support groundwater recharge, adopting rainwater harvesting at various scales, promoting conjunctive use of surface and groundwater, and implementing effective water demand management. These approaches can ensure long-term water sustainability in the Kathmandu Valley.

The sustainability of water supply services remains a critical global priority. Ensuring affordable, equitable, and long-term access requires effective financial strategies, particularly in rapidly urbanizing regions. In this context, a recent study proposes a pricing optimization method for piped water services in Kathmandu Valley, Nepal, designed to enhance cost recovery while maintaining fairness and service sustainability (Shrestha et al., 2023, Ojha et al. 2018)

The Melamchi Water Supply Project (MWSP) has recently begun supplying water to Kathmandu Valley with the objective of reducing chronic water scarcity. Using survey data from 1,500 households, researchers analyzed domestic water use and associated expenditures to model post-MWSP scenarios based on per capita consumption and pricing structures. Affordability was evaluated using the expenditure ratio (ER), which measures the proportion of household spending allocated to water, while sustainability was assessed through the working ratio (WR), defined as operating costs relative to utility revenue. Results indicate that a 54% increase in water tariffs is necessary to achieve a sustainable WR of 0.7. The study also suggests that a 30% increase in water consumption (minimum 80 LPCD) is achievable after MWSP implementation; however, consumption exceeding 135 LPCD may become unaffordable for low-income households and place additional pressure on groundwater resources (Pattanayak et al., 2021).

Objectives

The main objective of this study:

- Balance water supply and demand, improve water quality and manage risks such as floods and droughts. This includes the collection and analysis of geographically relevant data for water resources.
- Collect and analyze data related to the system's water-based assets.
- Identify the Water Distribution Network, Water Demand Forecasting, Water Security and Safety Management, Internet od Things (IOT) – based Asset Management for ensuring sustainability and resilience in water supply systems.

Methods and Materials

Damak is one of the oldest municipalities in Jhapa District, located in Koshi Province, Nepal. Geographically, it lies between the Ratuwa River to the east and the Mawa River to the west, with the Siwalik Hills forming its northern boundary and the confluence of the Ratuwa and Mawa rivers defining its southern limit. The Mahendra Highway the longest highway in Nepal passes through the city, nearly dividing it into two parts.

Damak is the largest urban center in Jhapa District, extending from 26°35'22" N to 26°45'00" N latitude and 87°38'17" E to 87°43'00" E longitude.

The existing water supply system currently serves Wards 1 to 9, covering an area between 26°37'58" N to 26°41'44" N latitude and 87°40'88" E to 87°43'00" E longitude. The system provides water services to a total population of 13,334. (fig 1).

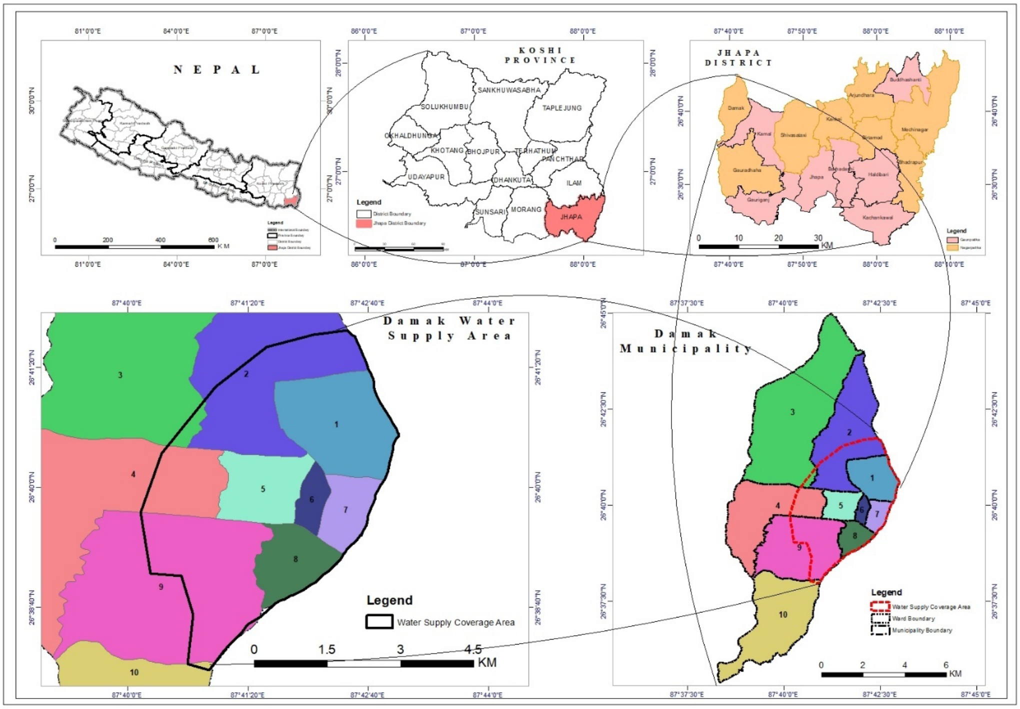
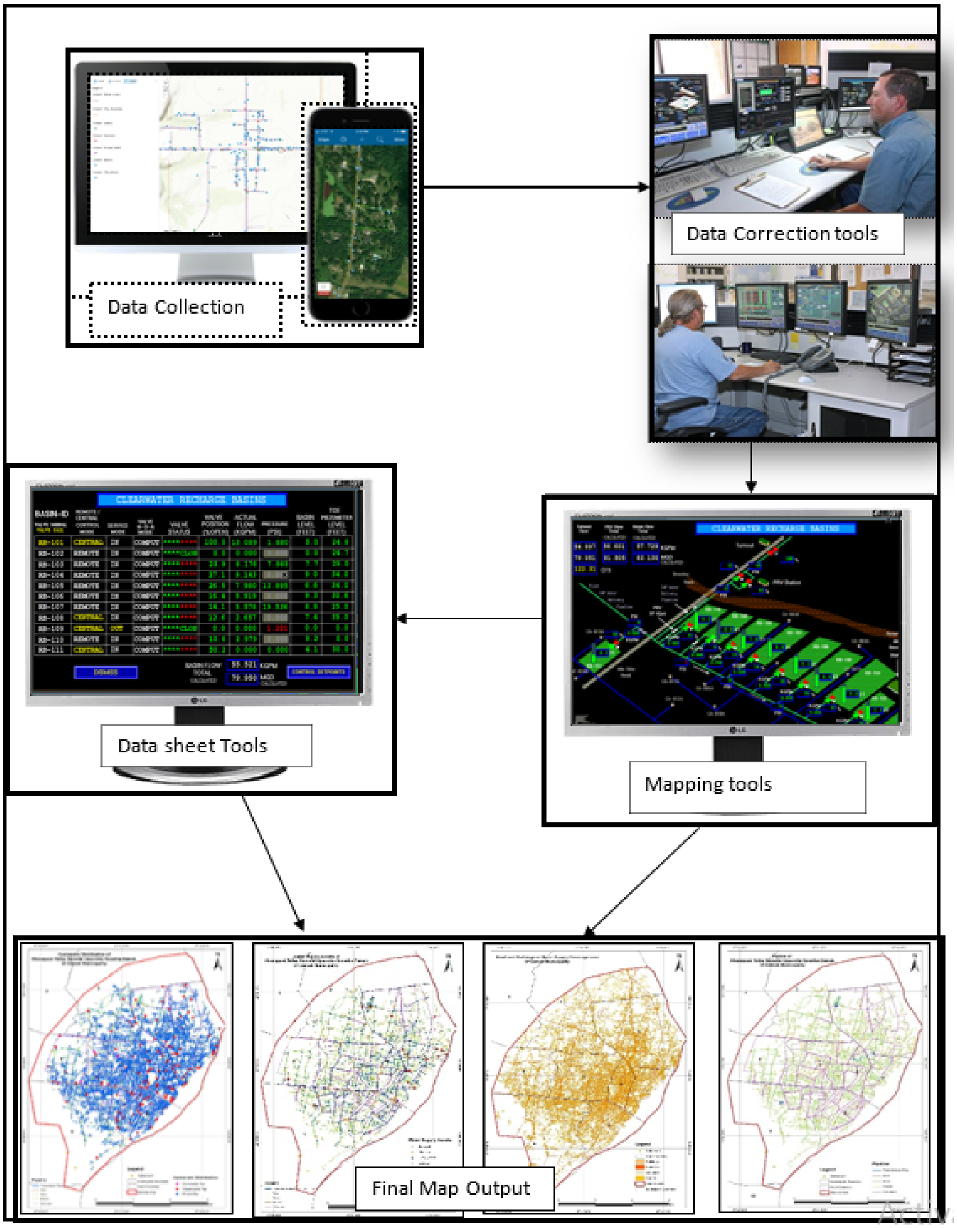


Figure 1. *Location Map of Damak Water Supply System*

This study is based on primary data collection as well as quantitative methods complemented by rigorous secondary data analysis and with limited field-based observation. The objective was to develop real-time household data collection on mobile applications and to manage the information by web GIS and desktop GIS platforms. A GIS survey was conducted on the households, with the detailed survey of water supply assets within the water supply coverage area. The functionality of water supply systems was assessed through structured questionnaires administered via a mobile application, complemented by direct field observations. Other necessary data were collected through literature reviews and key informant interviews. The literature review included government documents and published studies. The primary focus of the study was consumers served by *Khanepani Tatha Sarsafai Upavokta Sanstha* in Damak. Field visits were conducted to gain a deeper understanding of the actual conditions of the water supply system. Informal discussions with local elders and water users provided firsthand insights into the status and usage patterns of specific water points. Field observations enabled the researcher to evaluate construction standards, condition of the contributing watersheds, types of water points, and level of protection provided. Additional factors - such as waiting time for water collection and the distance between households and water points were observed, although not analyzed in detail. (fig 2).



Results and Discussion

Results

Balancing water supply and demand, improving water quality, and managing risks such as floods and droughts are essential components of effective water resource management. Modern approaches increasingly rely on the collection and analysis of geospatial data to support real-time monitoring of water supply assets, enabling timely decision-making and improved system performance (UN-WWAP, 2020; Sharma et al., 2023).

Damak Municipality, situated in southeastern Nepal, encompasses a total area of 70.84 square kilometers and has a population of 107,227, based on recent demographic data (CBS 2021). The gender distribution indicates a higher number of females (56,408) compared to males (50,819). The municipality is divided into ten administrative wards, each varying in area and population density. Ward 3 represents the largest geographical area (20.6 sq. km or 14.59% of the total area), accommodating a population of 11,037. Conversely, Ward 5, despite covering only 2.05 sq. km (1.45% of the total area), has the highest population count of 15,171, suggesting a high population density. Ward 1, Ward 2, and Ward 9 also show significant population figures, with 13,738, 11,632, and 13,996 residents, respectively. Ward 10 has the lowest population (5,874) despite its relatively larger area (10.61 sq. km), indicating a lower population density.

According to the field base data collection and the population situation of the Damak Municipality the water supply has not distributed for their all citizen. These data are critical for planning and implementing municipal services, including water supply systems, infrastructure development, and equitable resource distribution. Understanding population distribution patterns ensures that services are targeted effectively and address the needs of both densely and sparsely populated wards.

Table 1. *Population and water supply distribution of Damak municipality*

Ward	Household	Total pop.	Water users pop.	Area (Sq. Km)	Percentage of area	Percentage of Water Users
1	3669	13738	1308	3.68	5.19	16.91
2	2880	11632	7018	11.09	15.65	8.92
3	2687	11037	2209	20.6	29.08	0.00
4	2900	11297	4182	9.54	13.47	5.31
5	4084	15171	18204	2.05	2.89	23.13
6	1645	6378	8342	0.62	0.88	10.60

7	1801	7387	6771	1.23	1.74	8.60
8	2812	10717	10458	1.72	2.43	13.29
9	3657	13996	10415	9.7	13.69	13.23
10	1434	5874	0	10.61	14.98	0
Total	27569	107227	78700	70.84	100	100

Source: CBS 2021/ Field survey, 2024

The ward-wise analysis of population distribution and water supply coverage reveals significant spatial disparities across the municipality. Although the area hosts a total population of 107,227, only 78,700 people are currently served by the water supply system, indicating an overall coverage of about 73%. Wards 5, 6, 8, and 9 account for the highest proportion of water users, highlighting concentrated service availability in central and densely populated zones. In contrast, Wards 3 and 10 together representing nearly 45% of the municipality's total area have no water users, underscoring substantial gaps in infrastructure expansion toward peripheral or semi-urban regions. Moderately covered wards such as 1, 2, 4, and 7 show partial access, suggesting limitations in network density and household-level connectivity. Overall, the uneven distribution of water services points to the need for strategic infrastructure planning, prioritizing underserved large-area wards while ensuring pressure management and system upgrades in highly served localities for sustainable water supply management. This distribution indicates areas that may require future extension and investment to ensure equitable access to safe drinking water across the municipality. This distribution highlights both the reach and limitations of the existing water infrastructure within the municipality. An assessment of the water distribution network in Damak Municipality reveals significant variation in the number of households tap connections across its ten wards. A total of 13,075 tap connections are distributed throughout the municipality. Ward No. 5 records the highest proportion of connections, comprising 21.74% (2,842 taps) of the total. This is followed by Ward No. 1 with 19.63% (2,566 taps), and Ward No. 8 with 15.36% (2,008 taps). Other notable contributions include Ward No. 9 with 13.56% (1,773 taps), Ward No. 7 with 9.82% (1,284 taps), and Ward No. 6 with 8.70% (1,138 taps). Wards No. 2 and 4 have moderate coverage, representing 7.20% (941 taps) and 3.98% (520 taps), respectively. However, Ward No. 3 has only 3 tap connections (0.02%), indicating minimal coverage. Ward No. 10 lacks any registered tap connections.

Table 2. *Tap distribution of Damak Khanepani*

Ward	Tap	Tap Percentage
1	2566	19.63
2	941	7.20
3	3	0.02
4	520	3.98
5	2842	21.74
6	1138	8.70
7	1284	9.82
8	2008	15.36
9	1773	13.56
10	0	0
Total	13075.00	100

Source: Field survey, 2024

This distribution underscores spatial disparities in water access within Damak Water Supply System, suggesting the need for targeted infrastructure development in under-served areas to promote equitable water supply coverage.

The Damak Water Supply System comprises an extensive network of pipelines categorized into various sub-types based on their function and diameter. The total length of the pipeline infrastructure amounts to 392,089.20 meters, which is critical for efficient water transmission and distribution across the municipality. The transmission pipeline, responsible for transporting water from the source to the main storage or treatment facilities, covers a total length of 2,362.36 meters. The main pipelines, serving as the primary distribution conduits from the treatment plant to various zones, span 2,604.02 meters. Subsequently, the sub-main pipelines, which branch off from the main lines to reach broader areas, measure 93,456.60 meters. The minor pipelines, typically servicing neighborhood-level distribution, extend 164,387.35 meters, forming the largest segment of the network. Lastly, branch pipelines which connect directly to household tap points account for 129,278.87 meters. This hierarchical pipeline system supports the delivery of potable water and reflects the infrastructural capacity and complexity necessary to serve the growing demand within Damak Municipality.

Table 3. *Pipeline distribution of Damak Khanepani*

S N	Sub type distribution	Length (M.)
1	Transmission Pipe	2362.36
2	Main	2604.02
3	Sub-main	93456.60
4	Minor	164387.35
5	Branch	129278.87
6	Total	392089.20

Source: Field survey, 2024

The distribution of water taps in Damak Khanepani varies across all wards except Ward No. 10. Ward No. 3 has the lowest number of tap users with only 3 households while Ward No. 5 has the highest number, with 2,842 households. Damak Khanepani supplies water to the urban areas.

There is also uneven distribution of tap types within the service area. For instance, there are only 3 community-based taps, mostly located at temples or community centers where no tariff is collected. Most of the taps in the study area are 'organizational' distributed in schools, governments and clubs. The number of such taps distributed under Damak Water Supply System is 161 in total. On the contrary, there are 12,911 private taps with tariff collection, which have been the major source of income in the study area.

Table 4. *Tap type of Damak Khanepani*

Tap Type	Number	Percentage
Community Tap	3	0.02
Organization Tap	161	1.23
Private Tap	12911	98.75
Grand Total	13075	100

Source: Field survey, 2024

Tap type of Damak Khanepani

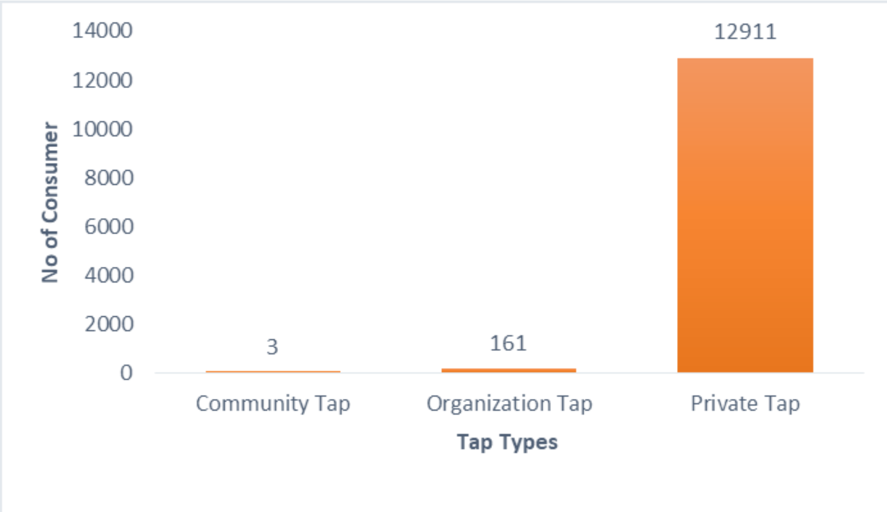


Table 5. *Water availability condition*

S N	Water Availability	Number	Percentage
1	Just sufficient for drinking	2	0.02
2	Sufficient for all daily needs	12988	99.33
3	Sufficient for drinking and cooking and washing	40	0.31
4	No water at all	23	0.18
5	No response	22	0.17
6	Grand Total	13075	100

Source: Field survey, 2024

A total of 13,075 households were surveyed to assess water availability. The majority of households (99.33%, or 12,988 households) reported having water that is sufficient for all daily needs. A small portion (0.31%, or 40 households) indicated that water is sufficient for essential uses such as drinking, cooking, and washing. Only 0.02% (2 households) reported having just enough water for drinking purposes. On the other hand, 0.18% (23 households) reported no water availability at all, and 0.17% (22 households) had no response regarding their water availability status.

Table 6. *Water quality condition*

S N	Water Quality	Number	Percentage
1	always turbid water	13	0.10
2	Turbid water during rainy season	19	0.15
3	No Turbidity	12989	99.34
4	No Data	54	0.41
5	Grand Total	13075	100.00

Source: Field survey, 2024

Out of total of 13,075 households surveyed, 99.34% (12,989 households) reported receiving clear water with no turbidity. However, 0.15% (19 households) experienced turbid water during the rainy season, and 0.10% (13 households) reported that the water is consistently turbid regardless of the season. However, 0.41% (54 households) did not provide any information regarding water quality. These findings suggest that although water clarity is generally maintained across the distribution system, seasonal turbidity issues still affect a small fraction of users, which may warrant further investigation and preventive measures to ensure water safety year-round.

Asset inventory of Damak water supply system

A comprehensive survey of the Damak Water Supply System revealed a diverse range of physical infrastructure assets critical to the operation and management of the municipal water network. The system comprises both point and linear features that ensure the sourcing, treatment, and distribution of potable water across the service area. The asset inventory includes 16 borewells, which serve as primary water sources, and 20 treatment plants for water purification. The distribution network is supported by 3 overhead tanks (OHTs), 16 pump stations, 18 water flow meters, and 172 valves, enabling efficient control and monitoring of water flow. Additionally, 2 fire hydrants and 3 community taps are installed to serve public needs. The infrastructure network comprises approximately 2,360 meters of transmission pipelines and 260,364 meters of distribution pipelines. A total of 13,075 household tap connections and 80 chambers have been established. The system also features 1,437 junctions, 13 structure polygons, and 16 reducers. This inventory provides a foundational understanding of the physical assets deployed, which is essential for future planning, maintenance, and service expansion of the water supply system in Damak Municipality.

Table 7. *Assets collection details*

S. N.	Assets Name	Measures Unit	Quantity
1	Borewell/Water Source	Number	16
2	Chamber	Number	80
3	Junction	Number	1437
4	OHT	Number	3
5	Pump Station	Number	16
6	Valve	Number	172
7	Fire Hydrant	Number	2
8	Treatment Plant	Number	20
9	Water Flow Meter	Number	18
10	Tap/Yard	Number	13075
11	Community Tap	Number	3
12	Transmission Pipe	Meter	2360
13	Distribution Pipe	Meter	260364
14	Structure Polygon	Number	13
15	Reducer	Number	16

Source: Field survey, 2024

Discussions

The use of Geographic Information Systems (GIS) to manage Damak's water delivery infrastructure has produced valuable insights into asset allocation, service coverage, and geographical inequities in access. This study found that GIS is an effective tool for methodically documenting, evaluating, and visualizing infrastructure components such borewells, treatment facilities, transmission and distribution pipes, reservoirs, and consumer connections. The investigation indicated that only 13,075 tap connections were built out of a total population of 107,227, suggesting gaps in water accessibility and emphasizing the need for more infrastructure growth. Wards 1, 5, 6, 7, and 8 have strong service coverage, however Wards 3, 4, and particularly Ward 10 have low or no coverage, highlighting the need for targeted infrastructure investments.

Furthermore, the entire length of pipeline infrastructure—which includes about 2.36 km of transmission mains, 260.36 km of distribution pipes, and 129.28 km of branch lines—demonstrates the enormous physical network that requires frequent monitoring and repair. The integration of asset information, such as valves, pump stations, meters, and community taps, establishes a foundation for lifecycle planning and future investment prioritization. Water quality and availability evaluations also revealed localized difficulties, such as turbidity during the monsoon season and insufficient pressure in certain places. These findings highlight the need of integrating hydrological data with infrastructure mapping in order to improve water delivery dependability and safety.

This study underlines the use of spatial data in decision-making for water supply system modifications, equitable service delivery, and long-term viability. Implementing such methods at the municipal level has the potential to dramatically improve the effectiveness, transparency, and sustainability of water supply management in Nepalese urban areas. Regular asset inventory updates, combined with community feedback and hydrological evaluations, are critical for improving water governance in the Damak Municipality's water supply system.

Conclusion

The results show that, while the Damak water supply system serves a substantial portion of the municipality's population, service distribution remains highly uneven across wards. Several central wards exhibit high levels of coverage, whereas large peripheral wards despite their significant land area and population receive little to no water service, reflecting major disparities in infrastructure reach and service accessibility. This study provides a thorough overview of present infrastructure and its spatial distribution by methodically mapping and analyzing important components such as borewells, reservoirs, pipelines, pumps, valves, and consumer connections. Some heavily inhabited neighborhoods have a high tap connection density, whereas others, particularly Wards 3 and 10, remain underserved. The GIS analysis enables the precise identification of such inequalities, providing crucial information for prioritizing infrastructure construction.In addition, the study underlines the importance of continual data maintenance, condition evaluation, and capacity growth in asset management. Integrating GIS into everyday water utility operations helps improve planning, transparency, maintenance scheduling, and long-term sustainability of water services. Overall, GIS-based asset management is an important tool for enhancing water service delivery and guaranteeing efficient, fair, and sustainable infrastructure development in such as Damak municipality. Future initiatives should concentrate on increasing coverage, including real-time monitoring, and synchronizing asset planning with demographic and environmental trends.

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