GIS-based assessment of drinking water distribution infrastructure of Bahawalpur

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Abstract

Infrastructure/asset management is the cornerstone of water supply service delivery. Thorough knowledge of the location, features, age, capacity and risk associated with asset is required to manage the assets for sustainable service delivery. The goal of the study was to generate baseline information to optimize water supply distribution network of Bahawalpur City. Current problem in the Bahawalpur city is that the water infrastructure is aging and is not adequate. Keeping in view the importance of infrastructure, the water supply system of the city has been assessed and improvement interventions has also been proposed. A key component of this process is Geographical information system (GIS) based mapping and geospatial analysis of assets. High resolution Quickbird imagery is used for mapping infrastructure including pipelines. The condition assessment of each individual asset has been done in order to prioritize their replacement. Each asset is categorized in 5 classes in terms of its condition. Condition of existing assets has been done using electrical instruments like pressure gauge, power analyser, flow meter, tachometer, IR gun and visual observation. Various steps has been taken during the process including identification and development of GIS based surveyed inventory along with attributes of Water Supply assets/infrastructure. Results showed that 176 km of water pipes are in poor condition out of total 264 km pipelines of the city. Similarly 42 tube wells (TWs), 2 ground storage tanks (GSTs) and 6 overhead reservoirs (OHRs) are in poor condition out of total 74 TW, 18 GSTs and 12 OHRs respectively. After the condition assessment three type of main interventions has been proposed for improvement of Bahawalpur water supply system which are; Replacement of poor water pipes, Rehabilitation of poor assets and construction of new assets. GIS is a technological breakthrough which helps in making informed decisions to improve water supply infrastructure for achieving service delivery targets.

Key words: condition assessment; water supply; GIS mapping; assets; infrastructure

1. Introduction

A huge amount of money is invested to all over the world to provide pipes water to the people. Even then, large number of population of the world is lacking adequate water supply system. Water transmission and distribution network costs approximately 80 to 85 percent of the cost of a total water supply system [7].

The community heath and its economic growth is extremely correlated with the condition of water supply distribution system. The aging and declining water supply infrastructure need to be considered for rehabilitation to provide reliable and safe water supplies [9]. For this purpose, various condition assessment methods has been used for water supply assets management. A preliminary component of this process is condition assessment of each individual asset in order to identify poor assets and prioritize their renewal or rehabilitation [1].

Bahawalpur's water supply is not fulfilling the required standards. There are about 20,667 households at present in current water supply network; of which only 5217 households have active water supply connections, excluding the cantonment. It is alarming that only 5 % of total population is in coverage of water supply. Hence, there is a need to fulfil this service delivery gap and to provide a sustainable plan for the water supply system.

2. Demographic Profile of Bahawalpur

According to census 2017 by Pakistan bureau of statistics (PBS) Bahawalpur City has population of 682 thousands with 48.8% of male and 51.2 % of female population. A summary of demographic profile is described in table 1.

Table 1: Demographic profile of Bahawalpur

Item	Value
No. of UCs	18
Total area of City	96 km^2
Total Population of City [5]	681,696
Population – Male	48.8%
Population – Female	51.2 %
Literacy rate (census 1998)	58.5%
Average household size	7.1
Growth rate [5]	3.14 %
Total Cantonment Area	6.56 km^2

2.1 Population Projection

The population is estimated for the year 2047. The growth rate was taken from District Census Report and population projection has been worked out as per the following formula:

Pn = Po (1+r) n

Where,

Pn = Projected population for required year

Po = Population of base year

r = Annual population growth rate

n = Number of years, counted from base year

Growth rate, in this case, is taken as 3.14%.

Peak Factor is taken by using the Harmon's Formulae:

Peak Factor = 1 +14/ (4 + (P) 1/2), Where, P is the contributing population in thousands.

Bahawalpur district population has doubled in the last 20 years. Population projections are tabulated below based on population of the city as per census 2017.

Table 2: Population projection of Bahawalpur

Population 2017	Growth Rate (1998-2017)	Future Population Estimates (000)		
		2027	2037	2047
681,696	3.14	879	1,134	1,463

2.2 Water Demand

Current (2017) and future water demand (2027, 2037 & 2047) has been calculated based on current and projected populations for Municipal Corporation. Water demands for existing future service areas are shown in Table 3 below, excluding the cantonment area.

Table 3: Water demand

	Water Demand (Gallons per Day)			
	2017	2027	2037	2047
Population (000)	681	879	1,134	1,463
Domestic (MGD)	22,496,001	29,022,329	37,442,015	48,304,341
Commercial (MGD)	3,374,400	4,353,349	5,616,302	7,245,651
Institutional (MGD)	2,249,600	2,902,233	3,744,202	4,830,434
Industrial (MGD)	2,249,600	2,902,233	3,744,202	4,830,434
Losses (MGD)	9,110,880	11,754,043	15,164,016	19,563,258
Total (Gallons/ Day)	**39,480,482**	**50,934,188**	**65,710,737**	**84,774,119**

Water supply network is designed on the water demand based on the projected population for at least 30 years. In the current study design period has been taken up to 2047 for the design of water supply system of Bahawalpur.

3. Situation Analysis of Water Supply system of Bahawalpur

Bahawalpur's water supply is not fulfilling the required standards. There are about 20,667 households at present in current water supply network; of which only 5217 households have active water supply connections, excluding the cantonment. It is alarming that only 5 % of total population is in coverage of water supply. Hence, there is a need to fulfil this service delivery gap and to provide a sustainable plan for the water supply system [3].

The piped water system in Bahawalpur is supplied by tube wells constructed at various locations in the city which pumps water into ground storage tanks (GSTs), overhead reservoirs (OHRs) or directly into the system. Valves have been installed on the network but MC's staff has not been using valves given the interconnectivity of the network and the production capacity of the system. Moreover, the valves installed have mostly been buried under the ground due to road construction and other construction activities, limiting the knowledge about their location. If one or two tube wells are dysfunctional, other tube wells in the vicinity feed the system thus catering for emergency needs [3, 6].

Approximately 18% of the area in the city receives water from the MC system while the remaining is served by private boring system inside the households. The limited number of users is due to idle water supply schemes in city. However, water quality is reported to be average, especially by consumers in the low-income areas of the city. The main complaints relate to odour and there is a perception that there is ingress of sewage into the water pipelines [6].

Most operational tube wells are rated at 0.5 cusecs. According to MC staff, water is supplied on average for 6 hrs. during daylight, allowing consumers to store water in their overhead tank during night hours. Within the Municipal limits, few households have installed their own tube wells to cater for gardening or excessive water use needs. Chlorination plants have been installed at almost all tube wells. Pumps have been maintained and where required necessary maintenance is done. Since the whole network is open and sufficient water is being produced, operational issues at one or two tube wells does not affect the overall water supply of a particular area [4].

Geographic Information Systems (GIS) and open source (OS) GIS is categorized as a powerful tool among all information technologies because it integrate multiple crosscutting environment for collaboration [2]. GIS enables that all the spatial and non-spatial data interconnected in the water supply network to be stored in a unique base. This enables the respective utility to manage and support in planning process. Applying GIS enable the management to provide services sin efficient way [10]. In the present study, GIS will be used to organize the data for usage in water distribution networks analysis. It will provide graphical display of results obtained from distribution network mapping, relating tabular data with geographic locations, and graphical drawing [10].

Water utilities employ GIS in particular for mapping of its infrastructure including pipelines, tube wells and other on ground infrastructure replacement or improvement planning [8].

As a case study, a geographic information system (GIS) was created and analysed the Bahawalpur Water supply network in Punjab using ARCGIS software. The city relied on outdated paper maps that has no spatial and attribute information of their infrastructure. Locations of all features found in the water system were collected using high resolution Quick bird imagery and field survey.

4. Methodology

Water utility assets are broadly categorized as above ground assets (that are tube wells, Overhead tanks, ground storage tanks etc.) and below ground assets (pipelines). The methods for mapping and condition assessment of the assets are described as flow chart (Fig. 1).

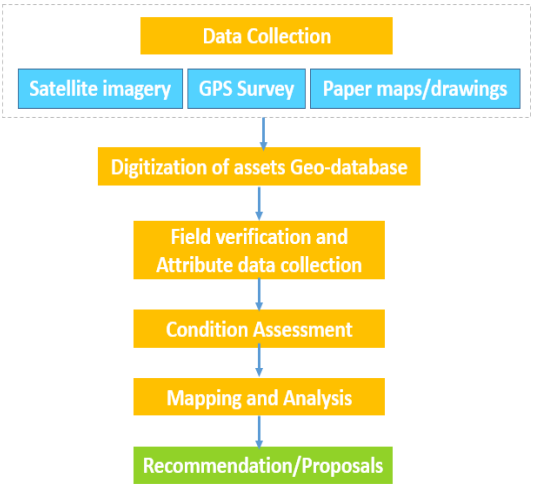

Fig. 1: Methodological workflow

4.1 Data Collection

Data was collected from various sources. Satellite imagery of Quickbird with resolution 0.6m was acquired from the Urban Unit, Government of Punjab, which was used as base map to digitize the water distribution network. GPS survey was conducted to map the locations of above ground assets and verification of water pipelines. Existing paper map and drawings were collected from the MC (Municipal Corporation) Bahawalpur.

4.2 Mapping and Condition assessment

Asset condition survey is conducted on the water supply assets of MC Bahawalpur. To measure the condition of an asset, physical inspection and the performance parameters are evaluated.

Table 4 is used to rate the assets on their condition.

Based on the asset condition rating chart, the assets are assigned by a condition rating from A to F. The priority improvement plan is based on this asset condition.

Table 4: Condition of assets rating

Rating	Asset Condition	Description
A	Excellent	No noticeable defects. Some aging or wear may be visible.
B	Good	Only minor deterioration or defects are evident.
C	Fair	Some deterioration or defects are evident, but function is not significantly affected
D	Poor	Serious deterioration in at least some portion of the structure. Function is inadequate
F	Failing	No longer functional. General failure or complete failure of a major structural component.

4.3 Field survey

Additional information is also collected during field verification survey which included diameter, installation year of pipe, pipe material, pipe type and condition of pipe. The map of water supply system is shown in fig. 2 below.

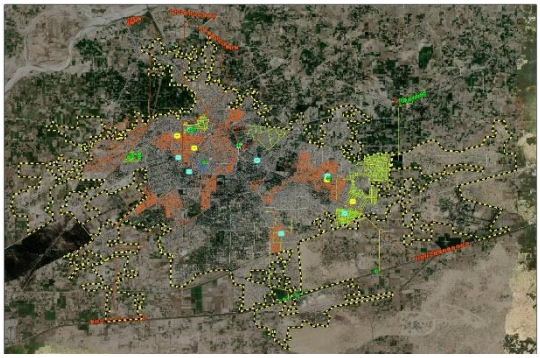

Fig. 2: Water Supply System Map

Condition assessment of the underground pipelines has been done by rapid assessment method based on the following parameters:

1. Year of Installation
    - Design Life
2. Water Quality
    - Corrosion
    - Sewage Mixing
3. Pipe Wall Thickness

Mohallah/colony wise random digging was performed with the help of MC staff for pipeline assessment. The survey pictures of are shown in fig. 3.

4.4 Mapping of Water Pipelines and Condition Assessment

Mapping water pipe network is done on high resolution Quickbird imagery using ARCGIS 10.5 with the help of Municipal Corporation staff.

- Pressure
- Current, Voltage & Kilowatts
- Power Factor
- Flow (Discharge)

Different devices/tools (table 5) were used to measure theses performance parameters at tube wells, OHRs and GSTs.

Table 5: Devices/instruments used for condition assessment

Sr.	Device/ tool	Parameter
1	Pressure Gauge	used to measure Suction & Discharge Head
2	Power Analyzer	used to measure Amps, Voltage, Power Factor, Kvars & kilowatts
6	Flow Meter	used to measure discharge and discharge velocity in the pipe
4	Tachometer	used to measure discharge and discharge velocity in the pipe
5	IR Gun	Temperature Measurement

Fig. 3: Condition assessment survey of TW, OHR, GST

Based on the mentioned indicators the overall condition of asset is rated as described in table 4.

5. Analysis and Results

5.1 Water Pipelines Analysis

The water supply is distributed (Fig. 4) through AC (asbestos cement) pipes and PVC (polyvinyl chloride) pipes laid into 264 km long network consisting of 3 inch to 28 inch diameter pipes . The age of these pipelines also varies and almost 50 % of the piping is more than 30 years old and has outlived its usable life.The following Table 6 shows length of distribution network in Bahawalpur.

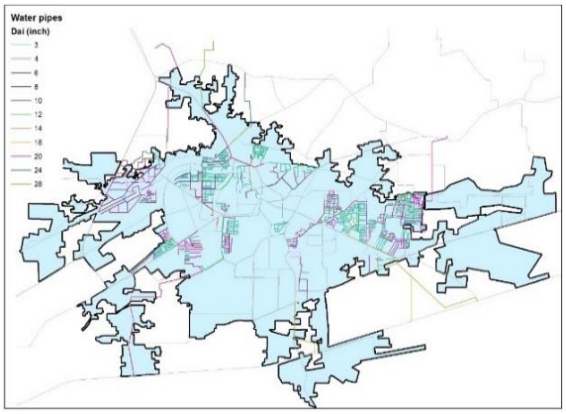

Fig. 4: Map of distribution pipes

Table 6: Diameter wise distribution pipes length

Diameter (inch)	Length (km)
3	84.6
4	39.4
6	23.1
8	10.6
10	9.4
12	10.8
14	2.9
16	2.2
18	14.2
20	20.2
24	3.7
28	2.6
N/A	39.7
Total	**263.9**

Condition map water pipe lines are given in the fig. 5.

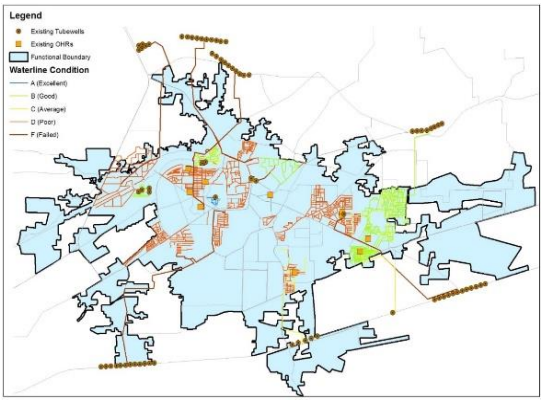

Fig. 5: Condition map water pipe lines

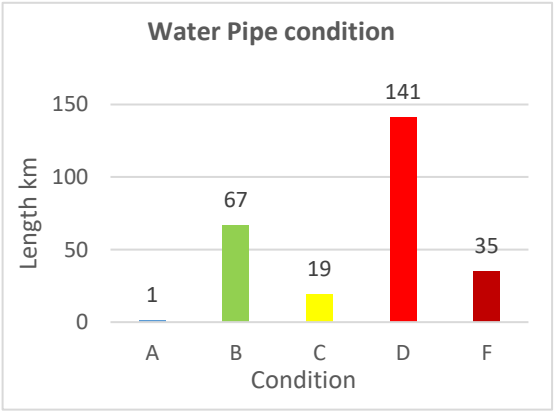

Fig. 6: Length of water pipe lines with respect to condition

Fig. 6 describes the calculated length of pipelines under each category of condition.

Table 7: Summary of above ground assets condition

Condition	TWs	GSTs	OHRs
A	3	6	0
B	26	6	1
C	3	4	5
D	1	0	3
F	41	2	3
Total	**74**	**18**	**12**

According to the conditional assessment of the distribution lines, more than 50% of the pipe lines are outlived and require immediate interventions. Most of the pipes are cast iron pipes and are corroded or damaged. All these pipes need to be replaced on immediate basis for increased water supply and to cater the future demands.

Proposed extension areas	Tube wells		OHRs / GST	
	No. of TWs	Capacity (Cfs)	No.	Unit Capacity (Gallons)
Satellite Town	0	-	1	200,000
BhattaJat	1	1	1	300,000
Quaid e Azam Colony	0	-	0	-
Bindra Basti	2	1	1	350,000
Rehmat Colony	1	1	1	450,000
Bahawal Colony	2	1	1	400,000
PHED	12	1	5	500,000
Islamia Colony	2	1	2	350,000
Maqbool Colony	4	1	2	350,000

5.2 Tube wells Condition

The city owns 74 tube wells (fig. 7), after condition assessment it is observed that 52 of the TWs are non-operational.

The summary of tube wells condition is shown in the table 7.

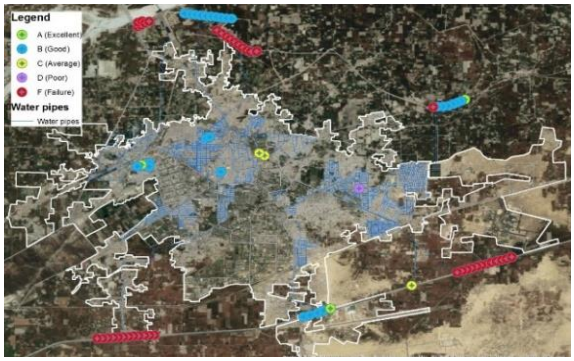

Fig. 7: Tube wells condition map

5.3 Overhead tanks Condition

There are twelve (12) elevated overhead reservoirs (OHR) distributed throughout the piped network with a total storage capacity of 645,000 gallons. Only 8 out of 12 OHRs (see Fig. 8) are currently in service with a total of 495,000 gallons' capacity.

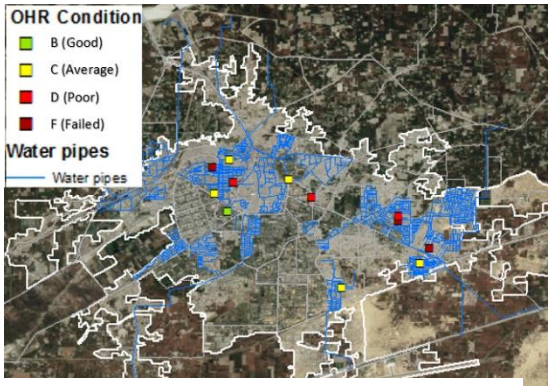

Fig. 8: OHR Condition

5.4 Ground Storage Tank (GST) Condition

The main storage source of drinking water in Bahawalpur is Ground Storage Tank (GST) built under SPBUSP and PHED projects shown in fig. 9. There are a total of 18 GSTs constructed with total capacity of 6.3 Million Gallons. Only 2 out of 18 GSTs are functional with storage capacity of 1.05 million gallons. The summary of GSTs condition is shown in the table 7.

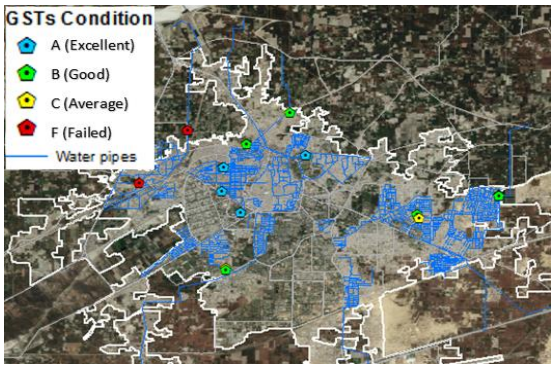

Fig. 9: GST condition map

Summary on condition of whole water supply infrastructure is shown in fig. 10.

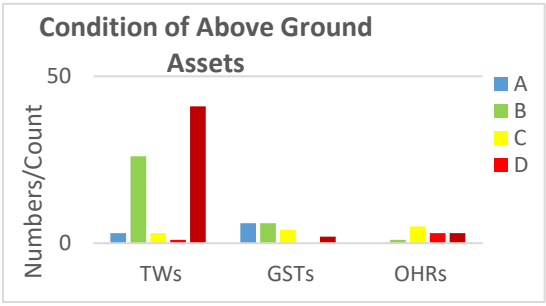

Fig. 10: Summary of WS Infrastructure

6. Conclusion and Recommendations

A system of water supply is becomes efficient through assessment, rehabilitation, development and management [10]. As GIS is a powerful technology in spatial planning and visualization of water network, effective management of water supply assets is facilitated by creating geospatial database that supports the management of water utility using GIS analysis functions and assist the process of prioritization planning for improvement of the assets. The gis inventory of assets also facilitates investigation process, abridge the working time and reduce the cost of maintenance and rehabilitation. On the basis of analysis and results following recommendations has been proposed for improvement of water supply system of Bahawalpur for better service provision.

6.1 Recommendations for Water supply system Improvements

Based on the existing infrastructure analysis including condition survey and service delivery gap analysis, the recommendations for improvement has been proposed.

In the first phase, the existing Water Supply network will be made functional and 23 new tube wells will be installed in unserved areas to cater the water demand up to 2047. It is better to construct OHRs in particular zones to reduce electricity cost. Because when water is pumped from tube well stations it is stored in Ground storage tanks and it is again pumped in distribution network at high cost of electricity.

This will include the condition improvement of existing Tube wells and Overhead Reservoirs along with installation of new tube wells (shown in Table 8).

A maintenance plan should also be made which will define the Standard Operating Procedures (SOPs) of regular and preventive maintenance of Tube well stations, Overhead Reservoirs, Ground.

6.2 Pipeline Network Improvement

The following interventions are required to improve the distribution network and system efficiency.

Replacement of poor pipelines in the existing distribution network:

Replacement of damaged or missing WS lines of SPBUSP project in Satellite town, Bindra Basti, Bhattajat and Quaid e Azam Colony. Diameters between 3 to 18 inches.

Installation of new lines in unserved areas:

Installation of new network in unattended areas Cheema Town, General Bus Stand, Maqbool Colony, Islami Colony, Qasim Town Baloach Colony and Muhalla Kajjal Pura. Diameters between 3 to 6 inches.

These interventions are essential to improve the performance of the existing network, and to fulfil the present water demands.

6.3 Extension of Services to Uncovered Area

Approximately 20% of the area within the current city boundary (14,400 households or 91,000 people) does not have access to water supply. The uncovered population is relying on private water resources (bore, open dug well and hand pump). In order to reach these beneficiaries additional water supply schemes comprising of tube wells and distribution network has been included in investment plan. The new water supply system should be based on the DNI (Distribution Network Improvement) model where quality water will be provided on a continuous 24/7 basis. A map of proposed interventions is displayed in fig. 11.

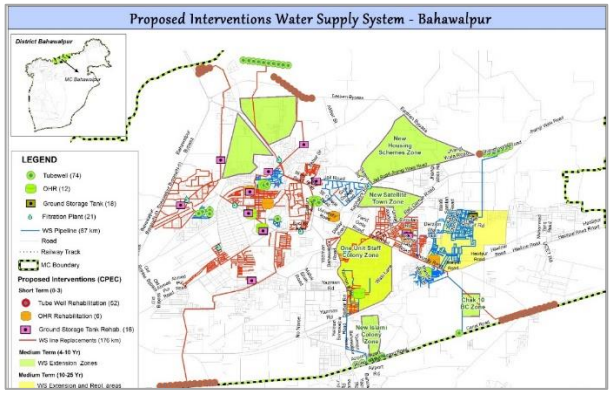

Fig. 11: Map of proposed intervention

7. Limitation

The study assessed the condition of underground pipes randomly, area wise by digging and could not use instrumental technology for pipe condition assessment. Ground penetrating instrument may be used further for this purpose which is a time-

consuming task but plays important role in the accuracy of the data.

8. Conflicts of interest

The Author(s) declare(s) that there is no conflict of interest.

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