INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr IV/4/2016, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 1899–1910
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2016.4.4.143

ANALYSIS OF THE STRUCTURE OF WATER CONSUMPTION IN RURAL HOUSEHOLDS IN TERMS OF DESIGN GUIDELINES WATER AND SEWAGE SYSTEMS

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Abstract

The aim of the paper was an analysis of the structure of tap water consumption by rural households considering the use of its results for designing the elements of water supply and sewer systems. The analysis of this structure was based on direct measurements of water consumption conducted in 2011-2014 in 30 households located in Przeginia Duchowna village (Czernichów commune, Malopolskie province). Double measurement of water consumption (water supply connection or water draw off point outside a residential building) enabled the separation water consumption for household and additional purposes from the total water consumption per household. Analysis of the collected data revealed considerable disproportions between the real water consumption and stated in the design guidelines. Calculated on the basis of the study, averaging 85.6 $dm^3 \cdot I^{-1} \cdot d^{-1}$, accounted for only 57% of the value of 150 $dm^3 \cdot I^{-1} \cdot d^{-1}$ most commonly used in design. Because of the possible determining the water consumption structure it was demonstrated, that the divergences concerned also the volume of domestic sewage discharged from rural households. Obtained results revealed also that application of the principle, where the volume of sewage equals the volume of water consumption by rural households, for designing sewer systems is usually incorrect. In the analyzed household in fact, only 83.1% of the volume of waste water was discharged in the form of waste water to the sewage system. The remainder was called. non-returnable water consumption for additional purposes.

Keywords: rural households, water consumption, structure of water consumption

INTRODUCTION

The basis for dimensioning water and sewage devices is correct determination of the demand for water, which is a difficult and responsible task. Observations of currently existing systems reveal a considerable number of those, which were incorrectly dimensioned already at the stage of designing. This leads to misuse of the investment means and a considerable increase in the operational costs in comparison to the project assumptions. The other outcome of this situation is also the fact that in some of the installations the assumed technological effects were not achieved. Some authors investigating this problem, see the cause of this state of affairs in the use of old fashioned design guidelines which do not correspond to reality (Ćwiertnia 2004, Bergel 2013, Pawęska *et al*. 2013). Analysis of water consumption conducted by these authors reveals considerable discrepancies between the actual and assumed in the project, amount of consumed water. Most rural water supply systems do not reach designed production capacity, even after more than a dozen years of operation.

A correct determination of water demand is also important due to planning of the development and modernization of water supply and sewer systems and the water and sewage charges. Water companies sell increasingly less water, but spend more money on improving water quality, which require great financial outlays (Bergel 2005). Wrongly estimated water demand causing an increase in the level of water consumption may cause lower incomes from the water charges and in consequence a lack of funding to cover the real expenditure of water companies (Roman *et al*.1996).

Therefore, an analysis of water consumption structure may be very helpful in correct determination of unit water consumption. Rural households use water for two basic categories of needs: household and additional, such as animal keeping, lawns watering and crop irrigation, washing of cars, vehicles and farm machinery, maintaining tidiness on farmyards, dilution of plant protection chemicals and for purposes described as other, such as: swimming pool filling in summer season. Water used for satisfying household needs may be taken and discharged into sewer system as sewage, whereas water used for satisfying additional needs, usually is not drained into the sewer system and constitutes so called non-returnable water consumption. Increase in water consumption in rural areas for additional purposes has been noticed in recent years. It is inter alia due to a greater number of vehicles and their frequent washing, better care of the inhabitants for their farmyards, common application of plant protection chemicals and watering lawns and irrigation of crops. Water consumption structure is therefore the main factor affecting the quantity and kind of sewage discharged from households. However, the principles applied by many designers, where the quantity of discharged sewage is assumed as equal to the consumed water, in practice leads to overestimation of costs of construction and operation of sewer systems, worsening of sewage treatment effects, over-dimensioning of sewer network and sewage treatment plant facilities and overestimating charges paid by the sewer system users for sewage disposal (Bergel 2005). In order to avoid the latter situation, farm owners more often decide to install additional water meters, which measure the amount of nonreturnable water consumption. Installing a water meter allows to reduce the costs because the charge is calculated only for water consumption but not for sewage disposal. In accordance with Polish law (Act 2001), technical conditions for the installation of an additional water meter may be issued to the owners of single-family houses and agricultural or horticultural farms.

Is studying the structure of water consumption are extremely valuable for water companies, designers and researchers in the field of water consumption. They provide information on the value of water consumption and sewage outflow indices, which are used at all stages of "technical life" of water supply and sewer systems, i.e. at the stage of designing, performance and exploitation.

The aim of the work is to analyze the structure of water consumption in rural households in the context of its use results in the design of water and sewage systems.

METHODS

The research was based on direct measurements of water consumption conducted from 1 January 2011 to 31 December 2014 in 30 selected rural households located in Przeginia Duchowna village (Czernichów commune, Malopolska district).

Total water consumption per household and water consumption for additional purposes were determined on the basis of quarterly readings from the residential and additional water meter in the analysed households. Water for additional purposes was most frequently drawn from draw-off taps mounted in utility rooms or outside the building. Also the current number of household members was noted in the investigations.

Calculated water use for household purposes ($dm^3 \cdot H^{-1} \cdot d^{-1}$) is a difference between water consumption indicated by the main and additional water meters. Taking into account the number of inhabitants, also unit water consumption for these purposes was computed and consequently a unit volume of household sewage ($dm^3 \cdot I^{-1} \cdot d^{-1}$).

Analyzed the consumption of water is characterized by the following descriptive statistics: mean, median, mode, minimum, maximum, standard deviation, skewness and curtosis.

RESULTS AND DISCUSSION

Water consumption per a conversion inhabitant

Direct measurement of water consumption allowed to determine the total daily water use per household. Taking into account the number of individual households members, the water use was analyzed with reference to so called conversion inhabitant ($dm^3 \cdot CI^{-1} \cdot d^{-1}$).

Table 1. Total water consumption on the household

Year	Measurement Period	Water consumption, [$dm^3 \cdot CI^{-1} \cdot d^{-1}$]		
		mean	maximum	minimum
2011	1st quarter	45.7	140.7	5.8
	2nd quarter	90.9	192.3	14.1
	3rd quarter	149.4	447.8	22.4
	4th quarter	87.1	287.7	18.9
	mean	**93.3**	**267.1**	**15.3**
2012	1st quarter	89.1	188.9	11.1
	2nd quarter	105.7	239.2	14.7
	3rd quarter	156.7	400.0	18.5
	4th quarter	88.1	188.9	12.0
	mean	**109.9**	**254.3**	**14.1**
2013	1st quarter	77.7	188.9	8.4
	2nd quarter	103.6	333.7	15.4
	3rd quarter	133.4	422.8	15.2
	4th quarter	113.8	402.2	19.6
	mean	**107.1**	**336.9**	**14.7**
2014	1st quarter	100.6	260.7	15.6
	2nd quarter	100.9	241.8	17.6
	3rd quarter	129.3	449.3	17.4
	4th quarter	94.5	268.1	15.2
	mean	**106.3**	**305.0**	**16.5**

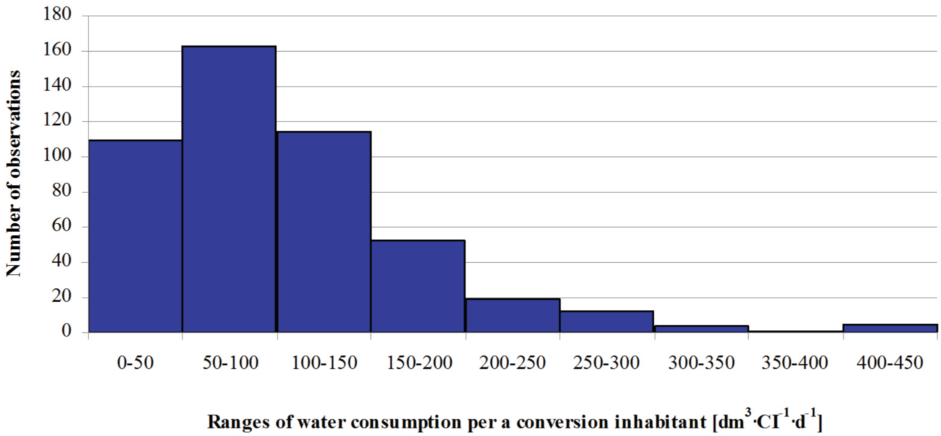

Figure 1. Histogram of total water consumption on the household

Values of mean daily water consumption and its maximum and minimum values for the investigated period in the analysed localities are presented in Table 1. Mean 4-yr total water consumption per a conversion inhabitant in Przeginia Duchowna was on the level of 104.2 dm^3·CI^{-1}·d^{-1} (Table 2). The value is lower than the one stated by Pawełek and Kaczor (2008), i.e. 153.4 dm^3·CI^{-1}·d^{-1} and within the rate from 67.0 to 135 dm^3·CI^{-1}·d^{-1} reported by Bugajski and Kaczor (2007).

Table 2. Descriptive statistics of total water consumption on the household

Kind of statistics	Unit	Value
Number of observations	[pcs.]	480
Mean	[dm^3·CI^{-1}·d^{-1}]	104.2
Median	[dm^3·CI^{-1}·d^{-1}]	92.5
Mode	[dm^3·CI^{-1}·d$^{-1/}$pcs.]	87.0/5 pcs.
Minimum	[dm^3·CI^{-1}·d^{-1}]	5.8
Maximum	[dm^3·CI^{-1}·d^{-1}]	449.3
Standard deviation	[dm^3·CI^{-1}·d^{-1}]	71.4
Skewness	[-]	1.7
Curtosis	[-]	4.1

Mean water consumption in Przeginia Duchowna was lower in 2011, whereas in the other years higher than the stated mean value.

A histogram was drawn in order to establish the range of total water consumption for the analysed period of research (Fig.1). Analysis of the amount of water use revealed the greatest frequency of water consumption as ranging from 50-100 $dm^3 \cdot CI^{-1} \cdot d^{-1}$. About 34% of the measurements showed this amount of water consumption. Water use ranging from 0-50 and 100-150 $dm^3 \cdot CI^{-1} \cdot d^{-1}$ was noted much more rarely, consituting respectively 23 and 24% of the observations. Water consumption exceeding 150 $dm^3 \cdot CI^{-1} \cdot d^{-1}$ constituted only 19% of cases.

Descriptive statistics of total water consumption on the household are presented in Table 2. They show a considerable variability of water consumption per a conversion inhabitant in 2011-2014.

The data were corroborated by the standard deviation value 71.4 $dm^3 \cdot CI^{-1} \cdot d^{-1}$ constituting as much as 68.5% of the mean value. Obtained coefficient of skewness indicated that a majority of results was below the mean value.

Water consumption structure

Double metering of water consumption allowed to separate from the total water use per household, the water volume, which after use is changed into household sewage and discharged into the sewer system.

Averaged values of water consumption per household for household and other purposes in individual quarters are presented in Table 3. The data show that the way of water use differed depending on the quarter, which was influenced in the first place by the variability of the seasons of the year. Mean daily water use for household purposes in individual quarters ranged from 155.2 to 481.4 $dm^3 \cdot H^{-1} \cdot d^{-1}$. On the other hand, water consumption for additional purposes varied, ranging from 12.5 to 137.0 $dm^3 \cdot H^{-1} \cdot d^{-1}$.

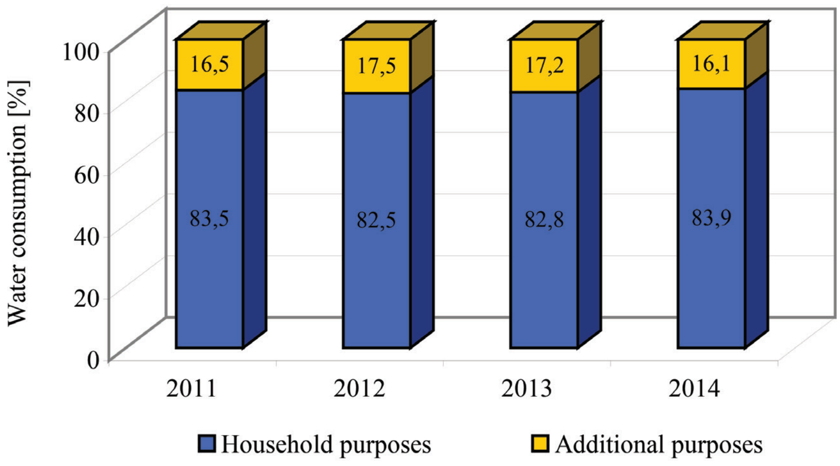

Figure 2. Structure of total water consumption in the analysed rural households

The highest values were registered in the 3rd quarter, which may be caused by additional purposes which emerged in this period, such as watering of lawns and crop irrigation, more frequent car washing, filling swimming pools, greater care for the cleanliness of farmyards or dilution of plant protection chemicals. The lowest values were registered in the 1st quarter, when water was used mainly for household needs of the inhabitants and for animal keeping. Water use for additional purposes in this period becomes considerably limited and in some household disappears altogether. Analysing the proportion of mean daily water consumption for individual purposes in total water use per household, it was found that between 77.8 and 88.3% (on average 83.1%) was used for household purposes and between 11.7 and 22.2% (on average 16.9%) for additional purposes.

Table 3. Structure of water consumption in Przeginia Duchowna

Year	Measurement period	Water consumption [$dm^3 \cdot H^{-1} \cdot d^{-1}$]	
		Household purposes	Additional purposes
2011	1st quarter	155.2	24.0
	2nd quarter	328.1	45.8
	3rd quarter	478.3	127.2
	4th quarter	277.6	12.5
	mean	**309.8**	**52.4**
2012	1st quarter	303.5	47.7
	2nd quarter	343.4	73.3
	3rd quarter	481.4	137.7
	4th quarter	291.1	57.9
	mean	**354.9**	**79.2**
2013	1st quarter	270.0	35.9
	2nd quarter	348.1	68.3
	3rd quarter	414.9	117.4
	4th quarter	359.5	88.9
	mean	**348.1**	**77.6**
2014	1st quarter	340.9	49.7
	2nd quarter	341.0	68.6
	3rd quarter	418.3	109.5
	4th quarter	321.9	53.5
	mean	**355.5**	**70.3**

The structure of water consumption in the analysed rural households is shown in Figure 2.

The percentage of mean water consumption for household purposes in Przeginia Duchowna is higher than the value of 78% reported by Pawełek and Bergel (2003).

Unit consumption of water for household purposes/domestic sewage outflow

As has been mentioned before, the amount of water used for domestic purposes is connected with the volume of forming sewage, which is then disposed by a sewer system to the treatment plant.

Table 4. Mean daily water consumption for household purposes (household sewage outflow) in 201-2014

Year	Measurement period	Water consumption [$dm^3 \cdot I^{-1} \cdot d^{-1}$]
2011	1st quarter	39.4
	2nd quarter	80.4
	3rd quarter	119.3
	4th quarter	70.7
	mean	**77.4**
2012	1st quarter	78.1
	2nd quarter	85.8
	3rd quarter	121.4
	4th quarter	73.6
	mean	**89.7**
2013	1st quarter	68.3
	2nd quarter	85.8
	3rd quarter	102.6
	4th quarter	90.1
	mean	**86.7**
2014	1st quarter	87.2
	2nd quarter	83.9
	3rd quarter	102.2
	4th quarter	80.1
	mean	**88.4**

The data on water consumption for household purposes and the number of inhabitants were used to calculate unit water consumption per inhabitant, which may provide a basis to determine a unit outflow of household sewage from rural households. Averaged values of unit water use (sewage outflow) in individual quarters of the years 2011-2014 are compiled in Table 4. They fluctuated widely from 39.4 to 121.4 $dm^3 \cdot I^{-1} \cdot d^{-1}$, assuming average values in the individual years on the level of 77.4-89.7 $dm^3 \cdot I^{-1} \cdot d^{-1}$ (on average 85.6 $dm^3 \cdot I^{-1} \cdot d^{-1}$). The average value is by 14.4 $dm^3 \cdot I^{-1} \cdot d^{-1}$ lower than the value of 100 $dm^3 \cdot I^{-1} \cdot d^{-1}$ stated in the regulation of the minister of infrastructure (Regulation 2002) for apartments fully equipped with sanitary appliances and discharging sewage to a collective sewer system. Definitely bigger differences occurred when the obtained values were compared with the regulation of the minister of agriculture (Zarządzenie 1966). For the same standard equipment of apartments with sanitary appliances, the regulation states the amount of water consumption on the level of 150 $dm^3 \cdot I^{-1} \cdot d^{-1}$. Therefore, water use computed on the basis of research is lower even by 64.4 $dm^3 \cdot I^{-1} \cdot d^{-1}$, constituting only 57% of this value.

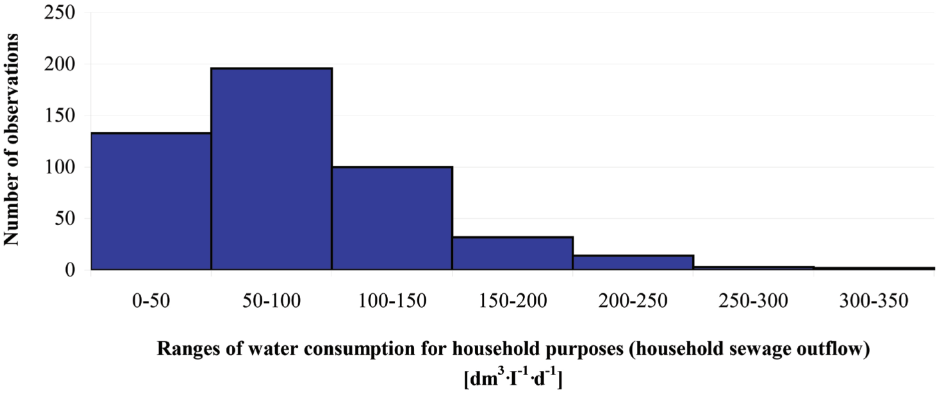

Figure 3. Histogram of water consumption for household purposes (household sewage outflow) in Przeginia Duchowna village in the years 2011-2014

The mean volume of water used for household purposes in Przeginia Duchowna was found to be higher by 18.5 $dm^3 \cdot I^{-1} \cdot d^{-1}$ than the value of 67.1 $dm^3 \cdot I^{-1} \cdot d^{-1}$ stated by Kaczor (2006), but lower than the value in the range of 140-220 $dm^3 \cdot I^{-1} \cdot d^{-1}$, reported by Jóźwiakowski (2012).Amount of unit water consumption for domestic purposes (sewage outflow), which appeared most frequently is presented in Figure 3. Water use for domestic purposes, providing a basis of determining the household sewage volume, like in case of water use per a conversion inhabitant, most frequently laid within the range from 50 to 100 $dm^3 \cdot I^{-1} \cdot d^{-1}$. The next in turn noted water consumption ranged from 0-50 $dm^3 \cdot I^{-1} \cdot d^{-1}$. It is due to reducing water consumption per a conversion inhabitant by so called "non-returnable water use", resulting in moving of water consumption on the histogram from higher to lower ranges.

Descriptive statistics of water consumption (sewage outflow) shown in the histogram per one inhabitant are presented in Table 5. The value of standard deviation 52.8 $dm^3 \cdot I^{-1} \cdot d^{-1}$ constituted 61.7% of the mean value of 85.6 $dm^3 \cdot I^{-1} \cdot d^{-1}$, which evidences a considerable variability of water use for household purposes and therefore sewage outflow. The highest unit sewage outflow was 344.6 $dm^3 \cdot I^{-1} \cdot d^{-1}$ and the lowest 1.6 $dm^3 \cdot I^{-1} \cdot d^{-1}$. Skewness coefficient indicates that a majority of results is below the mean value.

Table 5. Descriptive statistics of water consumption for household purposes (sewage outflow) from the analysed households

Kind of statistics	Unit	Value
Number of observations	[pcs.]	480
Mean	[$dm^3 \cdot I^{-1} \cdot d^{-1}$]	85.6
Median	[$dm^3 \cdot I^{-1} \cdot d^{-1}$]	79.2
Mode	[$dm^3 \cdot I^{-1} \cdot d^{-1/}$pcs.]	81.5/7 pcs.
Minimum	[$dm^3 \cdot I^{-1} \cdot d^{-1}$]	1.6
Maximum	[$dm^3 \cdot I^{-1} \cdot d^{-1}$]	344.6
Standard deviation	[$dm^3 \cdot I^{-1} \cdot d^{-1}$]	52.8
Skewness	[-]	1.3
Curtosis	[-]	2.7

The volume of household sewage discharged from rural households has been currently determined on the basis of water use, usually without considering its structure. Analysing the amount of average water use per a conversion inhabitant and mean water consumption for household purposes (sewage outflow) it may be seen, that the real volume of household sewage discharged from rural households is smaller than total water use. Therefore, application of the principle that the volume of household sewage discharged from rural households equals the amount of used water is incorrect.

Taking into account the structure of water consumption, it was determined that the real, unit outflow of household sewage from rural households in Przeginia Duchowna was on the level of 82.1% of water use per a conversion inhabitant. This value is lower than stated by some authors. For instance, Ćwiertnia (2004) says that the volume of discharged sewage constituted c.a. 93% of the volume of consumed water, whereas Heidrich (1998) gives the values on the level of 90-95%. On the other hand, the values similar to the ones obtained in the presented article were reported by Bergel and Kaczor (2007), who demonstrated that the value fluctuates between 76 and 86%.

CONCLUSIONS

Analyses of water consumption conducted in 2011-2014 and the dependencies between water consumption and the outflow of sewage discharged from rural households determined on this basis made possible formulating the following conclusions:

1. Mean total daily water use per household, referred to a conversion inhabitant was 104.2 $dm^3 \cdot CI^{-1} \cdot d^{-1}$.
2. The volume of sewage discharged to the sewer system does not equal total volume of water used per household, because structure of water use revealed that on average 83.1% of the total water consumption was used for household purposes and 16.9% for additional purposes.
3. Water consumption for household purposes, which should provide a basis for determining the volume of sewage discharged from households to the sewer system, was on average 85.6 $dm^3 \cdot I^{-1} \cdot d^{-1}$.
4. Mean unit sewage outflow from households was much lower than the values stated in the guidelines. It made up only 57% of the value of 150 $dm^3 \cdot I^{-1} \cdot d^{-1}$ most frequently used in designing.
5. Analysis of the research results revealed that the design guidelines on average standards of water consumption are considerably overestimated and should be updated. On the other hand, the structure of water consumption is crucial for the correct estimation of the unit sewage outflows from rural households.

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Received: 25.10.2016
Accepted: 22.12.2016