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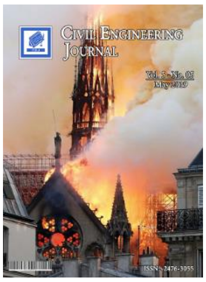

Rapid Performance Evaluation of Water Supply Services for Strategic Planning

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Abstract

The assessment of existing water supply services was carried out through selected performance indicators with the aim of using that data in future for strategic planning of urban Mardan. The key performance indictors studied were selected to assess both the quantity and quality of water. The quality of water was assessed by turbidity, pH, and E-coli tests for samples collected at the start, middle, and tail end of the distribution system. The quantity of water supplied was measured by calculating discharges from water tapes at the three selected locations in the distribution system. A total of thirty samples were collected from ten union councils out of fourteen covering urban Mardan. A number of issues are highlighted in the overall water supply infrastructure and short, mid, and long term remedial measures are recommended. The results are presented in the form of an interactive map using Google Earth and VBA based dynamic database. It was found that the overall quality of water is generally acceptable for drinking. However, the presence of bacteria is an issue in many cases which needs to be resolved. A significant decrease in discharge is observed in the distribution systems away from the source due to leakages and illegal connections. A comprehensive overhaul of both management and infrastructure is required for sustainable and satisfactory level of services.

Keywords: Key Performance Indicators; Turbidity; pH; E-coli; Discharge; VBA.

1. Introduction

Domestic and municipal water needs are fulfilled by ground water schemes in most cities of Pakistan. Tube wells are one of the most common type of water extraction method adopted for municipal water supply schemes. Ground water is pumped to the surface and distributed to the communities through a distribution system using different types of piping systems. These water supply schemes and network of pipelines are decades old in many cases. New interventions have also been made under the impact of increasing population and expanded coverage areas. As such the water services providers rely both on the newly constructed water supply schemes and existing old schemes. These water supply systems in various cities of Pakistan face many problems related to maintaining proper water supply to all communities and regarding quality of water being delivered.

The cities of Pakistan are growing rapidly in size and population due to high rates of population growth and migration from the rural areas. In most cases, the growth is random and involves no planning. This causes various issues with

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regards to provision of public utilities. There is a need for condition assessment of the existing water supply infrastructure to propose necessary interventions for meeting the present and future demands of these ever growing urban centers.

Surface and groundwater sources for drinking water are contaminated by coliforms, toxic metals, and pesticides throughout Pakistan. Pakistan is ranked 80 among 122 nations regarding drinking water quality [1]. A study in District Bannu found significantly higher values of total dissolved solids (TDS) and electrical conductivity (EC) than World Health Organization (WHO) permissible limits [2]. A review of 43 studies (>9882 groundwater samples) revealed that 73% of the samples had arsenic values higher than WHO permissible limit (10 $\mu g/L$) [3]. In District Charsadda, the concentrations of nitrate exceeded the permissible limit (10 mg/L) set by US-EPA at 13 sites, while concentrations of sulfate exceeded the permissible limit (500 mg/L) of WHO at 9 sites [4].

The general perception about water supply services is negative in most cities of Pakistan. In district Vehari of Punjab province, 48.6% of people disagreed that the drinking water of their area is good. These people reported more disease development (45.8%) compared to those who were satisfied (11.1%) with their drinking water quality [5]. However, the northern mountainous regions generally have good quality of drinking water. A study of 44 samples in Bajaur agency showed that hydrochemical characteristics and quality assessment parameters were within the permissible range set by WHO except SO_4^{-2}, K^+, NO_3^-, and HCO_3^- in 9%, 40%, 54%, and 67% of the analyzed samples, respectively [6]. A study conducted in Swat valley concluded that the physiochemical parameters were within their safe limits except in a few locations, whereas, the fecal contaminations in drinking water resources exceeded the drinking water quality standards of Pakistan Environmental Protection Agency (Pak-EPA), 2008 and World Health Organization (WHO), 2011 [7].

The water industry needs to develop values and a system wherein key performance indicators are used to identify areas of improvement, define rational targets, devise action plans and track improvements over time. One such system is to define and evaluate key performance indicators (KPIs) for a given water supply scheme [8]. KPIs are the fundamental components of a groundwork process whereby water utilities can assess their relative technical and financial performance against internationally defined standards [9]. They can be used by the water supply services providers for appropriate decision making and need based response. However, many of the internationally adopted systems involve so many indicators which make them too comprehensive and exhaustive to be utilized in developing countries such as Pakistan [10]. Therefore, there is a dire need for a more practical and economical system to meet the needs of water supply schemes in developing countries.

2. Study Area and Research Methodology

This research focuses on identifying easily obtainable key performance indicators for drinking water supply schemes in the urban settlements of Mardan city, present the data gathered in an easily accessible and comprehensible fashion, and to suggest measures for improving water supply services for consumers. Drinking water supply schemes in the fourteen union councils of Mardan city are studied. The field investigation part of the study focuses on developing a data collection tool in the form of a pro forma questionnaire, measurement of discharge values at different points in the distribution system, identification of issues in the infrastructure causing deterioration of the water supply services, and recommendations of remedial measures. The research will be helpful for improving the monitoring techniques in the existing system.

The step by step methodology adopted in this research study is shown in Figure 1. A pro forma containing questions related to condition assessment of the schemes was prepared and used in the field for data collection. Samples at three points in the distribution systems were collected for laboratory tests. Physical, chemical, and bacteriological tests were then performed and results analyzed.

Three laboratory tests, namely turbidity, pH, and total coliform are performed to assess the water quality of the selected schemes. Water samples at the start, mid, and tail end of each distribution system are collected and tested. The parameters selected represent a measure of both suspended solids and microorganisms in water. More parameters may be added if required and represented in a similar fashion.

In the last phase of the research an interactive map was developed based on Google Earth and using VBA based open source database application called Mapper. The user can select any parameter investigated in this study and the results are displayed for all the sampling points on a Google Earth environment. The database can also be easily extended to include more parameters in the future. This is an important development because it will help the non-technical decision makers understand engineering data easily.

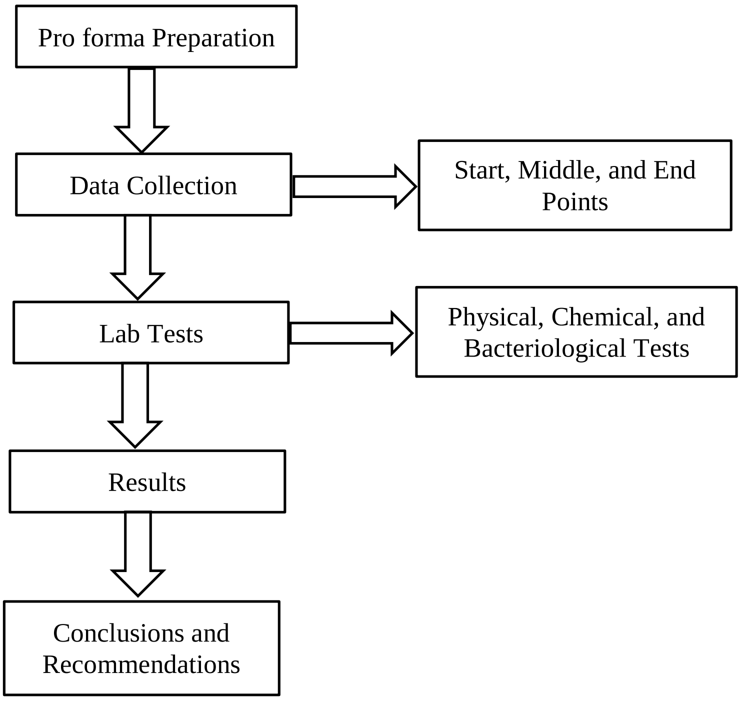

Figure 1. Steps followed in the research

3. Condition Assessment of Existing Infrastructure

A number of issues were observed in the overall water supply infrastructure and management during the field investigation part of this research study. Highlighting these issues is a first step towards a systemic improvement of the water supply services in urban centers of Pakistan. It is observed that the unplanned growth and trend of urbanization is also a major factor in adversely affecting the water supply infrastructure. Most of the city area is congested with narrow streets lacking proper water supply system, lack of appropriate sanitation arrangements and deficient cleaning provisions. Since the water supply is intermittent, many inhabitants have installed sucking machines to fill overhead tanks or ponds in their homes. Resultantly, the tail users are unable to receive the required quantum of water.

The managing authority of the water supply schemes have deployed a considerable number of employees for running and maintenance purposes. However, due to lack of proper tools, equipment, generators as an alternate power source and vehicles for logistics the services level could not be termed as satisfactory. The required skill was mostly available but due to lack of funds and absence of required facilities, the system could not run smoothly and to the desired satisfactory level. There is no appropriate strategy for line crossing through roads and irrigation channels depriving several areas and households from the service due to non-availability of crossing facilities. Sharp edges in pipes were observed which can cause more head losses as shown in Figure 1(a). Sometimes, the whole water supply scheme is nonfunctional as shown in Figure 1(b) due to lack of maintenance of critical equipment such as pressure pump as shown in Figure 1(c). In many cases, the distribution pipes and connections to consumers are passing through sewerage lines as shown in Figure 1(d). This can cause induction of bacteria and other impurities into the drinking water.

(a) Sharp edges in distribution pipes (b) Non-operation scheme

(c) Out of order pump

(d) Pipes passing through sewerage lines

Figure 2. Observed problems in water supply infrastructure

Since almost all the units are provided for a specific union council and there is no networking among different units except in few cases, the inhabitants are left without water supply in case the system fails due to one reason or the other. Similarly with the exception of few union councils, there are no alternate water supply arrangements. As a result, people try to get the required water through their own sources. One such arrangement is the extraction of ground water using private bore holes and pressure pumps. This puts an extra burden on the ground water resources in the area and many places are reporting lowering of ground water table.

4. Recommendations for Improvement

The service level can be greatly improved by taking necessary short-term, mid-term, and long-term measures. All the non-operational and damaged units should be repaired and rehabilitated to ensure adequate usage of the already installed infrastructure. In many cases, the rehabilitation cost is negligible as compared to the cost of developing a new scheme. Alternate power supply system i.e. generators, solar panels etc. needs to be installed to make sure a continuous power supply to the pumping units. The staff employed on site at these units are non-technical people and they have to call technicians for all kinds of minor and major issues which may develop and interrupt the supply of water. This process takes a long time in most cases. Therefore the onsite personnel should be trained so that they can take care of small repairs in the units and avoid unnecessary interruptions in water supply. All the illegal connections and sucking machines should be prohibited and strict action should be taken against those violating the rules in this regard.

Adequate machinery, vehicles, and equipment related to proper running of water supply services should be procured. Appropriate budgetary provision is needed in this regard in the government annual development program (ADP). The water losses (both real and apparent) are at unacceptably high levels, which threatens the water resources and also results in excessive energy costs for pumping and transmission. Therefore, reduction of real and apparent losses must become a key priority for the management.

A detailed master planning of Mardan city should be carried out to identify necessary measures for improving existing infrastructure and propose new schemes to meet the needs of future population. This should be made a regular exercise every five years. Proper networking among the schemes should be developed to ensure continuous water supply in case one of the units becomes non-operational. The water supply agencies operate financially in a completely unsustainable way as they are largely depending on the government subsidies with a very nominal share received from users in shape of water toll collection. Use of the flat rate system with un-measured amount of water does not ensure the full cost recovery of the services. To provide sustainable services, the concerned authorities must place greater focus on financial sustainability by maximizing revenue generation and reducing the costs of operation.

5. Results and Discussions

The discharge data for all three collecting points of each tube well is shown in Table 1. As can be seen, the discharge is not uniform for all the tube wells at a corresponding point in the distribution system. The maximum discharge was recorded at the start point of Bijligar union council with a value of 2769.2 G/day. The minimum discharge was recorded at the tail point of Nala Par Hoti union council with a value of 138.5 G/day.

The average discharge at start, middle, and tail points were calculated to be 1498.9 G/Day, 737.9 G/Day, and 487.8 G/Day respectively. The last column of Table 1 shows the percent decrease in discharge which occurs from start point to the tail point. A significant decrease in discharge is observed in all the tube wells from start point to the end point. The decrease is over 50 percent in all cases except one. The maximum drop in discharge was observed to be 80 percent in the Bijligar tube well. The average decrease was found to be 63.60 percent.

Table 1. Discharge data for each tube well

S. No	Union Council	Discharge G/day			Percent Decrease from Start to tail
		Start Point	Middle Point	Tail Point	
1	Muslim Abad	744.8	653.4	600.0	19.44
2	Mardan Khaas	1350.0	800.0	568.4	57.90
3	Nala Par Hoti	469.6	223.0	138.5	70.51
4	Barichum	1542.8	813.6	514.3	66.66
5	Jan Abad	1350.0	919.8	675.0	50.00
6	Bicket Gung	2160.0	986.0	617.0	71.44
7	Bughdada	2160.0	986.0	617.0	71.44
8	Dhagai	900.0	390.0	270.0	70.00
9	Bijligar	2769.2	872.0	540.0	80.50
10	Kas Korona	1542.8	735.8	337.5	78.12

Figure 2 shows the variation in discharge recorded for each tube well. There is a consistent drop in discharge for all tube wells from start point to end point. Leakages and illegal connections are the main reasons for the decrease in discharge.

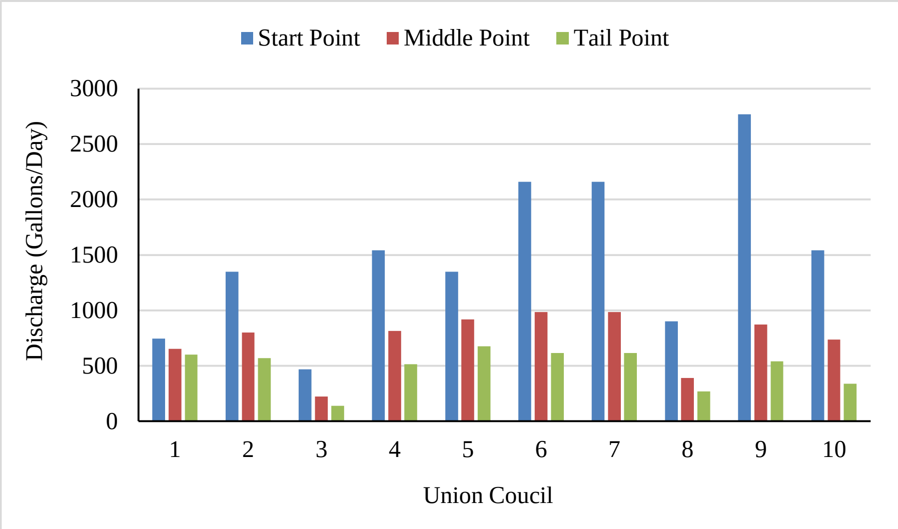

Figure 3. Discharge data for each tube well at three points

Water samples collected from the ten operational water supply schemes were tested in the environmental engineering laboratory of Civil Engineering Department at University of Engineering and Technology Peshawar, Pakistan to find their turbidity, pH, and E-coli values. The water samples were tested for turbidity according to ASTM D6855-17 [11] and the results are shown in Table 1. As can be seen from the results shown in Table 2, the turbidity generally increases from the starting point of the distribution system to the tail end. This shows that the ground water quality is good but external impurities are imparted to the system because of leakages and improper passage ways.

Table 2. Results of Turbidity tests

S. No	Union Council	Turbidity (NTU)			Comparison with WHO Standard (< 5 NTU)
		Start Point	Middle Point	Tail Point	
1	Muslim Abad	3.2	2.1	3.0	Acceptable
2	Mardan Khaas	3.2	3.4	3.5	Acceptable
3	Nala Par Hoti	2.6	2.4	2.4	Acceptable
4	Barichum	2.6	3.2	3.4	Acceptable
5	Jan Abad	2.4	3.0	7.3	Not Acceptable at Tail
6	Bicket Gung	2.0	2.1	2.3	Acceptable
7	Bughdada	2.7	2.7	2.7	Acceptable
8	Dhagai	2.4	2.2	2.7	Acceptable
9	Bijligar	1.4	2.2	2.5	Acceptable
10	Kas Korona	2.2	4.3	2.2	Acceptable

The bar charts in Figure 3 show turbidity results for three collection points of each tube well. The WHO limit is crossed only at the end point of Jan Abad union council as shown in the figure.

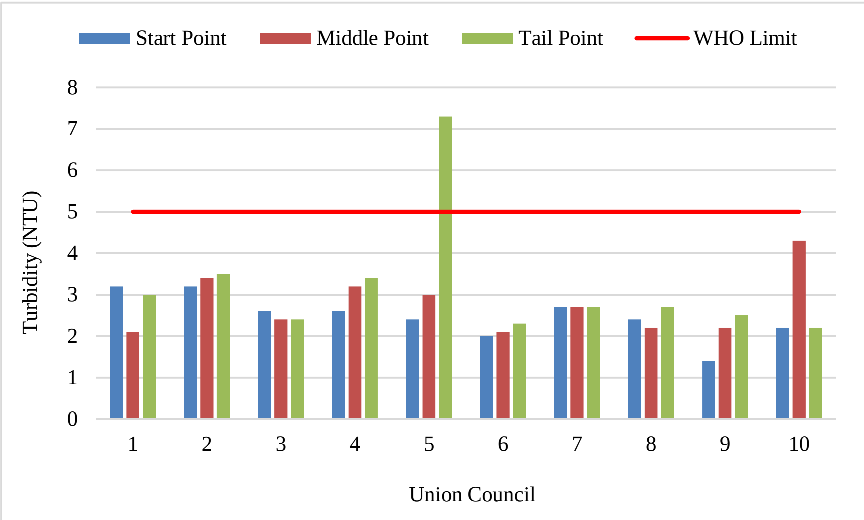

Figure 4. Results of turbidity test for each union council

The procedure outlined in ASTM D1293-12 [12] was followed during the pH test. The results obtained are shown in Table 3. Only one sample was found to have pH value outside the recommended range of WHO standards. The sample taken at the starting point of Bicket Gung scheme has a pH value of 9.4 which is greater than the acceptable upper limit of 8.5.

Table 3. pH test results

S. No	Union Council	pH			Comparison with WHO Standard (6.5-8.5)
		Start Point	Middle Point	Tail Point	
1	Muslim Abad	7.1	7.0	7.4	Acceptable
2	Mardan Khaas	7.5	7.5	8.0	Acceptable
3	Nala Par Hoti	5.5	6.3	8.0	Not Acceptable
4	Barichum	7.4	7.5	7.8	Acceptable
5	Jan Abad	8.0	6.0	8.0	Not Acceptable
6	Bicket Gung	9.4	7.0	7.6	Not Acceptable
7	Bughdada	7.2	7.3	7.8	Acceptable
8	Dhagai	7.6	8.0	8.0	Acceptable
9	Bijligar	6.3	8.0	8.0	Not Acceptable
10	Kas Korona	7.5	6	7.9	Not Acceptable

The pH values along with WHO limits are represented by the bar charts in Figure 4. Most of the pH values fall within WHO recommended range. However, values recorded at some points are less than the min limit of WHO guidelines.

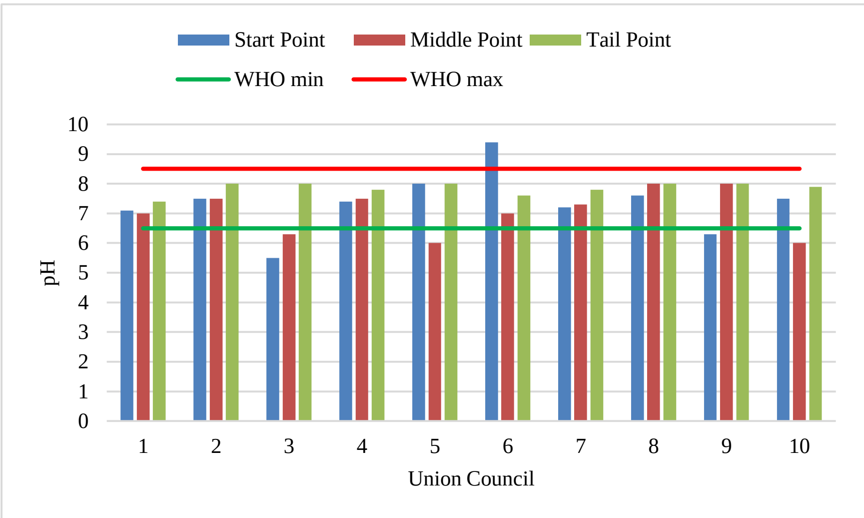

Figure 5. pH values at selected points of each union council

Table 4 shows the results obtained for all samples from the bacteria test [13]. Water of two units is completely free from bacteria, three units have traces of bacteria all along the distribution system, and the remaining units have traces of bacteria at some point(s) in the distribution system. These results indicate that the source of water is generally free from microorganism and the bacterial contamination is resulted from external impurities. The obvious reasons are leaked pipes and exposed unhygienic passages of the distribution system. A domestic remedy for this issue would be to boil the water before drinking and usage in food preparation.

Table 4. Bacteria test results

S. No	Union Council	Total Coliform (cfu)			Comparison with WHO Standard (0)
		Start Point	Middle Point	Tail Point	
1	Muslim Abad	0	0	9	Not acceptable at tail
2	Mardan Khaas	0	0	0	Acceptable
3	Nala Par Hoti	9	9	9	Not acceptable
4	Barichum	0	0	0	Acceptable
5	Jan Abad	0	6	9	Not acceptable at tail
6	Bicket Gung	8	0	9	Not acceptable
7	Bughdada	3	9	9	Not acceptable
8	Dhagai	0	0	6	Not acceptable at tail
9	Bijligar	0	3	3	Not acceptable at tail
10	Kas Korona	9	6	16	Not acceptable

The water testing and monitoring should be a continuous process to ensure suitable water quality for drinking water. Any apathy towards water quality assurance may result in water borne diseases which is a serious issue in many developing countries including Pakistan.

6. Representation of Data

One of the major issues in the decision making process of public infrastructure development is the communication gap between engineering professionals and non-technical decision makers. Often times, the message is lost in the heavily technical engineering terminology and cause unnecessary delays in decision making or complete rejection. The data presented in the form of tables and graphs is hard to understand by the non-technical managers and government officials. Therefore there is always a need for tools and techniques to make the technical engineering data easily comprehensible to the common public. Development of an interactive map as part of this research was intended to serve this purpose.

The graphical representation of the data is achieved by Google Earth using the Mapper software application. Mapper is a dynamic VBA based open source database application. It was initially developed for mapping water resources by a computer programmer named Owen Scott. However, certain modifications pertaining to data collected for our research was carried out by changing certain codes in Excel developer. Anyone can use the application on a personal computer with Google Earth and Excel software. The input data can be easily modified and updated. The information displayed on the map can be easily modified by selecting from the list of given parameters. The water scheme is displayed as an icon on a Google Earth image and list of selected information shown. Figure 2 shows screen shot of a map created for functionality of schemes. Data for each scheme can displayed in a tabular form on the map by clicking on a particular scheme as shown in Figure 2.

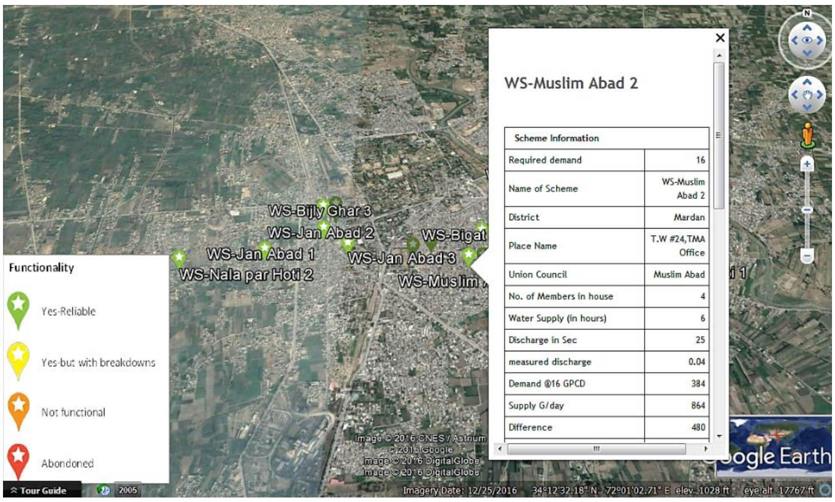

Figure 6. Screen shot of functionality map

7. Conclusion

The overall efficiency of the system is severely affected by the lack of proper maintenance arrangements as demonstrated by a number of issues found in the water supply infrastructure. About one-fourth of the schemes are in non-operational condition. Over 50 percent decrease in discharge was observed from start to end in the distribution system except for one scheme. The prime reasons were found to be leakages and illegal connections.

The turbidity level was found to be within the WHO acceptable limits for all the sampling points except at the tail point of Jan Abad distribution system. The pH values were found to be within the WHO acceptable limits of drinking water except for start point of Bicket Gung distribution system. Water of two units is completely free from bacteria, three units have traces of bacteria all along the distribution system, and the remaining units have traces of bacteria at some point(s) in the distribution system. The overall quality of water is generally acceptable for drinking. However, the presence of bacteria is an issue in most cases which needs to be resolved.

8. Acknowledgement

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9. Conflict of Interest

The authors declare no conflict of interest.

10. References

[1] Azizullah, Azizullah, Muhammad Nasir Khan Khattak, Peter Richter, and Donat-Peter Häder. “Water Pollution in Pakistan and Its Impact on Public Health — A Review.” Environment International 37, no. 2 (February 2011): 479–497. doi:10.1016/j.envint.2010.10.007.

[2] Arain, Muhammad Balal, Ihsan Ullah, Abdul Niaz, Nasrullah Shah, Afzal Shah, Zahid Hussain, Muhammad Tariq, Hassan Imran Afridi, Jameel Ahmad Baig, and Tasneem Gul Kazi. “Evaluation of Water Quality Parameters in Drinking Water of District Bannu, Pakistan: Multivariate Study.” Sustainability of Water Quality and Ecology 3–4 (October 2014): 114–123. doi:10.1016/j.swaqe.2014.12.005.

[3] Shahid, Muhammad, Nabeel Khan Niazi, Camille Dumat, Ravi Naidu, Sana Khalid, Mohammad Mahmudur Rahman, and Irshad Bibi. “A Meta-Analysis of the Distribution, Sources and Health Risks of Arsenic-Contaminated Groundwater in Pakistan.” Environmental Pollution 242 (November 2018): 307–319. doi:10.1016/j.envpol.2018.06.083.

[4] Khan, Sardar, Maria Shahnaz, Noor Jehan, Shafiqur Rehman, M. Tahir Shah, and Islamud Din. “Drinking Water Quality and Human Health Risk in Charsadda District, Pakistan.” Journal of Cleaner Production 60 (December 2013): 93–101. doi:10.1016/j.jclepro.2012.02.016.

[5] Khalid, Samina, Behzad Murtaza, Iram Shaheen, Iftikhar Ahmad, Muhammad Irfan Ullah, Tahira Abbas, Fariha Rehman, et al. “Assessment and Public Perception of Drinking Water Quality and Safety in District Vehari, Punjab, Pakistan.” Journal of Cleaner Production 181 (April 2018): 224–234. doi:10.1016/j.jclepro.2018.01.178.

[6] Jehan, Shah, Sardar Khan, Seema Anjum Khattak, Said Muhammad, Abdur Rashid, and Nisar Muhammad. “Hydrochemical Properties of Drinking Water and Their Sources Apportionment of Pollution in Bajaur Agency, Pakistan.” Measurement 139 (June 2019): 249–257. doi:10.1016/j.measurement.2019.02.090.

[7] Khan, Kifayatullah, Yonglong Lu, Mian Abdal Saeed, Hazrat Bilal, Hassan Sher, Hizbullah Khan, Jafar Ali, et al. “Prevalent Fecal Contamination in Drinking Water Resources and Potential Health Risks in Swat, Pakistan.” Journal of Environmental Sciences 72 (October 2018): 1–12. doi:10.1016/j.jes.2017.12.008.

[8] Vilanova, Mateus Ricardo Nogueira, Paulo Magalhães Filho, and José Antônio Perrella Balestieri. “Performance Measurement and Indicators for Water Supply Management: Review and International Cases.” Renewable and Sustainable Energy Reviews 43 (March 2015): 1–12. doi:10.1016/j.rser.2014.11.043.

[9] Alegre, Helena. “Performance Indicators for Water Supply Services - Second Edition.” Water Intelligence Online 12 (May 2013). doi:10.2166/9781780405292.

[10] Haider, Husnain, Rehan Sadiq, and Solomon Tesfamariam. “Performance Indicators for Small- and Medium-Sized Water Supply Systems: a Review.” Environmental Reviews 22, no. 1 (March 2014): 1–40. doi:10.1139/er-2013-0013.

[11] ASTM D6855-17, Standard Test Method for Determination of Turbidity Below 5 NTU in Static Mode. ASTM, International: West Conshohocken, PA, 2017. doi: 10.1520/d6855-03

[12] ASTM D1293-12, Standard Test Methods for pH of Water. ASTM International: West Conshohocken, PA, 2012, ASTM, International. doi:10.1520/d1293-99r05

[13] Rice, E.W., et al., Standard methods for the examination of water and wastewater. 22nd ed. 2012, Washington, D.C.: Washington, D.C. : American Public Health Association.