Journal of Water Supply: Research and Technology—AQUA | 60.1 | 2011

# Issues and recommendations for drinking water supply in an average Bosnian town: the case study of Zavidovići

Carlo Collivignarelli, Mentore Vaccari and Francesco Vitali

## ABSTRACT

The environment in Bosnia and Herzegovina, already compromised before the war by the development of heavy industry, has worsened since the conflict. According to WHO data, in Bosnia and Herzegovina almost 97% of the population have access to water, but its quality is often unsuitable for human consumption because of low protection of water sources, inappropriate water treatment and obsolete condition of the distribution systems. The results of the present study show that such an issue occurs also in the Municipality of Zavidovići (Central Bosnia, 46 000 inhabitants approximately). Water leakages along the municipal network lead to the loss of about 70% of volume drawn from water sources. Distributed water that is microbiologically safe very often contains excessive turbidity and a high permanganate index, due to an incomplete and, therefore, inappropriate water treatment. Moreover, in the large territory of the municipality there are numerous small waterworks whose characteristics are very often unknown. The current situation should therefore be improved not only through structural interventions, such as repairing the pipe network or the construction of specific treatments for removal of turbidity and organic matter from the raw water, but also by means of surveys aimed at identifying the characteristics of rural waterworks and the quality of distributed water.

**Key words** | Bosnia and Herzegovina, drinking water, water supply, water treatment

**Carlo Collivignarelli**
**Mentore Vaccari** (corresponding author)
**Francesco Vitali**
CeTAmb,
Research Centre on Appropriate Technologies for Environmental Management in Developing Countries,
DICATA department,
University of Brescia via Branze 43,
25123 Brescia,
Italia
Tel: +39 030 3711302;
Fax: + 39 030 3711213
E-mail: *vaccari@ing.unibs.it*

## INTRODUCTION

In developing countries, the public sector is usually responsible for environmental services, but municipalities and local authorities often neglect them because of lack of both finance and awareness (Basu & Main 2001; Korfali & Jurdi 2007). Such an issue affects the population's health as well as the environment, limiting access to adequate water supply and sanitation services for all (Jung 2006).

Likewise, the state of the environment in Bosnia and Herzegovina, already compromised before the war by the development of heavy industry, worsened after the conflict (Kastelan-Macan *et al.* 2007). The country is facing difficulties in the delivery of municipal services, which are not able to serve the whole population of the territory.

WHO (2004) data show that in Bosnia and Herzegovina almost 97% of the population have access to water, but its quality is often not suitable for human consumption because of low protection of water sources, inappropriate water treatment and obsolete condition of the distribution systems. Moreover, 85% of the households are connected to a sewage system but domestic and industrial wastewaters are seldom treated: they are usually directly discharged into open plots or rivers (Uzunovic-Kamberovic *et al.* 2005; Terzić *et al.* 2007; Stefanović *et al.* 2008).

The development of an institutional environment, necessary to assure the adequate planning of infrastructure and protection and management of water sources (Jung 2007) is limited by the lack of a recent regulation regarding the protection of water sources (Bogdanovic 2000); the regulation issued by the Socialist Federal Republic of Yugoslavia (SFRY 1987) is still in force in Bosnia and Herzegovina.

doi: 10.2166/aqua.2011.001

A further issue is the pollution caused by the inappropriate urban solid waste management (Collivignarelli & Vaccari 2006; Calò & Parise 2008). Only half of Bosnian municipalities have a well-organized service for (unsorted) waste collection and disposal, and the few official landfills are over-utilized and are not provided with systems for leachate and biogas collection and treatment (REC 2000).

This study considers the water supply system in the Municipality of Zavidovići (Central Bosnia, 46 000 inhabitants approximately). Data concerning characteristics of water treatment and distribution and properties of water supplied are discussed. The main pressing issues and needs are then identified and possible remedial interventions are proposed.

## Zavidovići

Zavidovići (Figure 1) is a small town, with a 520 km$^2$ territory crossed by the Bosna river and some of its tributaries. Its territory is split in 21 administrative districts, called 'Local Communities'. The local economy was compromised by the 1992–1995 war and it is still suffering, as demonstrated by the high unemployment rate (51.4%) and the low average monthly salary (373 Konvertibilna Marka, i.e. about €190) (Općina Zavidovići 2007).


**Figure 1** | Geographic location of Zavidovići municipality (44°26′30″N; 18°08′51″E) in Bosnia and Herzegovina.

The number of inhabitants, growing continuously until 1991, reduced because of war events and the average age has increased: in fact, the young and active population often moves away from the town looking for employment, while refugees (mainly elder people) go back home. The last official census (dated 1991) found a resident population in the municipality of 57164 inhabitants, whereas now it is estimated to be about 46 000 people, 16 000 living in Zavidovići town and the remainder in the several villages surrounding the urban area (LDA 2003).

The drinking water supply service in Zavidovići municipality is not uniform: besides the municipal network, which serves about 60% of the population, there are a further 379 water supply systems. Five of them are medium sized (serving between 500 and 1500 people) and the others are smaller. Overall, drinking water supply at a household level covers 94% of the population. The most critical situation is in Rujnica Community, where only 39% of inhabitants are served. An incomplete coverage of population is also present in other communities, such as Krivaja (served population = 67%), Maoča (86%), Donji Gostović (87%) and Lovnica (93%) (Ekoklek 2007).

## MATERIALS AND METHODS

Data were extracted from numerous existing documents and studies provided by all the subjects involved in the water supply service: local and cantonal authorities, the municipal concern, local environmental NGOs and the public health centre. Missing information was obtained through specific field surveys or interviews in order to define an all-round scenario.

No water analyses were conducted directly by the authors, but data reported were obtained through certified analytical methods. pH and conductivity were measured by calibrated portable probes, and turbidity was measured by calibrated turbidimeters. Total solids (APHA *et al.* 1997*a*), permanganate index (ISO 1993), ammonium (APHA *et al.* 1997*b*), nitrite (APHA *et al.* 2000*a*), nitrate (APHA *et al.* 2000*b*), chloride (APHA *et al.* 1997*c*), total coliforms (APHA *et al.* 1995*a*) and *Escherichia coli* (APHA *et al.* 1995*b*) were measured in laboratories at the hospital of Zavidovići or at the University of Prijedor.

## Main municipal water supply network

### Water source

Zavidovići territory is very rich from a hydrological point of view; it is crossed by the river Bosna, which receives water from its tributaries Krivaja and Gostović. In particular, the Gostović river has been exploited as a water source for many years because it rises in the Tajan park, which is a high-value naturalistic area.

Currently, water supply is provided through a pipe network built in 1980 and fed by a karst spring named 'Suha', in Kamenica locality in Tajan park. The superficial hydrographical basin has an area of 22 km$^2$, whereas the underground basin extends over more than 70 km$^2$.

Water is abstracted from an underground lake through a siphon and is taken to the chlorination plant by a 2800 m long asbestos-cement pipe, whose diameter is 450 mm. During dry summers the karst lake level sometimes decreases because of low rainfall, causing the interruption of water supply. The quantity of abstracted water is not known because there are no flow-meters either before or after the chlorination plant. The estimated quantity of supplied water is about 100 L/s (Munever 2007).

The physical-chemical quality of the abstracted water was not monitored regularly until 1999. The data of the conducted monitoring campaigns are reported in Table 1 and show that raw water does not meet the standards set by national regulation because of excessive values of permanganate index and turbidity. The few available data regarding microbiological quality of raw water show that bacterial charge was moderate (maximum concentration of total coliforms = 30 CFU/100 mL) and faecal pollution was absent for the last three years (as demonstrated by *Escherichia coli* absence).

### Water treatment

Raw water is treated by a simple chlorination unit at the Kamenica plant (built in 1980, 390 m ASL). The plant consists of only a chlorination square basin (4 m-sided and 1.5 m deep). Incoming flow rate is regulated through two hand-valves (handled through a wheel) placed up- and downstream of the chlorination basin. Every day the number of wheel loops needed to open those valves is registered by an operator but there is not an exact correlation with the flow rate. According to water level and pressure noticed in the downstream reservoir, the operator is prompted by phone to vary the opening rate.

Chlorination is conducted by dosing chlorine gas directly into the basin by means of a pump set to automatically ensure (according to flow rate) a free chlorine concentration in the treated water of 0.70 mg/L. Chlorine consumption is between 500 and 1000 g/h. According to the estimated mean flow rate (i.e. 100 L/s), the contact time is 4 minutes and that is too brief a period to guarantee a complete diffusion of the disinfectant in the water.

### Network characteristics

A 9200 m-long asbestos-cement pipe (D = 450 mm) links the chlorination station to a 500 m$^3$ storage tank placed at Deveti kilometar (270 m ASL). Then, another 9300 m-long asbestos-cement pipe (D = 450 mm) transports water to the main reservoir located at Potkleče village (250 m ASL). That reservoir was built in 1978 and consists of two parallel tanks (volume = 2000 m$^3$/each).

Finally, another asbestos-cement pipe (diameter = 500 mm, length = 1000 m) conveys water to Zavidovići city centre, where the secondary network supplies water to the properties. The drop of 80 m between the reservoir and the urban area allows most users to be supplied without pumping. Ten pumping stations are necessary to fill 21 secondary storage tanks to supply the remaining users.

The secondary network, which serves the final users (i.e. houses, factories, etc.), is made up of pipes of various diameters and materials (asbestos-cement, cast iron and different types of plastic).

The municipal concern 'JKP Radnik' is in charge of the operation and maintenance of the chlorination station, the intermediate storage tank, the main reservoir in Potkleče, the 21 secondary tanks and the 10 pumping stations.

### Quality of water supplied

The drinking water quality regulation issued by Socialist Federal Republic of Yugoslavia in 1987 is still in force in Bosnia and Herzegovina (RFSJ Socialist Federal Republic of Yugoslavia 1987).

 Journal of Water Supply: Research and Technology—AQUA | 60.1 | 2011

**Table 1** | Physical and chemical annual average characteristics of water drawn at Suha spring (Munever 2006)

| Year | No. of measures | pH [–] | Turbidity [NTU] | Conductivity [μS/cm] | Total solids [mg/L] | Permanganate index [mg $O_2$/L] | Ammonium [mg N-$NH_4^+$/L] | Nitrate [mg N-$NO_3^-$/L] | Nitrite [mg N-$NO_2^-$/L] | Chloride [mg $Cl^-$/L] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 5 | 7.8 | 0.40 | 306 | – | 1.7 | 0.09 | 0.1 | 0.003 | 4.1 |
| 1982 | 4 | – | – | – | – | 15.9 | 0.05 | – | 0.001 | – |
| 1999 | 3 | 7.5 | < 0.01 | 345 | 205 | 16.5 | < 0.01 | < 0.1 | < 0.001 | 6.7 |
| 2000 | 21 | 7.3 | 0.28 | 319 | 197 | 10.7 | 0.05 | 0.1 | 0.020 | 6.1 |
| 2001 | 17 | 7.4 | < 0.01 | 301 | 198 | 10.8 | 0.04 | 1.2 | < 0.001 | 5.2 |
| 2002 | 23 | 7.9 | 1.46 | 296 | 184 | 12.3 | 0.05 | 1.4 | < 0.001 | 4.7 |
| 2003 | 10 | 7.5 | < 0.01 | 307 | 189 | 13.1 | 0.04 | 1.8 | 0.010 | 5.4 |
| 2004 | 20 | 7.2 | 0.24 | 303 | 193 | 16.0 | 0.06 | 1.4 | 0.020 | 5.1 |
| 2005 | 12 | 7.2 | 1.28 | 321 | 206 | 10.1 | 0.21 | 1.2 | < 0.001 | 5.2 |
| 2006 | 5 | 7.4 | 2.36 | 328 | 197 | 9.2 | 0.05 | 1.2 | < 0.001 | 5.2 |
| 2007 | 10 | 7.3 | 1.31 | 297 | 197 | 11.2 | 0.06 | 1.3 | < 0.001 | 5.0 |
| Bosnian standards | | 6.5–8.5 | 1.20 | 500 | 800 | 8.0 | 1.00 | 10.0 | 0.005 | 200.0 |

The municipal concern regularly monitors the quality of supplied water. As summarized in Table 2, data from the monitoring campaigns conducted between January 2000 and October 2007 show that:

- pH ranged between 6.2 and 8.3 (mean 7.4); 5.1% of the samples were lower than the minimum value set by Bosnian regulation (i.e. 6.5).
- 31.9% of turbidity values did not meet the national standard (i.e. 1.2 NTU); mean value was 1.6 NTU and some anomalous peaks (up to 53 NTU) were recorded.
- Permanganate index was the most critical parameter: 70% of samples analysed exceeded the maximum limit (8 mg/L).
- Nitrite had a range between 0.001 mg/L and 0.02 mg/L; only 5 samples out of 136 exceeded the limit (0.005 mg/L).
- Other monitored parameters always met the Bosnian regulation standards: total solids concentration (regulation limit = 800 mg/L) ranged between 129 and 301 mg/L; conductivity (limit = 500 μS/cm) ranged between 169 and 381 μS/cm; maximum concentration of ammonium was 0.5 mg/L (limit = 1 mg/L); nitrate (limit = 10 mg/L) ranged between 1.3 and 2.3 mg/L; chloride concentration ranged between 1 and 10 mg/L (limit = 200 mg/L).

As regards other parameters, there are only a few data (collected in the 1980s) for sulphates, silicates, magnesium, iron, manganese and calcium: values were largely within the regulation limits, but a more frequent control of some secondary parameters (such as metals and organic micropollutants) is suggested anyway.

Table 3 summarizes the percentage of water samples not meeting the national standards per year (1999–2007). Data show that the percentage has always been very high, with peaks up to 100%. Moreover, these data show an alarming increasing trend since 2003.

As mentioned above, the most critical parameters for water quality are turbidity and permanganate index. Figure 2 shows, for each month of the year, the mean values and the percentage of measurements exceeding the national standard (1.2 NTU) for the parameter 'turbidity'. The mean value has two peaks during the year: in June and at the beginning of autumn. The percentage of measurements not meeting the national standard substantially confirms this (with the exception of March). Turbidity has no health effects; however, it can interfere with disinfection and provide

**Table 2** | Physical and chemical characteristics of drinking water supplied through the municipal network in the period 2000–2007

| | pH [–] | Turbidity [NTU] | Conductivity [μS/cm] | Total solids [mg/L] | Permanganate index [mg $O_2$/L] | Ammonium [mg N-$NH_4^+$/L] | Nitrate [mg N-$NO_3^-$/L] | Nitrite [mg N-$NO_2^-$/L] | Chloride [mg $Cl^-$/L] |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | | | | | | | | | |
| No of measures | 24 | 24 | 24 | 21 | 24 | 23 | 24 | 24 | 23 |
| Mean | 7.6 | 0.58 | 301 | 185 | 9.9 | 0.04 | 0.9 | 0.002 | 6.1 |
| Minimum | 6.7 | 0.00 | 229 | 161 | 4.7 | 0.00 | 0.0 | 0.000 | 3.0 |
| Maximum | 8.1 | 3.10 | 338 | 225 | 17.6 | 0.15 | 2.0 | 0.010 | 8.0 |
| % of non-accordance | 0.0% | 20.8% | 0.0% | 0.0% | 58.3% | 0.0% | 0.0% | 8.3% | 0.0% |
| 2001 | | | | | | | | | |
| No of measures | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Mean | 7.3 | 12.27 | 304 | 209 | 12.0 | 0.07 | 1.6 | 0.001 | 6.4 |
| Minimum | 6.6 | 0.00 | 279 | 192 | 8.8 | 0.00 | 1.1 | 0.000 | 5.0 |
| Maximum | 7.8 | 53.00 | 320 | 227 | 15.2 | 0.13 | 1.9 | 0.002 | 10.0 |
| % of non-accordance | 0.0% | 40.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | 0.0% |
| 2002 | | | | | | | | | |
| No of measures | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 | 9 |
| Mean | 7.8 | 2.79 | 309 | 213 | 14.5 | 0.04 | 1.5 | 0.000 | 4.8 |
| Minimum | 7.3 | 0.00 | 169 | 174 | 9.6 | 0.02 | 1.2 | 0.000 | 4.0 |
| Maximum | 8.3 | 9.06 | 381 | 301 | 34.8 | 0.07 | 1.8 | 0.001 | 5.0 |
| % of non-accordance | 0.0% | 33.3% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 2003 | | | | | | | | | |
| No of measures | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Mean | 7.5 | 0.37 | 302 | 188 | 10.1 | 0.03 | 1.5 | 0.002 | 5.7 |
| Minimum | 6.8 | 0.00 | 260 | 171 | 6.4 | 0.00 | 0.8 | 0.000 | 5.0 |
| Maximum | 8.0 | 4.13 | 327 | 200 | 15.2 | 0.07 | 2.0 | 0.020 | 7.0 |
| % of non-accordance | 0.0% | 13.3% | 0.0% | 0.0% | 53.3% | 0.0% | 0.0% | 6.7% | 0.0% |
| 2004 | | | | | | | | | |
| No of measures | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Mean | 7.3 | 0.44 | 302 | 187 | 11.4 | 0.05 | 1.5 | 0.001 | 4.8 |
| Minimum | 6.3 | 0.00 | 262 | 165 | 5.04 | 0.00 | 1.1 | 0.000 | 1.0 |
| Maximum | 7.8 | 6.45 | 365 | 219 | 38.4 | 0.14 | 2.0 | 0.002 | 6.0 |
| % of non-accordance | 11.1% | 11.1% | 0.0% | 0.0% | 55.6% | 0.0% | 0.0% | 0.0% | 0.0% |

**Table 2** | *(continued)*

| | pH [–] | Turbidity [NTU] | Conductivity [μS/cm] | Total solids [mg/L] | Permanganate index [mg $O_2$/L] | Ammonium [mg N-$NH_4^+$/L] | Nitrate [mg N-$NO_3^-$/L] | Nitrite [mg N-$NO_2^-$/L] | Chloride [mg $Cl^-$/L] |
|---|---|---|---|---|---|---|---|---|---|
| 2005 | | | | | | | | | |
| No of measures | 21 | 20 | 21 | 20 | 21 | 21 | 21 | 21 | 21 |
| Mean | 7.0 | 1.60 | 305 | 191 | 11.0 | 0.05 | 1.3 | 0.001 | 5.5 |
| Minimum | 6.2 | 0.00 | 254 | 129 | 7.6 | 0.00 | 0.9 | 0.000 | 4.0 |
| Maximum | 7.7 | 17.37 | 376 | 244 | 25.2 | 0.21 | 1.7 | 0.008 | 8.0 |
| % of non-accordance | 19.0% | 30.0% | 0.0% | 0.0% | 71.4% | 0.0% | 0.0% | 4.8% | 0.0% |
| 2006 | | | | | | | | | |
| No of measures | 22 | 22 | 21 | 22 | 22 | 22 | 22 | 22 | 22 |
| Mean | 7.4 | 1.88 | 291 | 182 | 11.6 | 0.04 | 1.3 | 0.000 | 5.2 |
| Minimum | 6.7 | 0.00 | 260 | 160 | 6.8 | 0.00 | 0.8 | 0.000 | 5.0 |
| Maximum | 8.0 | 5.97 | 331 | 205 | 21.6 | 0.10 | 2.3 | 0.002 | 6.0 |
| % of non-accordance | 0.0% | 59.1% | 4.5% | 0.0% | 77.3% | 0.0% | 0.0% | 0.0% | 0.0% |
| 2007 | | | | | | | | | |
| No of measures | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| Mean | 7.2 | 1.56 | 285 | 185 | 16.4 | 0.10 | 1.4 | 0.001 | 5.1 |
| Minimum | 6.5 | 0.00 | 269 | 160 | 6.8 | 0.01 | 1.0 | 0.000 | 5.0 |
| Maximum | 8.0 | 6.24 | 324 | 196 | 80.0 | 0.50 | 1.9 | 0.006 | 6.0 |
| % of non-accordance | 4.8% | 47.6% | 0.0% | 0.0% | 76.2% | 0.0% | 0.0% | 4.8% | 0.0% |
| TOTAL | | | | | | | | | |
| No of measures | 136 | 135 | 135 | 132 | 135 | 135 | 135 | 136 | 135 |
| Mean | 7.4 | 1.63 | 299 | 189 | 11.9 | 0.05 | 1.3 | 0.001 | 5.4 |
| Minimum | 6.2 | 0.00 | 169 | 129 | 4.7 | 0.00 | 0.0 | 0.000 | 1.0 |
| Maximum | 8.3 | 53.00 | 381 | 301 | 80.0 | 0.50 | 2.3 | 0.020 | 10.0 |
| % of non-accordance | 5.1% | 31.9% | 0.0% | 0.0% | 69.6% | 0.0% | 0.0% | 3.7% | 0.0% |
| Bosnian standards | 6.5–8.5 | 1.20 | 500 | 800 | 8.0 | 1.00 | 10.0 | 0.005 | 200.0 |

**Table 3** | Annual percentage of water samples not satisfying the Bosnian regulation

| Year | Number of analysed samples | % of non-accordance |
|---|---|---|
| 2000 | 24 | 79.2% |
| 2001 | 5 | 100.0% |
| 2002 | 9 | 100.0% |
| 2003 | 15 | 53.3% |
| 2004 | 18 | 66.7% |
| 2005 | 21 | 76.2% |
| 2006 | 22 | 73.3% |
| 2007 | 21 | 81.0% |
| Total | 136 | 76.5% |

a medium for microbial growth in the water supply system. High turbidity in source water can overwhelm treatment processes, allowing enteric pathogens into treated water and the distribution system. Particulates can protect microorganisms from the effects of disinfection and can stimulate bacterial growth. In all cases where water is disinfected, the turbidity must be low so that disinfection can be effective (WHO 2006). Values of turbidity inferior to 1 NTU are typical in treated waters (AWWA 1999). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhoea, and associated headaches. (USEPA 2009).

Figure 3 reports the comparison between monthly average values of parameter 'permanganate index' in both raw (i.e. before treatment) and the treated supplied water. It is evident that the permanganate index value in distributed water is often higher than in raw water, probably because contamination with organic substances occurs within the distribution network. Possible causes of that contamination could be the obsolescence of the network, which implies a low protection of water from external polluting sources, or the proliferation of bacterial colonies in the pipes.

Reducing as far as possible the dissolved organic matter, which provides nutrients for microorganisms, is suggested by WHO (2006) to optimize water treatment in order to prevent microbial growth, corrosion of pipe materials and the formation of deposits. Relatively high amounts of biodegradable organic carbon, together with warm temperatures and low residual concentrations of chlorine, can permit growth of *Legionella*, *V. cholerae*, *Naegleria fowleri*, *Acanthamoeba* and nuisance organisms during water distribution. Furthermore, the use of chlorine in waters containing natural organic matter (NOM), as in Zavidovići water treatment plant, although reducing the risk of waterborne disease, creates new potential risks because organic disinfection by-products (DBPs) are formed during the disinfection process. A number

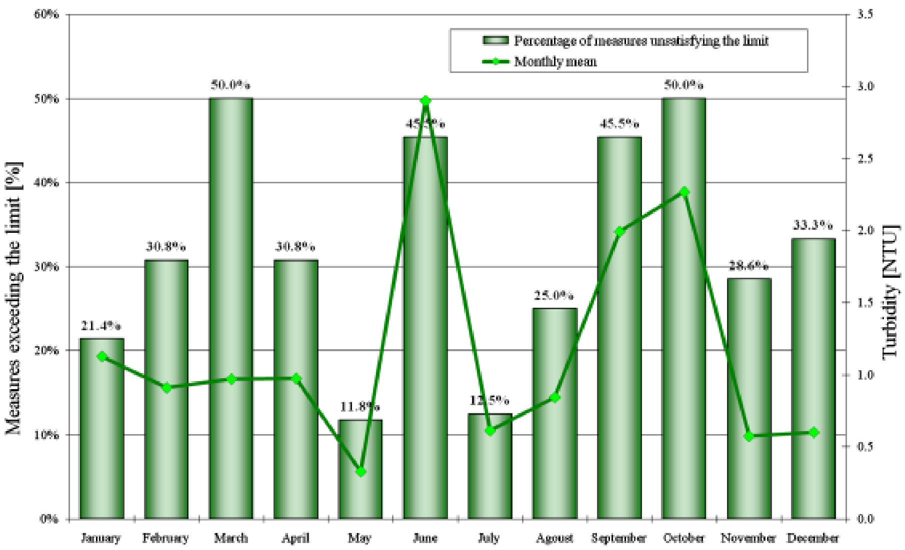


**Figure 2** | Monthly mean value and percentage of measures exceeding the Bosnian standard of parameter 'turbidity' (Munever 2006).

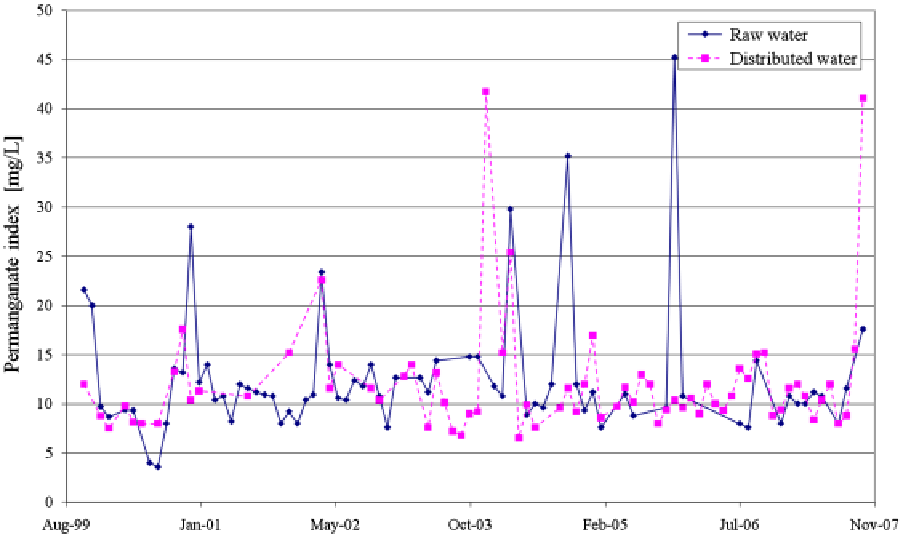


**Figure 3** | Comparison between monthly average permanganate index in raw and distributed water (Munever 2006).

of these compounds, such as trihalomethanes, have been shown to cause cancer and other toxic effects for the kidneys or central nervous system (AWWA 1999; USEPA 2009).

As concerns the microbiological quality of the distributed water, data show that total coliforms and *E. coli* were absent: chlorine dosage at Kamenica station is regulated in order to guarantee a residual concentration in the treated water of 0.70 mg/L. In this way, the residual chlorine value at the farthest users is always 0.1–0.2 mg/L (Munever 2006).

### Users and volume of water supplied

The municipal water network covers about 60% of households in Zavidovići territory and serves 6607 installations. 5% of them are commercial or industrial facilities (Munever 2007).

Specific data regarding water leakages in the network are not available. However, the comparison between the volume of water abstracted per year (assuming an estimated average flow rate equal to 100 L/s) and the volume invoiced by the municipal concern 'JKP Radnik' (comparable to the water volume actually supplied to final users) shows that water loss accounts for about 70% of abstracted volume (Figure 4). As confirmed by local institutions (Zavidovići municipality and JKP Radnik), such loss is due to the obsolete condition of the supply system.

### Other water supply infrastructures

As was previously reported, the municipal piped network does not cover the whole territory of Zavidovići. Furthermore, the irregularity of the water supply during summer pushes a large part of the population to draw water from alternative sources (e.g. springs situated outside the urban area) whose quality is not monitored.

Moreover, in rural areas there are many small waterworks supplying untreated water drawn from local springs;

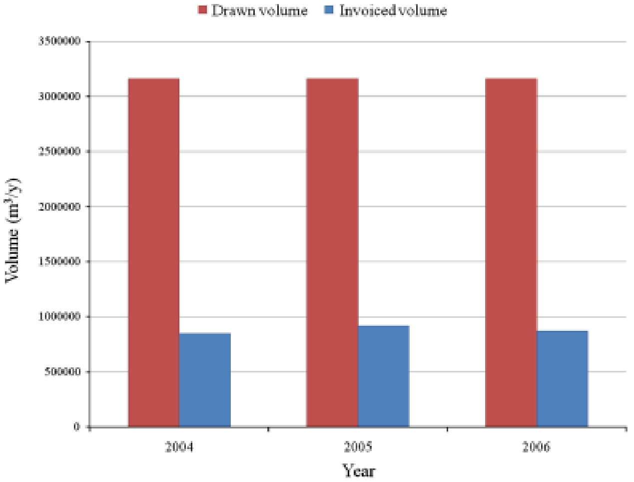


**Figure 4** | Comparison between water volume drawn and invoiced yearly in the period 2004–2006 (Munever 2007).

**Table 4** | Physical, chemical and microbiological characteristics of water distributed by pipe networks in rural areas (Općina Zavidovići 2007)

| Local community | pH [–] | Conductibility [μScm$^{-1}$] | Total solids [mg/L] | Permanganate index [mg $O_2$/L] | Ammonium [mg N-$NH_4^+$/L] | Nitrate [mg N-$NO_3^-$/L] | Nitrite [mg N-$NO_2^-$/L] | Chloride [mg $Cl^-$/L] | Total coliforms [CFU/100 mL] | Pathogens [CFU/100 mL] |
|---|---|---|---|---|---|---|---|---|---|---|
| Svinjašnica | 6.5 | 653 | 393 | 4.4 | < 0.01 | 0.3 | 0.001 | 5 | > 100 | 60 (*E. Coli*) |
| Brezik | 6.8 | 458 | 276 | 4.0 | < 0.01 | 0.9 | < 0.001 | 5 | 30 | 10 (*E. Coli*) |
| Kovači | 6.6 | 476 | 286 | 4.0 | < 0.01 | 1.3 | < 0.001 | 6 | 0 | 0 |
| Bajvati | 6.9 | 444 | 306 | 6.0 | < 0.01 | 0.2 | < 0.001 | 5 | 0 | 0 |
| Mahoje | 7.8 | 136 | 75 | 16.0 | 0.05 | 2.1 | 0.001 | 5 | 10 | 2 (*E. Coli*) |
| Lovnica | 7.6 | 329 | 207 | 5.6 | 0.01 | 0.5 | < 0.001 | 5 | 4 | 4 (*E. Coli*) |
| Rujnica | 6.7 | 409 | 241 | 3.6 | < 0.01 | 0.4 | < 0.001 | 6 | 40 | 0 |
| Haiderovići | 6.5 | 421 | 214 | 4.0 | 0.03 | 7.6 | < 0.001 | 13 | 30 | 0 |
| Šljivići | 7.8 | 247 | 137 | 4.4 | 0.01 | 0.7 | < 0.001 | 8 | 6 | 0 |
| Vozuća | 7.9 | 498 | 311 | 4.8 | 0.07 | 0.5 | < 0.001 | 6 | 20 | 2 (*E. Coli*) |
| Ribnica | 6.5 | 219 | 128 | 4.0 | 0.02 | 0.6 | < 0.001 | 7 | 0 | 0 |
| Maoča | 6.8 | 325 | 190 | 3.6 | 0.02 | 0.3 | < 0.001 | 7 | 0 | 0 |
| Bosnian standards | 6.5–8.5 | 500 | 800 | 8.0 | 1.00 | 10.0 | 0.005 | 200 | 0 | 0 |

physical and chemical water quality usually meets national standards for drinking water, but microbiological quality is not always adequate, as shown by data contained in Table 4.

## Recommendations for remedial interventions

The main issues in the municipal water supply service regard both quantity and quality of water distributed. As regards the water quantity, first of all, water abstraction at the spring 'Suha' should be improved by either lengthening the pipe or completing the abstraction infrastructure at springs 'Tajašnica' (this project is already ongoing); moreover, primary and secondary distribution networks should be analysed in detail in order to map the entire system (e.g. in terms of pipe diameters, materials and layout, location and types of hydraulic regulation devices, etc.). This kind of study would allow to identify where the leakages occur and prepare an appropriate program to repair or substitute pumps, valves, pipes, joints, etc., as well as planning their maintenance.

Such interventions would guarantee a much higher supplied flow rate that could reach 240 L/s. Such a flow rate would serve the urban areas around Zavidovići city that are not currently covered by the municipal network and the new urbanized areas.

Moreover, a flow-meter should be installed at the chlorination station and at other significant points as soon as possible in order to quantify and monitor the distributed water.

As regards the quality of the supplied water, the present simple chlorination treatment guarantees the microbiological quality of water. However, a more complex process should be implemented in order to remove turbidity and natural organic matter from water.

MWH (2005) indicates that a treatment train comprising coagulation, flocculation and filtration works well in low- to moderate-turbidity waters. Membrane filtration processes, although effective at removing turbidity, bacteria and protozoa-sized particles, are inappropriate for the local context because of their costs and complexity.

The use of a slow sand filter downstream of the coagulation-flocculation section could also remove residual pathogens and NOM (WHO 2006). Moreover, it would lead to a lower request of disinfectant and consequently to a lower consumption of chemicals and to a lower production of DBPs.

Further alternatives for NOM removal have been considered, but they do not seem appropriate to the present case study: ion exchange use is limited by disposal of the high-TDS regeneration brine, reverse osmosis presents high costs and concentrate disposal issues (MWH 2005), chemical oxidation is expensive and can produce toxic by-products.

According to the above considerations, the introduction of a treatment train comprising coagulation, flocculation and slow sand filtration upstream of the existing disinfection section seems the most suitable solution for the improvement of the present water treatment plant.

Currently, main chemical, physical and microbiological parameters are already monitored regularly in raw and supplied water. However, also heavy metals (e.g. arsenic, cadmium, iron, lead, manganese, zinc) should be monitored because they may be present or released by the piped network. Furthermore, considering both the significant content of organic matter in raw water and the high chlorine dosage, it would be appropriate to also measure DBPs (in particular trihalomethanes).

Finally, in the municipal territory there are several local waterworks, whose characteristics are very often unknown. Therefore, a survey aimed at identifying in detail the population served, systems layouts and quality of water distributed should be started. That survey should also identify whether regular chlorination is carried out in order to abate possible pathogenic microorganisms that are present in water.

## CONCLUSIONS

The analysis of the state of the drinking water supply in Zavidovići highlights a critical situation that is common in most of the municipalities in Bosnia and Herzegovina. Water leakages along the municipal network represents about 70% of volume drawn from water sources; water supplied is microbiologically safe but often contains excessive turbidity and permanganate index due to an incomplete and inappropriate water treatment. Moreover, in rural villages there are numerous waterworks often poorly managed by unskilled workers and seldom monitored.

The current situation should therefore be improved through structural interventions, such as the regular maintenance of the piped network and the introduction of specific treatments for turbidity and permanganate index removal from water. Moreover, surveys aimed at identifying the characteristics of rural waterworks and monitoring and controlling the quality of water distributed should be conducted.

## ACKNOWLEDGEMENTS

The authors are grateful to LDA, Local Democracy Agency in Zavidovići, for logistical and financial support and to all the people and local bodies who supplied us with data and information, particularly: the Municipality of Zavidovići, municipal multi-utilities company JKP Radnik, the presidents of the Local Communities, Ekopolicjia, Sloga enterprise, Rom Community representatives, Dom Zdravljia health clinic, local NGOs ATOM, Ekoklek and Peace Trees. Thanks to Veronica Di Bella for her useful comments and suggestions.

## REFERENCES

APHA, AWWA, WEF 1995a Chromogenic substrate coliform test. Enzyme substrate test, Section 9223 B. In *Standard methods for the Examination of Water and Wastewater*, 20th edn. (L. S. Clescerl, A. E. Greenberg & A. D. Eaton). APHA, Washington, DC.

APHA, AWWA, WEF 1995b Multiple-tube fermentation for members of the coliforms group. Standards total coliform fermentation technique, Section 9221 B. In *Standard methods for the Examination of Water and Wastewater*, 20th edn. (L. S. Clescerl, A. E. Greenberg & A. D. Eaton). APHA, Washington, DC.

APHA, AWWA, WEF 1997a Total solids dried at 103–105°C, Section 2540 B. In *Standard methods for the Examination of Water and Wastewater*, 20th edn. (L. S. Clescerl, A. E. Greenberg & A. D. Eaton). APHA, Washington, DC.

APHA, AWWA, WEF 1997b Ammonia – Mercuric Thiocyanate Flow Injection Analysis, Section 4500 G. In *Standard methods for the Examination of Water and Wastewater*, 20th edn. (L. S. Clescerl, A. E. Greenberg & A. D. Eaton). APHA, Washington, DC.

APHA, AWWA, WEF 1997c Chloride – Section 4500 D. In *Standard methods for the Examination of Water and Wastewater*, 20th edn. (L. S. Clescerl, A. E. Greenberg & A. D. Eaton). APHA, Washington, DC.

APHA, AWWA, WEF 2000a Nitrogen-Nitrite – Colometric Method, Section 4500 B. In *Standard methods for the Examination of Water and Wastewater*, 20th edn. (L. S. Clescerl, A. E. Greenberg & A. D. Eaton). APHA, Washington, DC.

APHA, AWWA, WEF 2000b Nitrogen-Nitrate – Cadmium Reduction Method, Section 4500 E. In *Standard methods for the Examination of Water and Wastewater*, 20th edn. (L. S. Clescerl, A. E. Greenberg & A. D. Eaton). APHA, Washington, DC.

AWWA 1999 Water Quality and Treatment. *A Handbook of Community Water Supplies. American Water Works Association*, 5th ed. Mc Graw-Hill.

Basu, S. R. & Main, H. A. C. 2001 Calcutta's water supply: demand, governance and environmental change. *Appl. Geogr.* **21**, 23–44.

Bogdanovic, S. 2000 The current state of Regulation in Bosnia and Herzegovina. *Water Int.* **25** (4), 534–543.

Calò, F. & Parise, M. 2008 Waste management and problems of groundwater pollution in karst environments in the context of a post-conflict scenario: The case of Mostar (Bosnia and Herzegovina). *Habitat International* **33**, 63–72.

Collivignarelli, C. & Vaccari, M. 2006 Alternatives for the improvement of the MSW management in Zavidovići (Bosnia-Herzegovina). In: *Proceedings of DepoTech 2006 Conference 'Abfall- und Deponietechnik, Abfallwirtschaf, Altlasten'*, Leoben, Austria, pp. 22–24 November 2006, 81–84.

Ekoklek 2007 *OPAZIL*. Survey report about water supply in Local Communities, Zavidovići (BiH).

International Organization for Standardisation 1993 ISO 8467 1993 Water Quality-Determination of Permanganate Index.

Jung, H. 2006 The new Water Sector Policy of Austrian Development Cooperation, ADC and its local implementation. *World Water Forum Bulletin* **82**(12), 4. Public Policies for Water and Sanitation, 4th World Water Forum, Mexico City, March 16–22, 2006, FT 3.48.

Jung, H. 2007 Dimensions of the appropriate technology concept and its functions as a steering tool for social development. In: *Proceedings of the International Conference 'The role of appropriate technologies in cooperation projects'*, Desenzano del Garda (I), December 16th, 2005, edited by Carlo Collivignarelli, pp. 9–30.

Kastelan-Macan, M., Ahel, M., Horvat, A. J. M., Jabucar, D. & Jovancic, P. 2007 Water resources management in Bosnia and Herzegovina, Croatia and the State Union of Serbia and Montenegro. *Water Pol.* **9**(3), 319–347.

Korfali, S. I. & Jurdi, M. 2007 Assessment of domestic water quality: case study, Beirut, Lebanon. *Environ. Monit. Assess.* **135**, 241–251.

LDA Local Democracy Embassy 2003 Introduction. In: *Proceedings of the conference 'Zavidovići, 10 years later'*, Zavidovići (BiH), 30 October–2 November, 2003, pp. 1–6.

Munever, P. 2006 *Prečišćavanje površinskih voda u cilju dobijanja vode za piće*. Graduation thesis in Civil Engineering, University of Prijedor (BiH).

Munever, P. 2007 Personal statement as technical worker of multi-utilities municipal company JKP Radnik. Zavidovići (BiH).

MWH 2005 *Water Treatment: Principles and Design*, 2nd edn. Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J. & Tchobanoglous, G.(eds). John Wiley & Sons, Inc, Chichester.

Općina Zavidovići 2007 II Osnove I Elementi Razvoja. Zavidovići (BiH).

REC Regional Environmental Center of Sarajevo 2000 Country report Bosnia & Herzegovina within strategic environmental analysis of Albania, Bosnia & Herzegovina, Kosovo and Macedonia. http://www.rec.org. Accessed 14 April 2009.

RFSJ Socialist Federal Republic of Yugoslavia 1987 Drinking water quality standards regulation. Official journal n.33.

Stefanović, G. M., Trajanović, M. D., Duić, N. Z. & Ferk, M. 2008 Pollution data in the western Balkan Countries: a state-of-the-art review. *Therm. Sci.* **12**(4), 105–112.

Terzić, S., Senta, I., Ahel, M., Gros, M., Petrović, M., Barcelo, D., Mütta, J., Knepper, T., Marfi, I., Ventura, F., Jovančić, P. & Jabučar, D. 2007 Occurrence and fate of emerging wastewater contaminants in Western Balkan Region. *Sci. Total Environ.* **399**, 66–77.

USEPA 2009 Drinking Water Contaminants. http://www.epa.gov/safewater/hfacts.html. US Environmental Protection Agency. Accessed 19 April, 2010.

Uzunovic-Kamberovic, S., Durmisevic, S. & Tandir, S. 2005 Environmental risk factors for hepatitis A infection in the Zenica-Doboj Canton, Bosnia and Herzegovina. *Clin. Microbiol. Infect. Dis.* **11**, 145–147.

WHO 2004 Data and statistics – Bosnia and Herzegovina. http://www.who.int/countries/bih/en/. World Health Organization. Accessed 14 April, 2009.

WHO 2006 Guidelines for Drinking-water Quality. First addendum to third edition. Volume 1 – Recommendations. World Health Organization. Available at http://www.who.int/water_sanitation_health/dwq/guidelines/en/index.html.

First received 23 December 2009; accepted in revised form 10 June 2010