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**Assessment of safe drinking water provision in rural areas of Karaganda region:
a case study from Bukhar-Zhyrau district**

6D110200 – Public Health

Thesis is submitted in fulfillment of the requirements for the degree of
Doctor of Philosophy (PhD)

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CONTENT

NORMATIVE REFERENCES

The following regulatory references have been used during this work:

Code of the Republic of Kazakhstan *On People's Health and Healthcare System* dated September 18, 2009, No. 193-IV.

Water Code of the Republic of Kazakhstan dated July 9, 2003, No. 481.

The State Program for the Regional Development 2020 approved by decree of the Government of the Republic of Kazakhstan on November 16, 2018, No. 767.

The State Program for the Regional Development 2020-2025 approved by decree of the Government of the Republic of Kazakhstan on December 27, 2019, No. 990.

Sanitary rules *Sanitary and epidemiological requirements for water sources, withdrawal points for domestic and drinking purposes, domestic and drinking water supply, places for cultural and social water use and safety of water bodies* approved by order of the Minister of National Economy of the Republic of Kazakhstan on March 16, 2015, No. 209.

Rules for *The use of water supply and disposal systems in settlements* approved by order of the Minister of National Economy of the Republic of Kazakhstan as of February 28, 2015, No. 163.

Resolution A/RES/55/2, United Nations Millennium Declaration adopted by the United Nations General Assembly on September 8, 2000.

Resolution A/RES/64/292, The Human Right to Water and Sanitation adopted by the United Nations General Assembly on July 28, 2010.

Resolution A/RES/70/1, Transforming our World: the 2030 Agenda for Sustainable Development adopted by the United Nations General Assembly on 25 September 2015.

DEFINITIONS

This thesis involves the following terms with the corresponding definitions:

Drinking water – means water in its natural state or after treatment which meets the quality established by national and hygienic standards and is intended for household and drinking needs of the population.

Safely managed drinking water – is water from an improved water source located on premises, available when needed and free of faecal and priority contamination.

Improved drinking water source – is a source that have the potential to deliver safe water by nature of their design and construction.

Basic drinking water source – is an improved source provided collection time is not more than 30 minutes for a round trip including queuing.

Limited drinking water source – is an improved source where collection time exceeds over 30 minutes for a round trip to collect water, including queuing.

Unimproved drinking water source – is an unprotected dug well or unprotected spring.

Open source (no service) – is a river, dam, lake, pond, stream, canal or irrigation canal.

Wastewater – is water generated as a result of human activities or in a contaminated area and discharged into natural or artificial water bodies, or onto local terrain.

Water supply – means a set of measures that ensure the abstraction, storage, treatment, delivery and distribution of water through water supply systems to water consumers.

Water discharge – implies a set of measures that ensure the collection, transportation, treatment and disposal of wastewater through the water disposal system in water bodies and (or) onto local terrain.

Water consumption – is using water from water bodies or using services of water organizations and receipt of water from water supply systems.

Water use means the use of water resources in the manner prescribed by the legislation of the Republic of Kazakhstan to meet own needs and (or) commercial interests of individuals and legal entities.

Maximum permissible discharge (MPD) – is the mass of substance in wastewater, maximum allowable for disposal at a given point of a water body per unit time in order to ensure acceptable water quality in the control point.

Maximum permissible concentration (MPC) – is the maximum amount of harmful substance per unit volume or mass, which does not cause any unhealthy changes in the body and adverse hereditary changes in the offspring under daily influence for an unlimited time.

Burden of disease – is a measure of population health that aims to quantify the gap between the ideal of living to old age in good health, and the current situation where healthy life is shortened by illness, injury, disability and premature death.

DESIGNATIONS AND ABBREVIATIONS

AIDS – Acquired Immune Deficiency Syndrome
CDC – Center for Disease Control and Prevention
CI – Confidence Interval
DNA – Deoxyribonucleic Acid
DQCSGS – Department for Quality Control and Safety of Goods and Services
ECDC – European Centre for Disease Prevention and Control
EHCSA – Energy, Housing and Communal Services Authority
GDP – Gross Domestic Product
HIV – Human Immunodeficiency Virus
HPA – Health Protection Agency
MDG – Millennium Development Goal
MPC –Maximum Permissible Concentration
MPD – Maximum Permissible Discharge
NESID – National Epidemiological Surveillance of Infection Diseases
NNDSS – National Notifiable Diseases Surveillance System
OR – Odds Ratio
PCR – Polymerase Chain Reaction
PHAC – Public Health Agency of Canada
RNA – Ribonucleic Acid
SAFE – Surgery, Antibiotics, Facial cleanliness, and Environmental change
SDG – Sustainable Development Goal
SWTR – Surface Water Treatment Rule
UK – United Kingdom
UNICEF JMP – Nations International Children's Emergency Fund Joint Monitoring Programme
UN – United Nations
UNO – United Nations Organization
USA – United States of America
US EPA – United States Environmental Protection Agency
UV – Ultraviolet
WASH – Water, Sanitation and Hygiene
WHO – World Health Organization
WSPs – Water Safety Plans

INTRODUCTION

Relevance of the research. Access to safe drinking water is the first aspect of public health, which significantly reduces incidence of disease and mortality. It also improves life expectancy, school attendance and gender equality, as well as reduces poverty and ensures social and economic development of the country. However, the benefits of access to the improved source of drinking water can only be fully realized if there is access to improved sanitation and personal hygiene [1-4].

The burden of diseases associated with water, sanitation and hygiene (WASH) accounts for 4% of all deaths and 5.7% of the total disease burden in the world [5]. Improved WASH could prevent the deaths of more than two million children under the age of five annually, since the main cause of death among them is diarrhea [6]. During diarrhea, water and electrolytes are excreted from the body, which may result in dehydration [7-10]. Diarrhea also indirectly affects stunting in children under five years of age, which, in turn, leads to increased susceptibility to infectious diseases of various etiologies (figure 1) [11-13].
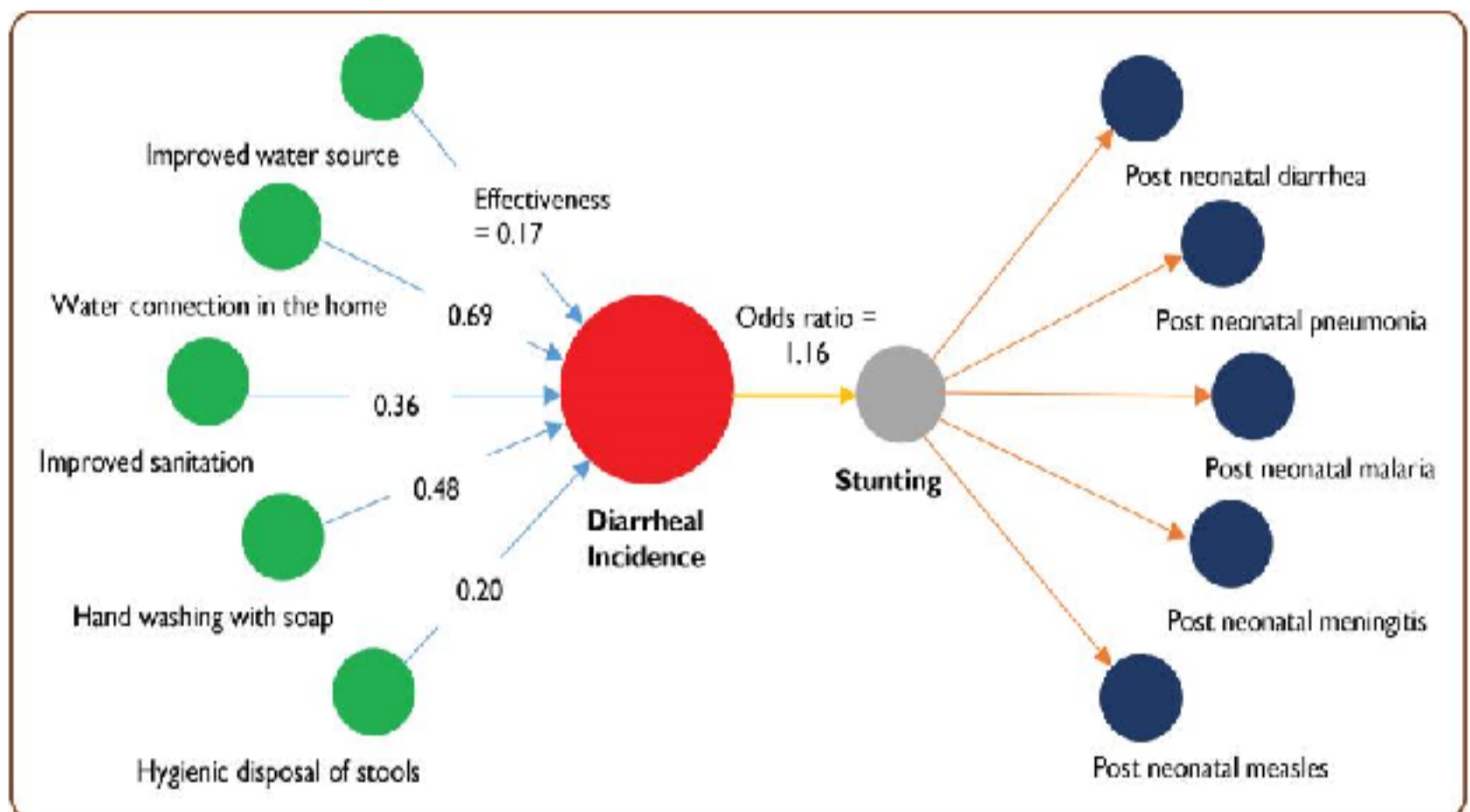
Figure 1 – The effectiveness of WASH components in reducing the cases of diarrhea among children under five years old [13, p. 4]

WASH concept means both the availability of technical means (drinking water, toilet, washstand and soap), and the development of human potential contributing to the improvement of conditions directly in households and hygiene skills among the population. It is often difficult to distinguish the direct cause of WASH-related diseases due to the intimate and complex relationships between the different WASH components. This may be one of the reasons why increases in water supply and sanitation service coverage sometimes does not reduce diarrheal infections [6, p. 15].

Therefore, to achieve any sustainable results in WASH, it is necessary to improve not one, but all the components [8, p. 2].

The target task of the Millennium Development Goal (MDG) 7.C was to halve a number of the population with no access to safe drinking water and basic sanitary facilities by the year 2015 [14-16]. Through implementing this target, the proportion of people with access to a basic drinking water service grew from 81% to 89% from 2000 to 2015 [17, 18]. However, a weakness of the MDGs monitoring was an insufficient attention to water safety [14, p. 1178; 19], which became a key element of the target task for water supply and sanitation upon design of the Sustainable Development Goals (SDG 6) [20, p. 1].

According to the United Nations (UN) Resolution 64/292: "The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses" [15, p. 283; 21]. Therefore, water safety is the integral element of achievement of the SDGs. SDG 6 aims to "ensure accessibility and sustainable management of water resources and sanitation for all" and includes six engineering purposes relating to drinking water, health affairs, wastewater management, water use efficiency, integrated water resources management and aquatic ecosystems protection [22]. SDG 6.1 call for full coverage of safely managed drinking water by 2030. The "Safely managed drinking water" indicator includes three following conditions: accessible on premises, available when needed and free from contamination [20, p. 1; 23, 24].

Achieving SDG 6 is a huge challenge for all countries, not only for low- and middle-income ones [8, p. 2]. The commitment to "leave no one behind" requires a focus on rural areas, which is typically neglected [17, 25-29]. Tens of millions of rural residents face ongoing problems with water systems, which results in loss of resources and false expectations. Many of those who supposedly use the improved service, de facto face poor quality, constant interruptions in the system and premature failure [1, p. 2; 20, p. 2; 29, p. 330]. About 844 million people in the world still do not have access to basic water supplies, and 79% of them are rural residents [30]. At the same time, 2.1 billion people have no safely managed drinking water supply system service. This means that 14.9% of the urban- and 45.2% of the rural population need improved services [20, p. 2; 24].

Kazakhstan is one of the countries on the Eurasian continent that experiences the most severe water shortages. Water shortage and its poor quality have been determined as vital issues threatening the future prosperity of Kazakhstan. Therefore, the above UN goal was integrated into a number of state programs, such as "State Program for the Regional Development 2020", "State Program for the Regional Development 2020-2025" and "Auyl - el besigi" [20, p. 2; 31-33]. In the Republic of Kazakhstan, *water withdrawal* was about *800-900 million cubic meters* for the last ten years. Furthermore, the coverage of water supply in the urban and rural areas of Kazakhstan differ significantly. Whereas the actual water consumption for household and drinking needs per an *urban resident is 100 liters a day on average*, it is only 32 liters for a villager. About 88% of urban residents have access to centralized water supply and 84% of them

to sewerage, while in rural areas these rates are only 52% and 11%, respectively [18, 20, p. 2; 34-36].

Despite the enormous state efforts to provide rural areas with safe drinking water, no sustainable solutions have largely been found. Consequently, rural areas represent the biggest challenge in achieving SDG 6. Any alternative strategies of water supply management are currently being sought to increase resistance and reduce the vulnerability of the population to water supply problems.

The aim of this research was to study and analyze the provision of drinking water to the rural population in order to develop further recommendations on how to improve access to safe drinking water in rural areas.

The following objectives have been set to achieve this aim:

1) to study the provision of rural population in Karaganda Region with centralized water supply;

2) to analyze WASH-related health issues in rural areas of Karaganda Region;

3) to analyze the results of the population's assessment of the current access to and water quality in the villages with various types of water supply;

4) to develop recommendations for improving access to safe drinking water in rural areas.

Scientific novelty and theoretical significance of the research. This thesis examines the access of rural households to safe drinking water, the spatial and temporal reliability of water supply sources, as well as unfulfilled needs and demand for tap water in villages through the lens of public health. This work also attempts to suggest possible environmentally sustainable and cost-effective ways to improve access to safe WASH facilities and practices in rural areas in order to enhance health indicators. Moreover, the problem of safe water supply to the rural population was studied in the specifics of the social and economic conditions of Kazakhstan.

The main findings to be defended:

− existing centralized water supply systems in rural areas is not able to satisfy the needs of the population for drinking water completely. That is why a significant number of people use water from alternative sources of unknown quality;

− the population's satisfaction with the quality of drinking water and the reliability of the source depends on its convenience of its operation; therefore, the borehole is recognized as the best quality and most reliable source of water supply, and tankered water is considered to be of poor quality and unreliable;

− to improve access to safe WASH facilities and practices among the rural population requires a systematic approach to implement of measures for the organization of water supply, control and monitoring of their completeness and effectiveness. It will cover the entire chain of the water supply system from the intake to the consumer and the discharge of wastewater from the consumer to natural sources.

Practical significance of the research. The practical significance is to develop recommendations for improving access to safe WASH facilities and practices among the rural population. The findings of this research have been adopted by Akimat (local council) of Bukhar-Zhyrau District in Karaganda Region (the adoption deed is

available), and two intellectual property certificates have been obtained (Appendices A, B, C).

The author's personal contribution. The collection of primary material, a questionnaire construction, processing and statistical analysis of the data, formulation of the main findings and conclusion of the thesis belong to the author. The author has personally organized, documented and formalized all the materials in the thesis.

Thesis approbation. The main results, findings and conclusions of the thesis were reported and presented at:

– "Winds of Change: Towards New Ways of Improving Public Health in Europe", 11th European Public Health Conference, Ljubljana city, Slovenia, November 28 – December 1, 2018;

– "Modern Technologies of Diagnosis, Treatment and Prevention of Infectious And Parasitic Diseases", International Scientific and Practical Conference, Bukhara city, Uzbekistan, April 8 – 9, 2019;

– "Fundamental Science and Clinical Medicine – Human and Health, 22nd International Biomedical Conference of Young Researchers, Saint Petersburg city, Russia, April 20, 2019;

– "Prospects for the Development of Biology, Medicine and Pharmacy", VIth International Scientific Conference of Young Scientists and Students, Shymkent city, Republic of Kazakhstan, December 7 – 8, 2018;

– "PhD Day – 2016" organized by Karaganda State Medical University, Karaganda city, Kazakhstan, December 9, 2016;

– Meetings of the Department of Threpsology and Hygiene of Karaganda Medical University (Minutes No.14 of May 03, 2019);

– Meetings of the Scientific Advisory Board of Karaganda Medical University (Minutes No.12 of June 26, 2019).

Publications. According to this thesis, *thirteen sc*ientific works were published: *four* articles in some publications recommended by the Committee on the Control of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan; *two* more articles, in an international peer-reviewed journal called *International Journal of Environmental Research and Public Health* indexed in the databases Web of Science and Scopus (*IF=2.44 in 2017 and IF=2.81 in 2018*); five abstracts, in materials of international scientific conferences, including three ones in materials of foreign conferences (one of them, in the international peer-reviewed journal called *European Journal of Public Health* indexed in the database Web of Science (*IF=2.234 in 2018*)). There is also two certificates of entering information into the State Register of Copyrighted Items.

The structure and scope of the thesis. The thesis is presented on 98 pages of Microsoft Word text editor and consists of introduction, literature review, descriptions of materials and methods, results of own research divided into two sections, conclusion, practical recommendations, references and six appendices. The thesis is also illustrated with eight tables and twenty-seven figures. References include 275 sources in Kazakh, Russian and English languages.

1 DRINKING WATER AS A RISK FACTOR TO PUBLIC HEALTH (LITERATURE REVIEW)

1.1 The significance of WASH in human activity

Sustainable development of national economy depends on availability and condition of water resources [37]. WASH are basic human needs that influence on health, living standards and quality of life [38-40]. Unimproved hygiene and inferior sanitary conditions, as well as insufficient and unsafe drinking water are responsible for 7% of the total disease burden and 19% of child mortality worldwide [5, p. 1; 6, p. 7]. According to the World Bank [41, 42], low WASH lead to about 675,000 premature deaths every year. Annual economic losses of some countries are estimated in up to 7% of Gross Domestic Product (GDP) [43].

1.1.1 Health implication of safe drinking water supply: basic terms

Water is a key factor in human health [44-46]. Almost all of its sources are exposed to anthropogenic and technogenic influence of varying intensity [47]. Tap water is used for different purposes and the range of its application is expanding with increasing social standards of living. It is used for drinking, bathing, washing, watering plants or lawns, replenishment of swimming pools and many other activities that expand as the country develops. Alternative water use imply different requirements to water characteristics, in other words, when it comes to drinking water, its quality is important but it is of less importance when water is used for other purposes [43, c. 193; 48].

In terms of physical, chemical and bacteriological parameters, the water of acceptable quality, which is safe to drink and can be used in cooking, is defined as *drinking water*. According to common values, the rate of daily water consumption for physiological needs is at least two liters per person weighing 60 kg [49]. When the air temperature exceeds $25 \pm {}^{0}$C, water consumption rises sharply. As compared to the adult population, infants and children consume more water [50]. Besides satisfying some physiological needs, water is essential for hygienic and domestic purposes. Therefore, actual water consumption depends on many factors including climate and physical activity as well as health-promoting culture of people and its availability [43, c. 193].

National water consumption standard in rural areas is 30 liters per capita per day and 48-44% access to safe water and sanitation [51]. *Water supply* means 30 liters of safe water per capita per day within 250 meters, where one point serves about 250-500 people. *Safe water* is water that meets national requirements for drinking water quality [52]. *Water supply* includes the delivery of water for domestic use, apart from irrigation or stockbreeding. *Sanitation* is used in a strict sense of sanitary disposal, except for other environmental health activities such as management of domestic solid waste and surface drainage [53]. *Access to water* is defined as the presence of water, at least 20 liters per person per day from a source within a kilometer from the user [54]. *Improved drinking water source* is a drinking water source or a delivery point, which protects the

water source from outside contamination, particularly faeces, by virtue of its construction and design [43, p. 193; 53, 55].

According to the World Health Organization (WHO) [44, p. 135; 56], water contains 13,000 potentially toxic elements. The problem of water contamination in lakes, rivers and ground water has become very acute over the past few decades [57]. Harmful substances can accumulate in the body causing a variety of diseases up to malignant neoplasms [43, c. 193; 44, c. 135; 56, 58-62].

The direct health benefits from the improvement of water supply and sanitary conditions in rural areas are well known. These activities involve the safe disposal of human waste, efficient use of water for hygienic purposes (washing, cleaning, etc.) and satisfaction of basic needs with drinking water [52, p. 1170; 63]. Safe water supply exerts a considerable impact on reduction of water-related diseases and rise in the living standards and quality of life (figure 2) [37, 43, c. 193; 44, c. 137; 56, 57, c. 1; 58, p. 361].
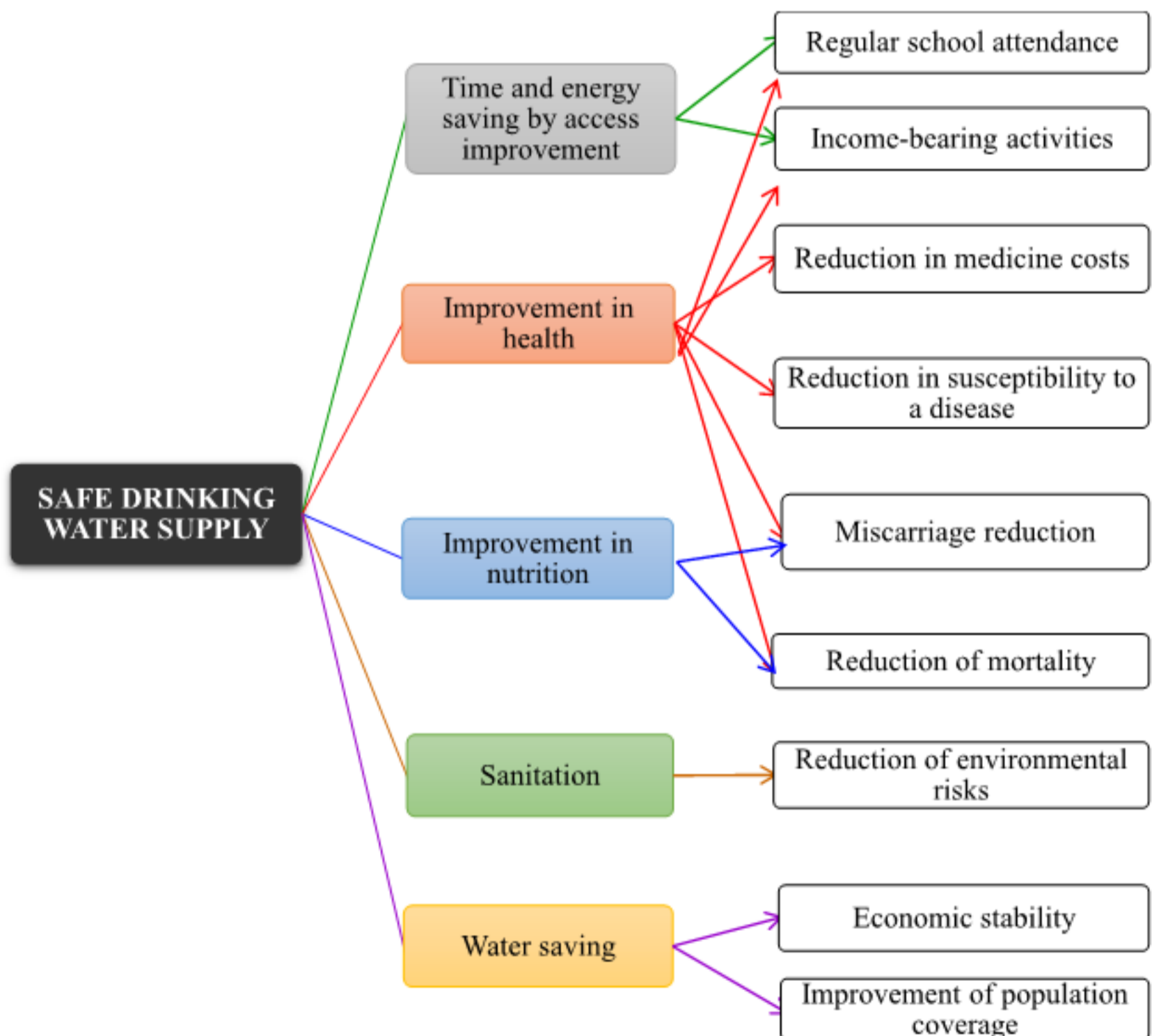

Figure 2 – Health implications associated with safe drinking water

MDG 7 was "to halve a proportion of people without continuous access to safe drinking water and basic sanitation by 2015 (compared to 1990 level)" [55, 64]. This was supposed to be achieved by increasing the coverage of population with access to safe and reliable water and sanitation services from 40% to 55% by 2009, and thereby to reduce the incidence of diseases transmitted through water and related to sanitation by about 50% [65]. While the global progress in achieving these objectives is different, 147 countries have reached the target on drinking water, 95 countries have solved the problem of providing people with sanitation facilities, and 77 countries have implemented the one and the other [34, 43, c. 194].

However, the improvement in water supply was largely uneven: eight out of ten people living in rural areas did not have any improved sources of drinking water, and over the past two decades, most of the world population continued to live without improved water services [1, p. 9; 18]. For instance, between 1990 and 2006, the absolute number of people not covered by these services in 19 countries within Sub-Saharan Africa increased from 29 million to 272 million [1, p. 2; 18]. Population increase and migration led to greater urbanization, as well as growth in more densely populated rural areas, which has been accompanied by increased demand for a higher level of water supply. Many of those who are thought to be covered by improved service, in fact, have systems that are currently not working properly or completely out of order. The rural population suffer most from poor water supply [1, p. 2]. WHO and United Nations International Children's Emergency Fund Joint Monitoring Programme (UNICEF JMP) for Water Supply and Sanitation has monitored drinking water and sanitation since 1990 and cooperated with partners of UN-Water to develop a basis for integrated monitoring of water and sanitation [66]. According to them, 84% of people with no access to improved drinking water sources live in rural areas [1, p. 2; 43, c. 194; 67].

In the early 1990s, 30-40% of rural water systems in developing countries did not work [1, p. 2; 68]. Studies in different countries show that this indicator has not changed since then, as about 30-40% of systems, especially hand pumps, either still do not work at all, or work at nonoptimal levels [1, p. 9; 18]. According to the data of Tarlor from Tanzania [1, p. 2; 69], 25% of the systems no longer work just two years after their installation. Failures of this magnitude represent a significant level of wasted investment, probably hundreds of millions of dollars over the past 20 years [1, p. 2; 43, c. 194].

1.1.2   Sanitation and hygiene in preventing water-related diseases

Since 1990, the worldwide share of rural population without access to improved sanitation facilities has decreased by nearly a quarter. In 2015, the proportion of people who resort to open defecation was reduced from 38% to 25% in rural areas [34]. Still, almost half of rural people do not have improved sanitation facilities, and one in four people resorts to open defecation as before. In contrast, in urban areas only 18% of people have no access to improved sanitation facilities. People in rural areas, as well as those who belong to poor and marginalized groups, much less often have access to improved water sources and sanitation facilities. They are also much less likely to use

tap water in dwellings. The United Nations Organization (UNO) [34] reports that the gradual elimination of inequalities in access to public services and their quality will remain an important area in the agenda after 2015 [43, c. 194].

Adequate sanitation facilities, along with proper hygiene and safe water, are central to good health, and social and economic development [70]. Gastrointestinal diseases transmitted through water bring great economic losses, such as the billions of hours of disability among adults, as well as economic and healthcare costs [43, c. 194-195; 71, 72].

The main factors that reduce the relevance and impact of gastrointestinal diseases in public health are good sanitation conditions, abundant availability of quality water, adequate disposal of human and animal excrements and education in sanitation and hygiene [50]. Some literature assumes [50, 73] that the quality of drinking water is a necessary but not sufficient condition for elimination of gastrointestinal diseases as a public health issue. Furthermore, the amount of water used for personal and household hygiene is more important than the quality of drinking water during diarrhea [53, 74]. This means more frequent bathing and hand washing, more thorough washing of food products, as well as the inner cleanliness [50]. For example, washing one's hands with soap reduces the risk of endemic diarrhea, as well as respiratory and skin infections, while face washing prevents trachoma and other eye infections. A systematic review of the literature [75] confirmed that the hygiene, especially hand washing in childbirth and postpartum period, also contributed to reducing newborn mortality. Dr. Haldan Mahler said: "The number of water taps per 1,000 people is a better indicator of health than the number of hospital beds" [43, c. 195; 50].

The diseases associated with poor sanitation particularly correlate with poverty and infancy [6, p. 7]. Systematic reviews [76-78] show that improvement of sanitation may reduce the level of diarrheal disease by 32-37%. Unfortunately, the current policies in most areas of the world focus on drug treatment. In contrast to good sanitation, it is not the preferred solution because it is much more expensive [3, c. 1; 43, c. 195; 53, 70, p. 1].

Improvement of sanitation also brings some social and economic benefits. The latter include lower healthcare costs, fewer days lost from work or school due to illness or caring for a sick relative, timesaving and convenience [53, 79]. In total, the prevention of diseases related to water and sanitation can save about US $7 billion a year as health system costs; the cost of avoided deaths also adds to this amount US $3.6 billion per year [43, c. 195; 53, 80].

Thus, certain measures in WASH are the most cost-effective way to prevent most of the devastating burden of water-related diseases. They play a direct role in the right for sufficient living standards and rising the life quality of population. Solving problems of sustainable development in the 21st century, such as human development, creating livable cities, counteraction to climate change, and ensuring food and energy security, is impossible without improving the control system of water resources and ensuring the access to reliable services of water supply and sewage system [43, c. 195].

1.2   Burden of water-related diseases in developing countries

The quality of drinking water is a serious problem in developing countries, where half the population is exposed to one or more diseases associated with water and sanitation [38, c. 1; 48, p. 1; 52, p. 1170; 81]. In developing countries, about 400 children per hour die from diseases that are transmitted by water [52, p. 1170]. The sources of drinking water pollution are agricultural chemicals, inappropriate operation of sewerage system, improper storage and disposal of domestic waste, spillage of industrial materials and natural substances [40, c. 48; 52, p. 1170; 82].

1.2.1   Classification of water-related diseases. Water-related infectious diseases

About 2.4 million deaths (4.2% of all deaths) [44, c. 135] all over the world could have been prevented with a good and reliable sanitation and drinking water. Diarrhea is the cause of 3.3 million deaths per year, basically among children under five (and nearly a billion cases of diarrhea each year); about one-third of people in developing countries are infected with intestinal worms; six to nine million people suffer from blindness after trachoma; 200 million people are infected with schistosoma [82, c. 97; 83].

Frequent bouts of diarrhea and intestinal parasitosis are important causes of malnutrition, which makes children more susceptible to other diseases. For example, when malnourished children recover from a diarrhea episode, they are susceptible to pneumonia. Twenty-six per cent of all cases of childhood pneumonia can be associated with susceptibility induced by diarrhea [84]. Similarly, 7% of the WASH-associated disease burden is directly related to malnutrition, and 29% accounts for diseases that are malnutrition consequences [82, c. 97; 5, p. 1; 6, p. 7].

In addition, the main reason of growth retardation for millions of children in developing countries is poor nutrition because of frequent bouts of diarrhea. Repeated bouts of diarrhea inhibit the body's ability to assimilate food for a longer period than the actual duration of diarrhea. Thus, children who had diarrheal diseases are at risk of stunting from malnutrition [50, 52, p. 1170; 82, c. 98].

Lack of access to safe drinking water is also associated with several non-diarrheal diseases [85]. Chronic or acute influence of many organic and inorganic chemicals adversely affects the consumers' health. The consequences vary from acute nausea, vomiting or skin rash to cancer and fetal abnormalities [49, p. 41; 82, c. 97-98; 85, p. 274; 86].

The first attempt to simplify the connection between water and public health in developing countries was made by David Bradley [53, 55, 82, c. 98; 87], who developed a classification of water-related diseases:

1) waterborne diseases occur when people ingest water contaminated with faecal matter. Cholera and typhoid fever are classic examples of the waterborne diseases. It takes only a few microorganisms with high infectivity to cause severe diarrhea. Shigellosis, hepatitis A, amoebic dysentery and other gastrointestinal diseases can also be transmitted by water;

2) water-washed diseases are due to the lack of quality water for washing, bathing and cleaning. Pathogenic organisms are transmitted from human to human or upon

contact with contaminated surfaces. Under such conditions, there can be skin and eye infections, as well as diarrheal diseases. Bacteria, viruses, protozoa and helminths are transmitted through water;

3) water-based diseases are caused by parasites, particularly helminths of various kinds, which spend a part of their life cycle in the different hosts. They spend one cycle of development in water shellfish, and the other, as adult parasites, in the body of the host – an animal or a human. Since a favorite inhabitation for parasites is stagnant surface water, e.g. reservoirs, human activities significantly affect the occurrence of the diseases, such as dracunculiasis and schistosomiasis;

4) water-related insect vector routes diseases are caused by stings of insects that breed in water. Transmitting insects, such as mosquitoes, carry malaria, chikungunya and other diseases.

However, as noted by a number of authors [82, c. 98; 88-91], there are some shortcomings in the classification, as follows:

–   the classification has no chemically-mediated diseases, such as poisoning with arsenic and fluoride, which have a serious impact in some parts of the world [82, c. 98; 88, p. 301; 90, p. 304];

–   the classification does not consider that the need to collect and transport water affects the health of many people. For example, a lot of children and women in developing countries have to carry heavy water containers for long distances every day. There have been no systematic studies on how this affects the locomotor apparatus [82, 89];

–   long walks to collect water may also increase the spread of some other communicable diseases [82, c. 729; 91, p. 75];

–   unpleasant tastes or odors of tankered water (e.g., arising from chlorination or iron content in the ground water), which is microbiologically safe, can serve as a deterrent to the use of safe sources, and therefore expose the users to the health risks associated with unprotected water sources [82, c. 98; 89, p. 1].

According to the WHO [58, p. 361; 92], water contains 13,000 potentially toxic elements. Over the past few decades, contamination of lakes, rivers and ground water has become very acute [59, p. 302]. Harmful substances can accumulate in the body causing a variety of diseases up to malignant neoplasms [46, c. 17; 54, 58, p. 362; 60, p. 311; 61, p. 231; 63, p. 260; 82, c. 98].

Osman A. Dar and Mishal S. Khan [67] propose to amend the Bradley's classification by adding neoplasms caused by high concentrations of arsenic in drinking water and fluorosis caused by intake of water with a toxic dose of fluoride into the category *Waterborne diseases* [82, c. 98].

Access to clean water is essential for the individual and public health, especially in reducing the burden of infectious gastrointestinal diseases [39, c. 181; 44, c. 137]. According to the WHO [51], infectious diseases caused by pathogenic bacteria, viruses and protozoa or helminths are the most widespread, and they make a principal risk factor for the public health associated with drinking water. Ten major diseases transmitted through water are responsible for more than 28 billion cases of disease in developing countries each year. Gastrointestinal diseases among them have the highest

mortality rates [50, 52, p. 1176]. One of the studies of diarrheal diseases in rural areas of Bolivia reports that only 30% of respondents associate diarrhea with dirty water, and that many people view diarrhea as a normal phenomenon at an early age [50, 93, p. 340]. This lack of knowledge about the possible cause-and-effect relationships and casual views of diarrhea in children are common in developing countries [52, p. 1176; 82, c. 98].

The following microorganisms are recognized as pathogens of water-related infectious diseases [82, c. 98; 94]:

– Bacteria: *Aeromonas Hydrophila, Burkholderia Pseudomallei, Campylobacter Jejuni, Campylobacter Coli, Escherichia Coli, Francisella Tularensis, Helicobacter Pylori, Legionella Pneumophila, Leptospira Interrogans, Mycobacteria, Salmonella Typhi* and other *Salmonellae, Shigella Dysenteriae, Shigella Flexneri, Shigella Mansoni, Vibrio Cholerae;*

– Viruses: *Adenoviridae* (Adenoviruses), *Astroviridae (Astroviruses), Caliciviridae* (Noroviruses, Sapoviruses), *Hepeviridae* (Hepatitis E Viruses), *Picornaviridae* (Enterovirus, Parechovirus, Hepatitis A Viruses), *Reoviridae (Rotaviruses);*

– Protozoa: *Acanthamoeba spp., Cryptosporidium Hominis, Cryptosporidium Parvum, Cyclospora Cayetanensis, Entamoeba Histolytica, Giardia Intestinalis, Naegleria Fowleri, Toxoplasma Gondii;*

– Helminths: *Dracunculus Medinensis, Fasciola Hepatica, Fasciola Gigantica, Schistosoma Mansoni, Schistosoma Japonicum, Schistosoma Mekongi, Schistosoma Intercalatum, Schistosoma Haematobium.*

On the average, the minimum infectious dose (the smallest amount of ingested pathogens required to cause a disease) for healthy adult varies widely depending on different kinds of microorganisms. This dose ranges from several organisms for *Salmonella Typhi*, several hundred organisms for Shigella Flexneri, several million cells for *Salmonella Enterica* and up to one hundred million cells for *Vibrio Cholerae*. The minimum infectious dose also varies depending on the age, state of health, nutrition and immunological status of the person [50, 52, p. 1176; 82, c. 99].

Over a year diarrhea kills more small children than the so-called "big three" (Human Immunodeficiency Virus (HIV) / Acquired Immune Deficiency Syndrome (AIDS) + Tuberculosis + Malaria) [7, p. 710]. The key to its control is hygiene, sanitation and water [5, p. 1]. About 90% of all deaths from diarrhea diseases accrue to children under five, and 15 developing countries account for 73% of them [82, c. 99; 95, p. 1].

1.2.2 Water-related parasite invasion

Good sanitation can prevent not only endemic diarrhea but also parasitic diseases transmitted through water by protozoa, intestinal helminth infestations, as well as many other globally important diseases [5, p. 1]. In infancy, parasitic diseases may result in immune system imbalance [95, p. 1]. Helminthiases have an adverse effect on the nutritional status of infected individuals with subsequent impact on the growth in young children and cause anemia, especially in pregnant women [96-98].

Helminthiases also reduce the effectiveness of some vaccines, e.g., against tuberculosis, HIV and malaria [46, c. 15; 82, c. 99; 99, p. 205].

WHO expert judgment shows that helminth infections have the third highest number of patients in the world, and malaria is the fourth among the most important infectious and parasitic diseases: 1.4 billion and 600 million patients respectively. For comparison, the annual number of patients with influenza and other acute respiratory infections in the world is 395 million (the 6th place) [92, p. 3]. Based on the damage for human health, intestinal helminth infections are included in the four leading causes of all diseases and injuries [76, p. 42; 82, c. 99; 100].

Adult helminths live in the gastrointestinal tract where they reproduce sexually. Their eggs are ejected from the infected host with faeces, and in such a way, they are passed to other people, mainly, when defecating in the open air. Replacement of the open defecation for a good sanitation can reduce this transmission path completely, but the majority of modern helminth control programs is based on drug treatment, the intake of which must be periodically repeated in the absence of sanitation [53, 82, c. 99; 101, 102].

Up to 10% of population in developing countries is infected with helminths, a large percentage of which is caused by ascarid. Severe forms of ascariasis are responsible for 60,000 deaths per year, mostly in children [103]. Largely, this is a disease of people exposed to raw wastewater or food products grown with it. Eighty-five thousand hectares in the Meskital valley in central Mexico is a classic example of using raw wastewater for crops irrigation, which leads to a considerable increase in the incidence of diarrhea and ascariasis [82, c. 99; 104, 105].

Worldwide, about 190 million people are infected with schistosomes, which can lead to chronic exhaustion, hematuria, dysplasia, urocyst diseases and colorectal cancer, as well as a significant malfunction in organs [102, p. 464]. Adult schistosomes live in the portal vein, where they pass their eggs into the environment through the urine (*Schistosoma haematobium*) or faeces (other human schistosomiasis). After completing a part of their life cycle in aquatic snails, where they reproduce asexually, cercariae are discharged into the water, where they come into contact and infect humans through the skin. Thus, measures to improve sanitation and water are essential to any long-term control and elimination of Schistosomiaisis [53, 82, c. 99; 101, p. 311].

Trachoma is an endemic disease in many poor countries of the world. It is due to a clamidiosis bacterium and is a leading cause of blindness in the world [106]. Trachoma is mainly controlled with antibiotics, despite the surgery, antibiotics, facial cleanliness, and environmental change (SAFE) strategy [53, 107, 108]. However, in recent times a cluster-randomized trial in Ghana [109] found that the provision of toilets reduced a significant number of flies *Musca Sorbens* (a vector for trachoma) and decreased the incidence of trachoma by 30%, thus confirming the role of improved sanitation in the control of trachoma [82, c. 99-100].

Between the past century and 2004, around the world it was reported 325 protozoal parasitic outbreaks transmitted by water, whereas during a much shorter period, between 2004 and 2010, there were 199 reports of such outbreaks [110]. This

essential difference in the number of reported outbreaks is caused by significant improvement in data reporting and establishment of surveillance systems in the developed countries. The highest prevalence of parasitic protozoa infections are known to occur in developing countries because of low standards [12, p. 6603; 82, c. 100].

The etiologic agent in the reported outbreaks was *Cryptosporidium spp.* in 60.3% (120) of cases; *Giardia lamblia,* in 35.1% (70); other protozoa, in 4.5% (9). Four outbreaks (2%) were caused by *Toxoplasma gondii*, and three ones (1.5%) by *Cyclospora cayetanensis*. During two outbreaks (1%), *Acanthamoeba* was identified as the causative agent [82, c. 100; 111].

For 12 years, 39 documented outbreaks of waterborne cryptosporidiosis have occurred in the United States of America (USA), Canada, United Kingdom (UK) and Japan [112]. Activities related to livestock breeding, in particular, the spread of faecal, as well as deposition and wash-out from contaminated pastures, have been proposed as the cause of many of these outbreaks [82, c. 100; 113-115].

Developments in the molecular genetic analyze of water-borne protozoan parasites including the determination of the identity of species and subtypes will help to understand their contribution to the environmental pollution. Significant research in this area is ongoing, and several methods of genotyping have been designed for *Cryptosporidium, Giardia, Microsporidia spp. and Toxoplasma* [116-119]. Spores of *Microsporidia* are persistent in the environment and remain infectious from a few days to a few weeks outside the host [120-122]. Their small size (5±1 mm) makes them difficult to remove using conventional filtration methods. It is also feared that they may have improved resistance to chlorine disinfection [82, c. 100; 123, 124].

Two toxoplasmosis outbreaks associated with the consumption of water contaminated by oocysts were well-documented [124, p. 100; 125, 126]. The first outbreak occurred in the British army in Panama. Epidemiological data showed that the most likely means of transmission had been contaminated brook water. The second outbreak occurred in British Columbia, Canada, in 1995: 110 acute infections, 55 cases of which were related to infection of non-pregnant women. Forty-two cases included pregnant women and eleven ones were associated with children [82, c. 100; 123, p. 1379; 126, p. 173].

In the estimation of specialists, the annual number of people falling ill with parasitic diseases in Russia exceeds 20 million and tends to increase [47, c. 18; 127]. Thus, according to the number of patients, parasitic diseases in Russia are second only to acute respiratory infections [82, c. 100-101; 100, c. 13].

Investigations carried out in Medical Parasitology and Tropical Medicine named after E.I. Martsinovski [100, c. 13] showed that water in open reservoirs near water intakes often contained lamblia cysts. This pathogen is also found in the tap water. Outbreaks of giardiasis associated with poor quality of tap water are regularly registered in the USA and other developed countries where the necessary investigations are conducted. In Russia, the only interpreted giardiasis outbreak has been registered in the city of Perm [82, c. 101; 100, c. 14].

1.2.3 General concept of non-communicable water-associated diseases

Evaluation of possible links between drinking water and malignant neoplasms means identifying chemicals that are found in the water in concentrations sufficient to represent a significant risk of cancer [58, p. 361]. Inorganic contaminants in drinking water, which are the causes of diseases, include arsenic, copper, fluorine, lead and nitrates. Organic compounds sparking concern include pesticides, chlordane, phenol and trihalomethanes [82, c. 101; 120, p. 203; 128].

Some chemicals matters such as arsenic, asbestos, radon, agricultural chemicals and hazardous waste are of the greatest interest to researchers of environmental risk of tumors [64, 129, 130]. Epidemiological studies in Taiwan [63, p. 260; 64] assumed that arsenic in drinking water posed a significant risk of canceration in liver, lungs, bladder, kidneys, pancreas [64], gullet [63, p. 260], rectum [62, p. 104] and breast [61, p. 231]. Although the toxicological studies do not provide an unequivocal evidence of carcinogenicity of the given element, other epidemiological studies [64, 131] also confirm the results of the Taiwan ones. Estimates of the risk of malignancy [131, c. 585] show that the average arsenic level of 2.5 mg/l in drinking water in the USA is responsible for about 3000 cases of cancer per year [82, c. 101].

Lead: concerns about the potential impact of dissolved lead on health led to significant efforts to reduce its concentrations in drinking water. Elevated lead levels are found in nature only in a few areas, such as the Debet River basin in Armenia. The usual sources of lead contamination are pipes used in plumbing, and their replacement is the only long-term strategy. Reduced water capacity of dissolving lead can be achieved by dosing orthophosphate or adjusting the pH from acid to alkaline, or both [82, c. 101; 127, c. 3].

Arsenic is a known human carcinogen that causes various types of cancer diseases. In the estimation of specialists, in the south-eastern part of Hungary and along the border with Romania, 400,000 people were affected by this element in concentrations exceeding WHO standards in 1981 [92, p. 75]. Now, in the areas with no alternative source for the removal of arsenic from drinking water, a chemical precipitation technology is used. In 1995, it was estimated that the number of people exposed to arsenic in Romania and southeastern Hungary was reduced to 20,000 people [120, p. 203]. High concentration of arsenic in drinking water is an acute problem for Turkey [82, c. 101; 122, p. 227].

Fluoride: excess concentration of fluoride in drinking water is the cause of fluorosis. Although the exact prevalence of the disease is unknown, according to WHO estimates, fluorosis affects millions of people worldwide. According to WHO guidelines, in most countries the concentration of fluoride is less than 1.5 mg/l. However, in Estonia 25%-35% of drinking water samples analyzed since 1988 exceeded the standard, and 0.7% of population was subjected to high concentrations of this element [120, p. 203]. In Sweden, where fluoride occurs naturally, according to experts, 2.4% of population is exposed to concentrations above the standard. About 35% of people in Moldova is also exposed to high concentrations of fluoride [113, p. 107]. In India, 62 million people in 17 of 32 states suffer from dental, skeletal and/or non-skeletal fluorosis [82, c. 101; 104, p. 229].

Nitrates (and nitrite): many European countries report the high concentrations of nitrates in drinking water. Nitrate can be reduced to nitrites in the body and may cause juvenile methemoglobinemia. Only a few countries keep records of the disease, and the majority of reported cases are associated with well water, which often comes from shallow wells affected by agricultural activities. Indicators of the reported cases of methemoglobinemia per 100,000 people is 0.26 in Hungary, 0.56 in Slovakia, 0.74 in Romania and 1.26 in Albania [120, p. 205]. It is estimated that one third of the European population is exposed to nitrates in concentrations above the WHO standard [82, c. 101].

Thus, the reviewed sources revealed that gastrointestinal diseases, intestinal helminth infestations and protozoan infections as well as the risk of carcinogenic and mutagenic effects on the human body were largely attributed to poor-quality drinking water. However, the literature gives more attention to pathogenic water pollutants than the chemical ones, since infectious diseases caused by pathogenic bacteria, viruses, protozoa and helminths are the most common and widespread health risks associated with drinking water [82, c. 102].

1.3   Current state of WASH-related health problems based on the study of protozoan parasites in drinking water

Protozoan parasites are identified as the second most frequent etiological causes of the mortality among children under five years old. Globally they are responsible for 1.7 billion cases of diarrhea, which leads to 842,000 deaths per year [2, c. 321; 20, c. 2; 11, p. 14; 12, p. 6603]. Parasitic diseases transmitted through water by protozoa cause epidemic and endemic diseases in both developed and developing countries [132]. However, the former have better hygiene conditions so parasitic protozoa are commonly not considered as a reason of these diseases [133]. The latter, where population consume both treated and untreated water, have the high rates of protozoan diseases in spite of having achieved their water treatment standards. Thus, it is necessary to take many measures to improve WASH in resource-poor settings for identifying these organisms in developing countries [8, p. 1; 9, c. 108; 134].

During recent years, there appears to be an increase in outbreaks of waterborne or water-washed parasitic diseases worldwide [135, 136]. The reason for this seems to be crumbling or poorly maintained community sanitary and water supply systems [136-137]. In addition, tests for protozoa are not frequent and even absent in small treatment facilities. In practice, challenges in research of drinking water for cysts and oocysts of pathogenic enteric protozoa are withdrawal and delivery of significant quantities of water (50 l) to a laboratory, the duration of filtration, low probability of identification of cysts and oocysts and expensiveness of the method. That is why microbiological indices of water quality in government standards usually include only indicator bacteria, especially in developing regions [8, p. 2].

1.3.1 Protozoa classification and occurrence

There are about 15,000 species of *protozoa* [138] on the earth. However, mainly the following classes have a significance for health: *Sarcodina, Flagellata, Sporozoa,*

and *Infusoria* (figure 3). Parasitic protozoa that are transmitted through water and those that cause human infections are *Toxoplasma gondii, Entamoeba histolytica, Cyclospora cayetanensis, Isospora belli, Blastocystis hominis, Balantidium coli, Acanthamoeba spp., Sarcocystis spp.* and *Naegleria spp.* However, the most common water-related parasitic infections are cryptosporidiosis and giardiasis [139, 140]. Zoonotic agents *Giardia* and *Cryptosporidium* are more often identified during outbreaks caused by contaminated drinking water. The majority of giardiasis outbreaks (71%) occurs in systems with surface water, while the majority of cryptosporidiosis outbreaks (53%) ensues in the groundwater system [132, p. 255]. These enteric protozoan parasites are important causes of diarrheal disease [12, p. 6603; 135, p. 1; 137, p. 1; 141], especially among children in developing countries [8, p. 2; 142].
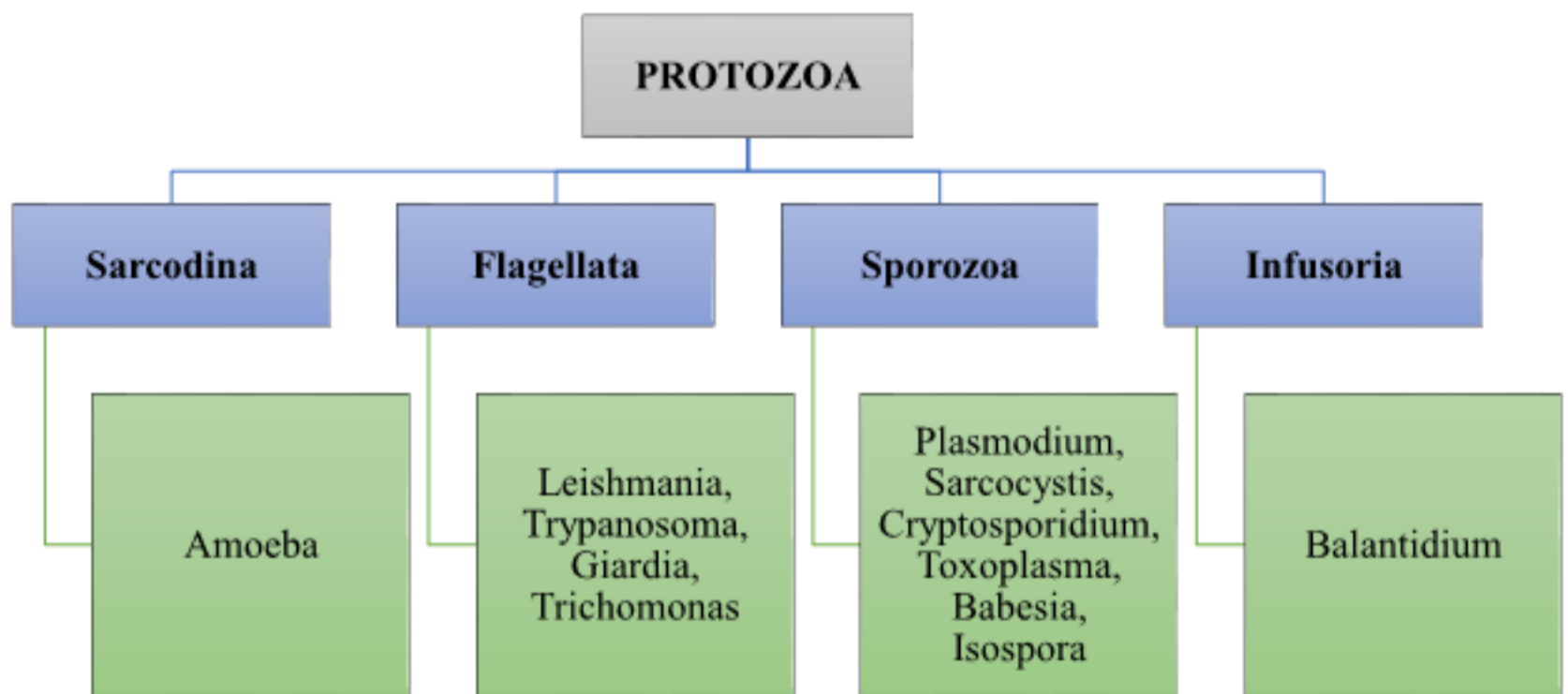
Figure 3 – Classification of parasitic protozoa

Cysts and oocysts of protozoa are found in waste, surface, and groundwater sources, as well as drinking water samples even after treatment using conventional methods [132, p. 226]. Since they mainly aim at the removal of pathogenic bacteria such as *Vibrio cholerae, Salmonella typhi, Salmonella paratyphi,* and *Escherichia coli* [143, 144], chlorine-resistant parasitic protozoa such as *Cryptosporidium parvum* and *Giardia lamblia* are of particular concern [122, p. 227; 130, c. 19; 145]. Cysts of *Giardia* and oocysts of *Cryptosporidium* can penetrate through the water treatment system because of their small size (1–17 μm) and may cause outbreaks and epidemics after consumption of purified drinking water [8, p. 3; 141, p. 195].

Figure 4 describes the life cycle of parasitic protozoa in terms of *Giardia* [146, 147]. Cysts are responsible for transmission of giardiasis and oocysts for cryptosporidiosis. Both cysts and oocysts are resistant forms and can survive in cold water for several months. The infection begins with ingestion of cysts or oocysts in contaminated water, food, by hands or fomites into the digestive tract of the host. Each cyst produces two trophozoites in the small intestine. Trophozoites multiply by longitudinal binary fission, remaining in the lumen of the proximal small bowel where

they can be free or attached to the mucosa by a ventral sucking disk. Encystation occurs as the parasites transit toward the colon. Both cysts and trophozoites can be found in the faeces [146]. Because of defecation, cysts and oocysts are excreted into the external environment and infect other hosts [8, p. 3; 146, 148, 149].
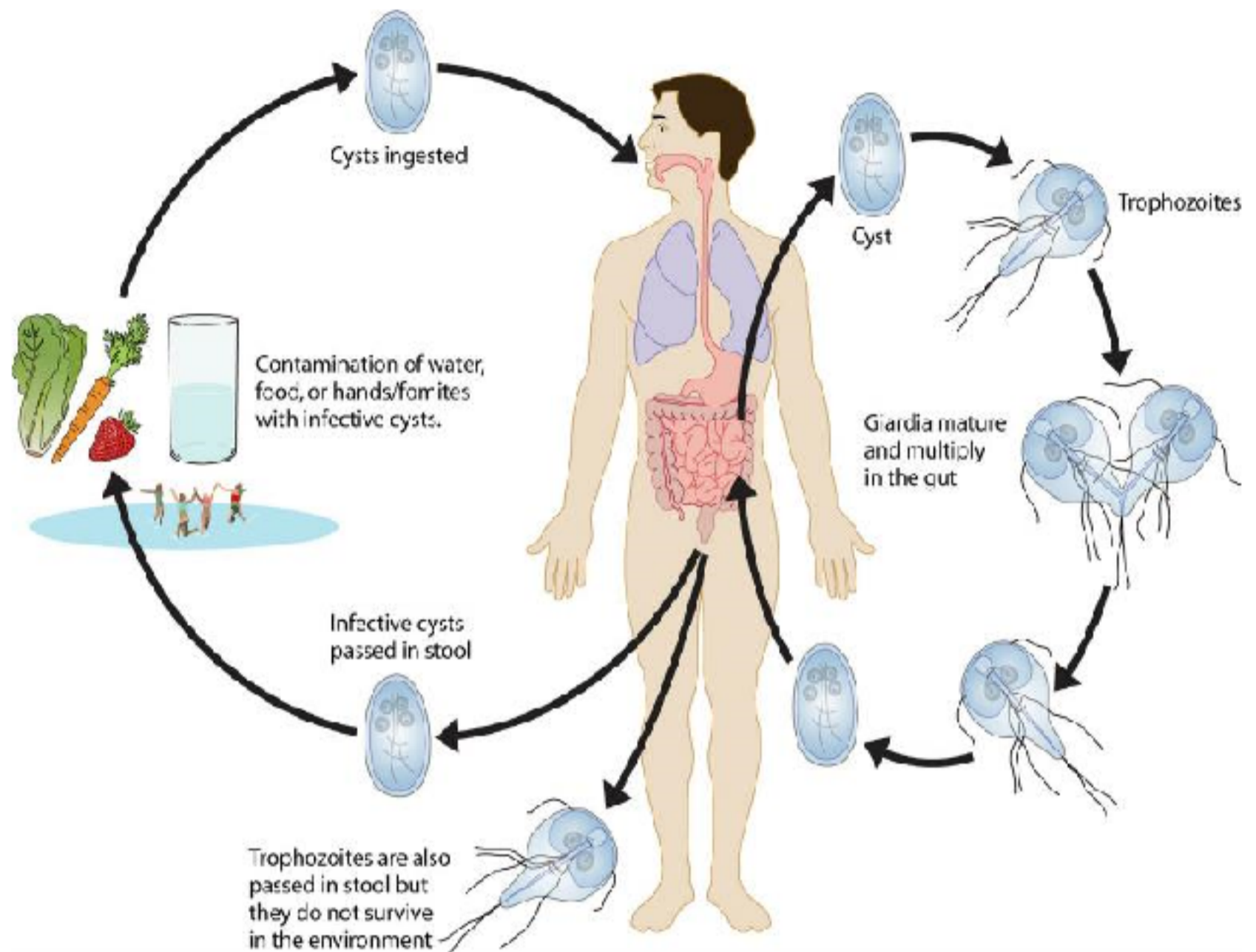
Figure 4 – Giardia's life cycle

1.3.2 Ways for pollution of water sources and drinking water

The source of infection for cryptosporidiosis and giardiasis is an infected human or animal, who secretes invasive cysts and oocysts in their faeces. The transmission of *Cryptosporidium* and *Giardia* is fecal-oral. Infection occurs through drinking water or swallowing water while swimming in open pools [136, p. 1]. The small size of protozoa allows them to pass through filters at drinking water treatment facilities. A study carried out in Japan showed that *Cryptosporidium* oocysts were detected in 35% (9/26) of filtered water samples (geometric mean concentration was 1.2 oocysts/1000 l) and *Giardia* cysts in 12% (3/26; geometric mean concentration was 0.8 cysts/1000 l) [150]. In addition, they have high stability in water and can maintain viability up to 6–12 months or more in the aquatic environment. This is because of the fact that *Cryptosporidium* oocysts and *Giardia* cysts have a thick wall around them. The formation of such protective wall contributes to "freezing" of metabolism of protozoa, and they stay in the so-called "suspended animation" [8, p. 3; 151, 152].

The main cause of waterborne and water-washed diseases is fecal material in the water supply and lack of hygiene [137, p. 3]. Faeces can enter the water in various ways such as [153]: wastewater overflow, nonfunctioning sewage systems, contaminated storm drains, and agricultural effluent. Causative agents of protozoan disease along with liquid sewage from improperly arranged toilets, cesspools, and livestock farms penetrate into the soil and aquifers. Untreated livestock wastes from facilities located in close proximity to settlements that use the upper aquifers for water supply are especially dangerous. Melt and rainwater on the ground can penetrate the groundwater aquifers and pollute the quality of water used for drinking. Confined water constitutes an underground reservoir between the confining strata with a time-constant level and relatively high-water quality [154]. Confined water is the most reliable in sanitary and parasitological terms. However, cysts and oocysts seeding even of confined water can occur if the integrity of the confining strata is violated or there is no supervision over old wells [8, p. 4; 153].

Since protozoan parasites are known to live in the environment for many months [155, 156], there is a need to study improved purification methods that can effectively eliminate these organisms to prevent further waterborne and water-washed outbreaks caused by *Giardia* and *Cryptosporidium* [157]. Nowadays there are no requirements for testing recreational waters for protozoan parasites, although it has been shown that these pathogens can be discharged into recreational water during outbreaks [158, 159]. Unlike swimming pools, recreational beaches have bottom sediment that can contain bacterial and parasitic pollution indices 1000 times more than overlying water [160]. Thus, it is important to conduct parasitological control in treatment plants and to establish regulations for acceptable concentrations of cysts and oocysts based on the subsequent use of wastewater [8, p. 4; 9, c. 108; 161].

As mentioned above, statistics on direct causes for diarrhea outbreaks are difficult to assess due to the great uncertainty on interactive WASH components. The majority of laboratory-confirmed cases comes from the developed countries. For instance, 411,041 outbreaks caused by *Cryptosporidium* and *Giardia* associated with drinking water were registered in the USA for 1990–2012 [162, 163]. According to these data, treatment deficiency was the most common cause during outbreaks. Obviously, number of outbreaks of waterborne or water-washed parasitic protozoan diseases in low- and middle-income countries are significantly higher. Unfortunately, we do not have any comparable findings for developing regions [2, c. 322; 20, c. 1; 8, p. 4; 163].

1.3.3 Drinking water treatment

Traditional methods of drinking water treatment include a number of processes. When applied to raw water sources, they contribute to reducing microorganisms that cause concern for public health [163]. Coagulation, flocculation, and settling act to separate solids from the liquid phase when particles settle under gravity. Microbial agents (protozoa, bacteria, and viruses) tend to sorb into coagulation or flocculation and thus removed. The *Cryptosporidium* oocysts and *Giardia* cysts removal efficiency is about 90% [132, p. 255; 163, 164, p. 71]. Unfortunately, these methods are regarded as economically unprofitable for developing countries. Plummer et al. [165]

investigated the efficiency of clarification (sedimentation versus dissolved-air flotation) for removal of *Cryptosporidium* oocysts under various conditions. The results of this study showed that oocyst absorption was maximal at pH 5.0, and when coagulants were used at doses higher than those currently in use to remove turbidity [8, p. 4; 163, 166].

Filters with the proper design and operation can serve as a consistent and effective barrier for microbial pathogens [167]. The transfer efficiency depends on technological parameters such as the size and density of microbes, size and surface charge of organisms and coagulant particles, as well as depth of the filter material and filtration rate [168]. Rapid filtration, such as a simple screen filter, does not remove microbial pathogens effectively. Slow sand filters can be very effective in removing microbial contamination from water [132, p. 256]. However, it has been shown that diatom filtration is more effective in reducing the concentration of *Cryptosporidium* oocysts and *Giardia* cysts than other conventional filtrations or granulated media [8, p. 4; 163, 169-171].

Pressure-actuated membrane processes (microfiltration, ultrafiltration, nanofiltration, and reverse osmosis) play a significant role in the production of drinking water in the USA and Europe [163, 172, 173]. Microfiltration, ultrafiltration, nanofiltration and reverse osmosis received great attention as an alternative to the traditional purification and removal of protozoal cysts [163, 172, p. 119]. Microfiltration membranes have the largest pores in the range from 0.1 to 10 μm and the highest permeability. Microfiltration is effective for removing particles that can cause problems in further processing. The use of microfiltration membranes in water purification includes clarification, pre-treatment, and removal of particles and microbes [163, 172, p. 119; 173, p. 46]. Ultrafiltration membranes have smaller pores (0.002–0.1 μm), so their permeability is much lower than in microfiltration, and high pressure is required. At present, the use of ultrafiltration membranes in water treatment involves the removal of particles and microbes. Physical sieving is considered to be the main mechanism for removal of protozoal cysts. The pore sizes for microfiltration and ultrafiltration used in water purification range from 0.01 to 0.5 μm, which is at least one order of magnitude smaller than the size of protozoan cysts (4–15 μm) [163, 172, p. 120]. Nanofiltration membranes have pores of around 0.001 μm. Nanofiltration withdraw divalent ions from water; thus, it is widely used for water softening. Reverse osmosis membranes have the smallest pores of approximately 0.0001 μm. Reverse osmosis is needed for drinking water preparation from seawater, brackish water or groundwater due to their ability to monovalent ions removal [8, p. 4; 174].

LeChevallier et al. [175] conducted a study of 66 conventional water systems in the USA and found that compliance with the criteria set out in the Surface Water Treatment Rule (SWTR) did not ensure that filtered water was free of water-related protozoa. Therefore, better disinfection was necessary to protect humans against water-borne protozoa such as *Cryptosporidium* and *Giardia*. Disinfection is an essential component for most treatment facilities, especially for those that use surface water, since granular filter material by itself do not remove most pathogens from water. The main reason for widespread occurrence of reagent methods of drinking water

disinfection is the ease of continual assessment of their effectiveness. With a centralized water supply system, water quality monitoring based on epidemiological indicators must be carried out at least once per hour. In reagent disinfection methods, evaluation of the effectiveness of water disinfection is carried out by determining the residual amounts of disinfecting agent in it [163]. The main factors that influence the effectiveness of disinfection are concentration of the disinfectant, contact time, temperature and pH (depending on the disinfectant) [8, p. 5; 132, p. 256].

Chlorine is the most commonly used disinfectant for drinking water treatment in many countries. The use of chlorine has a long history in water treatment [163, 176], and it has been successfully used for both drinking- and wastewater. Additionally, chlorine is recommended as a water treatment method in the household, especially in developing countries, since it is affordable and easy-to-use disinfectant [163, 177, 178]. Additional chlorine disinfection at point-of-use can reduce the risk of diarrhea caused by Escherichia coli among children by 29% [163, 177, p. 354]. Nevertheless, it has several disadvantages: ineffectiveness against protozoa, loss of effectiveness, strong odor and disagreeable taste due to organic material in the treated water [177, p. 354; 179]. In terms of resistance to chlorine inactivation, viruses and bacteriophages are considered to be more resistant than vegetative bacterial cells [176, p. 1]. Jarroll et al. [180] determined that *Giardia* cysts had been relatively resistant to chlorine inactivation. *Cryptosporidium* is one of the most resistant microorganisms in the water. According to the published data, the inactivation of *Cryptosporidium* was not observed even after 18-h contact with 1.05% and 3% chlorine [163, 181-183]. Whereas chloroamination of drinking water won popularity because of concerns about the hypothetical risks of long-term consumption of chlorinated by-products of disinfection. Monochloramine is considered a weak biocide compared to free chlorine, since it requires 25–100 times more exposure time than chlorine to achieve comparable inactivation [8, p. 5; 132].

The primary focus of many researchers is currently on alternative disinfectants including chlorine dioxide, ozone, and ultraviolet (UV) radiation [184]. Chlorine dioxide exists as an undissociated gas dissolved in water in the pH range 6.0–9.0. It is a strong disinfectant and, as a rule, it is considered that its biocidal efficacy is comparable to or slightly higher than that of chlorine under certain conditions [132, 176, p. 1]. Chlorine dioxide is an effective disinfectant against *Giardia* and *Cryptosporidium* (about 90% inactivation of cysts and oocysts). Nevertheless, this disinfectant form by-products like chlorite and chlorate. In addition, chlorine dioxide is about five to ten times more expensive than chlorine [8, p. 5; 185].

By comparison, ozone is a very strong oxidant, which is toxic to most pathogens in water, even for some protozoan cysts, such as *Cryptosporidium*. It is used to improve taste and color, as well as to remove organic and inorganic compounds in water [186]. Despite the advantages of ozone, it has a number of disadvantages that limit its use in water treatment such as high cost, need for operating and service infrastructure, and no residual protection in the distribution system [8, p. 5; 52, p. 1172].

A different view is UV water-disinfection occurs via the ability of UV radiation to penetrate the cell wall and reach its information center, i.e., deoxyribonucleic acid

(DNA) and ribonucleic acid (RNA). UV water-disinfection irreparably damages the DNA, which leads to impairment of cell replication and/or cell death [187]. The advantages of UV radiation are mainly that it does not depend on the use of chemical additives, is effective in inactivation of protozoan parasites, requires a relatively short contact time, and there are no disinfection by-products identified [163]. Its disadvantages, however, include differences in efficiency between various types of UV lamps and reactor designs, inability to measure the lamp dose in practice, interference of turbidity, and no residual protection in water distribution system [8, p. 6; 163].

Unfortunately, neither ozonization, nor UV radiation have bactericidal after-effect, therefore they may not be used as independent means of water disinfection when treating water for utilities, drinking water supply, or swimming pools. Ozonization and UV disinfection are used as additional methods of disinfection. When used in combination with chlorination, they increase its efficiency and reduce the number of chlorine-containing reagents added [8, p. 6; 163].

In 1994, United States Environmental Protection Agency (US EPA) published the *Cryptosporidium* Criteria Document [188] and thus declared *Cryptosporidium* to be the main pollutant of drinking water. The attention to this genus of protozoa increased and subsequently led to further investigation. Detection of *Cryptosporidium* and *Giardia* in water requires specialized equipment and skills to provide reliable data that can be used to monitor compliance, and to determine the microbiological risks of diseases associated with drinking water [163, 189]. US EPA has approved Method 1623 for simultaneous detection of *Cryptosporidium* and *Giardia*. This method is considered the gold standard and requires filtration, immune-magnetic separation of cysts and oocysts, immunofluorescence analysis to determine protozoan concentrations with confirmation via staining with live dyes (4.6-diamidinophenylindole) and microscopy of differential interference contrast [190]. Any alternative procedures are allowed provided that the required quality tests are carried out and all quality control criteria in these methods are met. Although, the Method 1623 is now available for monitoring of *Cryptosporidium* and *Giardia* in water, other powerful methods include molecular analyses, such as polymerase chain reaction (PCR) alone or in combination with an analysis of infectious cell culture (cell culture-PCR). These methods are used for genetic typing as well as to determine the viability/infectivity and genotypes of *Giardia* cysts and *Cryptosporidium* oocysts [191-197]. Such tools should be used to gain further *understanding* of transmission of these pathogens. The problem is that these methods are not affordable for the low- and middle-income countries [8, p. 10; 190, p. 6].

1.3.4 Waste-water treatment

In industrialized countries, the use of treated wastewater for domestic, industrial and agricultural purposes is currently the most important method of reuse of wastewater when providing sanitary and environmental guarantees [161, p. 3528]. Wastewater treatment plants can become a source of pollution for drainage areas if the wastewater is not treated properly before being discharged to nearby rivers or ponds [130, c. 20]. Moreover, cysts and oocysts can withstand conventional water

disinfection (see the previous section), so they can be found in significant amounts of treated wastewater [8, p. 6; 198-202].

Various studies of treatment plants, where only primary treatment was carried out or each treatment was considered individually, revealed low rates of removal efficiency in the primary stages [203, 204]. The primary treatment includes elimination of contaminants, such as fats, oils, sand, gravel, and stones, which are easily collected and removed. The main goal of the primary stage is to obtain a homogeneous liquid that can be biologically processed. However, some treatment plants use only primary processing, and since the removal of parasites is not the goal of primary treatment, the efficiency of such facilities is minimal [161, p. 3528]. *Giardia* cysts and *Cryptosporidium* oocysts have not been eliminated even after secondary treatment. The study conducted in Spain by Castro-Hermida et al. [161, p. 3529] with an analysis of wastewater samples from 12 treatment plants showed that cysts and oocysts were presented in all samples of treated wastewater (100%) that flowed out of the treatment plants throughout the year, with the largest number of cysts and oocysts was found in spring and summer. The average removal efficiency for these parasites, which had both primary and secondary treatment, was 16% to 86% for *Cryptosporidium spp.* and 2% to 90% for *Giardia lamblia* [8, p. 6].

Proper management, treatment, and dispersion of human and animal faeces are important for hygiene and safety of drinking and recreational water. When the amount of faeces entering the environment is taken into account, the magnitude of the problem may seem overwhelming [198, p. 3393; 199, p. 37; 200, p. 1455; 201, p. 5297; 202, p. 3945]. Throughout the world, there is a big difference in the coverage of toilets. Approximately 1.77 billion people around the world use pit latrines as the primary means of sanitation [8, p. 8].

Pit latrines are the simplest and most inexpensive form of improved sanitation. They usually consist of a round, rectangular or square hole in the ground and are covered with a concrete slab or a floor with a hole through which faeces fall [205]. Pit latrines usually lack a physical barrier, such as concrete, between stored excrement and soil and/or groundwater [206]. In some countries, where pit latrines are common, greater than two billion people use groundwater as a source of drinking water [205, p. 521]. Therefore, contaminants from pit latrines can enter groundwater and create a threat to human health. The degree of transfer of microbes from the pit latrines to groundwater mainly depends on the ecological context of the area, especially hydrological and soil conditions. The distances and rates of movement of contaminants are determined and regulated by soil type, flow rate and direction of groundwater for natural and anthropogenic conditions, and biogeochemical conditions of groundwater. The potential for large-scale contamination of groundwater by pit latrines also depends on social factors, such as use of toilets, toilet density, maintenance, and pumping of groundwater [8, p. 6; 205, p. 521].

There are concerns that pit latrines can affect human health and the environment due to more common use of both pit latrines and groundwater resources in low-income countries. One gram of fresh faeces from an infected person can contain about 106 viral pathogens, 106–108 bacterial pathogens, 104 protozoan cysts and oocysts and 10–104

helminth eggs [207]. The toilet type, design, materials and quality of construction also affect the localization of contamination from pit latrines. Thus, it is necessary to take into account both ecological and anthropogenic factors to assess safety of location of pit latrines and groundwater sources [205, p. 522]. Dzwairo et al. [208] stressed three important factors. Firstly, analysis of some critical parameters, such as the depth of infiltration layer and the direction of groundwater flow. Secondly, developing alternative sanitation, such as raised or leveled pit latrines, to minimize the impact on groundwater. Finally, application of a comprehensive approach including geotechnology and hydrogeology to solve sanitation problems [8, p. 7].

Each country has its own standards for the construction of toilets. For instance, in Haiti, toilets should be located at least 30 m away from any source of surface or drinking water, and the excavation bottom should be at least 1.5 m above the maximum height of the groundwater level [209]. According to the recommendations for groundwater in South Africa, pit latrines should be located at least 75 m away from water sources [210]. WHO suggests a minimum risk of groundwater contamination if the distance between the pit latrine and groundwater level is greater than two meters, provided that the fill rate is less than 50 $l/m^2/day$. In addition, 15 m is proposed as a safe lateral distance between pit latrines and wells [211]. However, in later and more conservative recommendations, WaterAid [212] suggests that toilets and water sources should be at least 50 m apart. The Sphere Project [213] recommended 30 m as the minimum standard for the lateral distance between local sanitation systems and water supply sources [8, p. 7].

Pit latrines remain an important strategy for improving the conditions of human excrement removal despite the potential for groundwater contamination. This system is the most basic option for low-income countries to reduce the level of open defecation and expand access to improved sanitation. Given that approximately 1.11 billion people do not currently have sanitation [205, p. 525], it is expected that pit latrines coverage will increase as people try to proceed from open defecation to basic sanitation [214]. Therefore, great efforts are needed to develop more reliable but viable approaches to the placement of pit latrines and water sources. The proposed guidelines must ensure the protection of groundwater from the entry of any pathogens [8, p. 7; 205, p. 525].

1.3.5 The importance of personal hygiene in the prevention of waterborne infection diseases

The main factors that reduce the relevance and impact of protozoal infections in the field of public health are education in sanitation and hygiene, abundant availability of quality water, good sanitary conditions and adequate disposal of human and animal excrements [52, p. 1171]. Education and motivation to change people hygienic behavior should take place in the context of the family [215]. People can protect themselves and others from water-related protozoan diseases by practicing good personal hygiene, which includes washing hands before preparing and eating food, after going to the bathroom, after changing diapers, and before and after tending to the sick [8, p. 7; 216].

Even if there is an uninterrupted supply of microbiologically safe water, it can be contaminated by consumers at the household level through the improper use [217, 218]. Therefore, the water tanks must be clean and closed, it is necessary to clean and disinfect them on a regular basis. When collecting or storing water, it is not allowed for anyone to put one's hands into the water and drink directly from the water tank. If possible, water tanks should have a narrow neck and a stopper to avoid contact of water with hands, otherwise water must be taken from the tank with a ladle or a mug. In addition, it is necessary to use the available water to the end, and then rinse the tank thoroughly with clean water before next filling. Moreover, water for domestic purposes should be kept in tanks for as short a time as possible [219]. With non-centralized water supply, people should be aware of how important it is to protect the source of water supply from contamination by pathogenic protozoa, and how to do so, as well as take responsibility for the safety of water they consume. People should keep wells closed when installing a hand pump and proper drainage, also keep jugs, jars and other utensils, which are used to collect and store water, clean and in clean places. It is critical to dispose of faeces and sewage away from any sources of water supply and build toilets according to the requirements. Finally, population should conduct a periodic inspection of water sources and water quality [8, p. 8; 211, 219].

Water purification at a household level is another significant aspect of hygiene in developing countries. Some small water purification devices have been developed to be used directly on-site. For instance, filters can purify small water volumes at a household level. In this case, all filters have one common property, they must be operated in the correct manner (i.e., they must be regularly cleaned and maintained) [216]. However not all home water filters can remove parasitic protozoa. Therefore, it is believed that boiling is the best method of obtaining water that is free from biological contamination. In many developing countries, people routinely boil drinking water, as there is no confidence in the safety of water supply or it is under threat [220]. To kill or inactivate *Cryptosporidium* and *Giardia*, water should be kept at a rolling boil for a minute (boiling for three minutes at elevations above 6500 feet). Water should then be cooled, stored in a clean sanitized container with a tight cover and refrigerated [153, 221]. Nevertheless, it is economically unprofitable and environmentally unsustainable to recommend daily boiling of drinking water to the population of developing countries with a low income. Therefore, boiling as a method of disinfection of drinking water can be recommended only in emergency situations and is used regularly only by those who can afford it [8, p. 8; 220, p. 11352].

Safe disposal of human faeces, so that it is isolated from contact with humans, animals or flies, is the main barrier to prevent the spread of protozoan parasites contained in faeces in the home and near-home environment [222]. According to Fewtrell et al. [80, p. 5], improved conditions for the disposal of human faeces can reduce the risk of intestinal diseases by 32%. The toilet should be flushed after each use, regularly brushed using special cleansers and flushed after that. It is also necessary to use a de-rusting solution in the toilet. The surface of the toilet bowl, as well as other surfaces that contact with hands, such as the edge, toilet seat, lid and flush handle must be regularly washed using special detergents. It is also significant to use a separate rag

to wash the toilet bowl. Then, the brush and rag must be washed with soap or detergent, rinsed and dried well. In addition, the toilet must be kept closed to prevent the spread of infection by flies [8, p. 8; 219].

In the areas with no centralized sewerage, the disposal and treatment of human faeces is done at the "local" level (septic tanks, pit latrine, etc.). It is important that the soil where the excrement seeps is properly selected and the toilet is correctly installed, taking into account the distance from the water supply sources and the depth of groundwater, and maintained well *(see recommendations in the previous section)*. People who do not have access to basic sanitation should immediately bury their excrements and not defecate near the house [222, p. 22]. Moreover, it is important to use suitable and safe methods of anus care. Even a small amount of remaining faeces can contain a large number of pathogenic protozoa. The best way to care for the anus after defecation is to use toilet paper or other material, after which it should be discarded into the toilet bowl or dug into the ground. In many developing countries, after defecation people use leaves, sticks, stones, etc. In such cases, it is important that these items are safely disposed, for example, buried in the ground. When using running water, it is necessary to rinse the anus thoroughly, flush, and then make sure that this water is not left on the toilet bowl or on the floor. Washing hands after defecation is also strictly recommended [8, p. 8; 219].

Since cryptosporidiosis and giardiasis are widespread among children, the safe disposal of children's excrements is important in preventing the transmission of these protozoan diseases [135, p. 3; 223]. Small children should be taught to use a pot. It is required to use toilet paper to wipe children's bottoms, and if it is not available, for example, in rural areas, to rinse the bottom under running water or with water from a bucket, so that the rinse water accumulates in the pot. This is important, since the rinse water can contain pathogenic protozoa. The contents of the pot, toilet paper, etc. must be poured out into the toilet bowl. The pot must be washed, dried out and covered so as not to attract flies. If children defecate without a pot, the faeces must be disposed of immediately by pouring it into the toilet bowl or digging into the ground. If defecation occurs in the house, the place needs to be washed and, if possible, disinfected. It is also necessary to wash hands after such hygienic procedures with a child [224]. Consequently, improved personal hygiene behavior is a crucial factor in the prevention of cryptosporidiosis and giardiasis [8, p. 9].

Based on the above, safe water supply exerts a considerable impact on reduction of WASH-related diseases and rise in the living standards of population. A significant number of cases can be prevented with a better access to safe water supply, adequate sanitation facilities and better hygienic practices, especially in the developing countries [8, p. 12].

2 MATERIALS AND METHODS

2.1 Research agenda

A complex of scientific methods was used to achieve the research aim and the objectives (figure 5):

The first stage included a meta-analysis of foreign and domestic literature regarding the research problem, working hypotheses, objective setting and definition of tasks. The search for sources was conducted in PubMed, Scopus, Web of Science and Google Scholar. Two hundred and seventy-four references out of 497 were selected as analytical materials.

The second stage was a population-based study of the availability and status of centralized water supply for the rural population in Karaganda Region based on official data. These data from the Energy, Housing and Communal Services Authority (EHCSA) of Karaganda Region, as well as data on the epidemiological monitoring of water situation for 2012-2016 from the Department for Quality Control and Safety of Goods and Services (DQCSGS) of Karaganda Region were statistically analyzed.

The third stage comprised a population-based cross-sectional study of the general and infectious disease incidence of the rural population in the Republic of Kazakhstan and Karaganda Region (Bukhar-Zhyrau District). The sources of information were statistical compilations *Public Health in the Republic of Kazakhstan and Activities of Health Organizations* for 2007-2017 and *Reports on Selected Infectious and Parasitic Diseases* for 2008-2018 from DQCSGS of Karaganda Region. In addition, there was an analysis of *country data on water-, sanitation and hygiene-related disease burden* for 2002 by WHO.

The fourth stage included a sampling study by interviewing the population in the region of interest (questioning followed by interviewing) to estimate the current access to and public satisfaction with safe drinking water in the villages with various types of water supply. The data obtained were statistically analyzed and compared with data from government agencies reviewed in the previous phase of this research.

At the fifth stage, the results of own research were summarized and compared with literature data to develop recommendations for improving access to safe drinking water in rural areas.

2.2 Description of the study region

Karaganda Region, being the largest industrial area in Central Kazakhstan, is located on the Eurasian continent and characterized by sharply continental and exceedingly arid climate. This territory covers 15.7% of the total Kazakhstan area (427,982 km^2) and includes nine cities of oblast status and nine rural districts [225]. According to data for 2016, 7.78% of the total population of the Republic lives in Karaganda Region (1,383,772 people); rural inhabitants account for 21.41% of them (296, 229 people) [36, c. 123].

AIM

Study and analyze the provision of drinking water to the rural population in order to develop further recommendations on how to improve access to safe drinking water in rural areas

OBJECTIVES

| to study the provision of rural population in Karaganda Region with centralized water supply | to analyze WASH-related health issues in rural areas of Karaganda Region | to analyze the results of the population's assessment of the current access to and water quality in the villages with various types of water supply | to develop recommendations for improving access to safe drinking water in rural areas |

MATERIALS

- data on the provision of rural population in Karaganda Region with drinking water from the EHCSA of Karaganda Region for 2016
- data on epidemiological monitoring of water situation from the DQCSGS of Karaganda Region for 2012-2016

- *Public Health in the Republic of Kazakhstan and Activities of Health Organizations* Statistical compilations for 2007-2017
- reports on isolated infectious and parasitic diseases for 2008-2018 from the DQCSGS of Karaganda Region
- *Country data on water-, sanitation and hygiene-related disease burden* for 2002 by WHO

- questionnaire on satisfaction of the rural population with the quality and quantity of drinking water supply (n=1369)
- in-depth interviews with people (n=136)

- results of own research
- domestic and foreign literature

METHODS

- population
- descriptive
- statistical analysis

- population
- cross-sectional
- statistical analysis

- sample-based
- survey (questioning and interviewing)
- statistical analysis

- meta-analysis
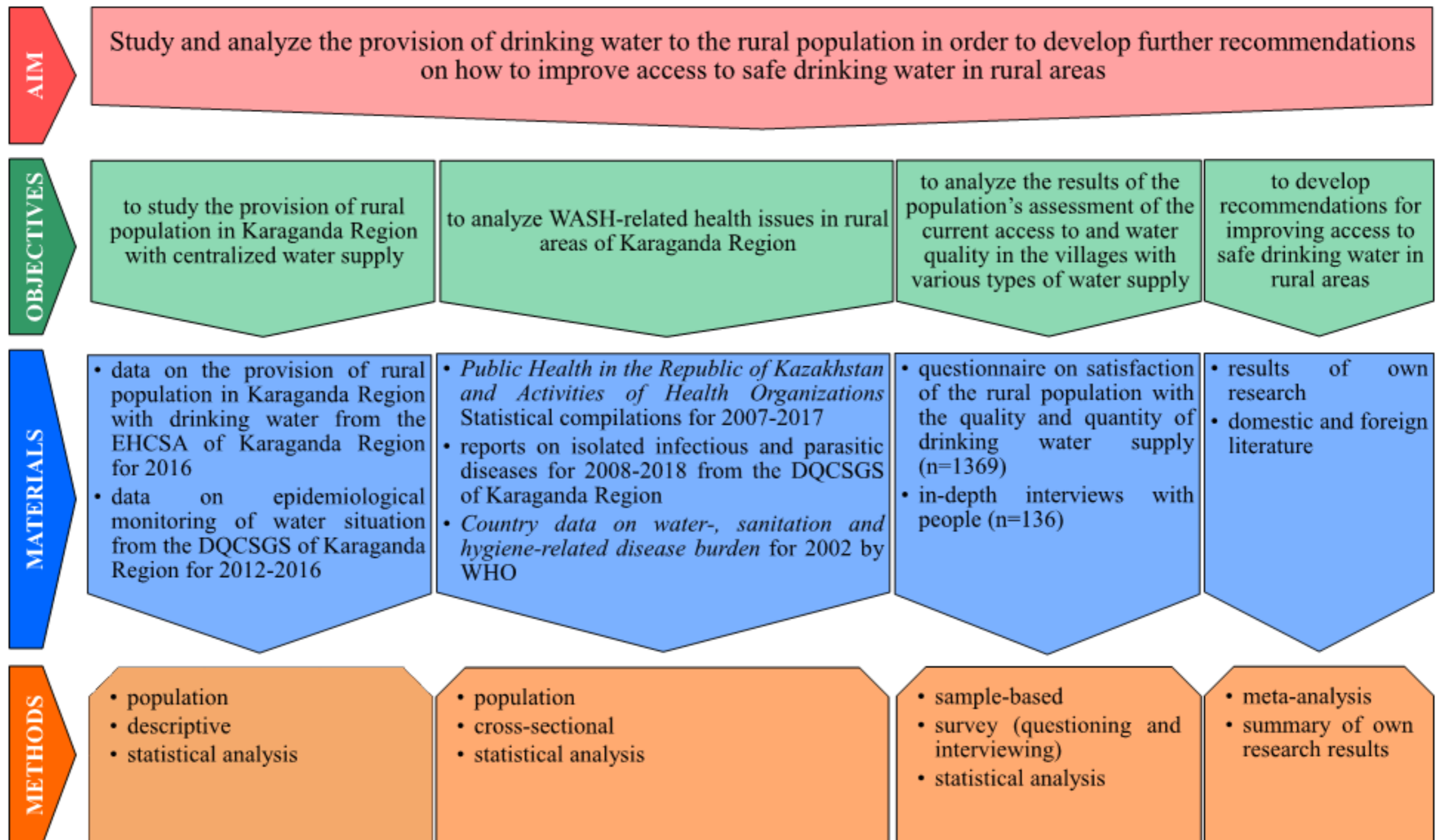- summary of own research results

Figure 5 – Research design

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The study was carried out in Bukhar-Zhyrau District (49º57,21' N – 73º43,01′ E, 500-700 m elevation, 14,576 km^2) located in Central Kazakhstan (figure 6). The climate here is continental with an average temperature of +19 to +21°C in July and –15 to –17°C in January, in addition to an average annual precipitation of 300-350 mm. The topography is flat and most of the territory of the district is covered by the Kazakh Uplands [226]. Bukhar-Zhyrau District has the largest number of inhabitants compared with other rural areas of Karaganda Region. A population of 64,683 (in 2017) live in 67 villages scattered throughout the Region. Another feature of this area was the availability of all types of water supply (centralized, decentralized and tankered) existed in Kazakhstan [20, p. 3; 20, 226].
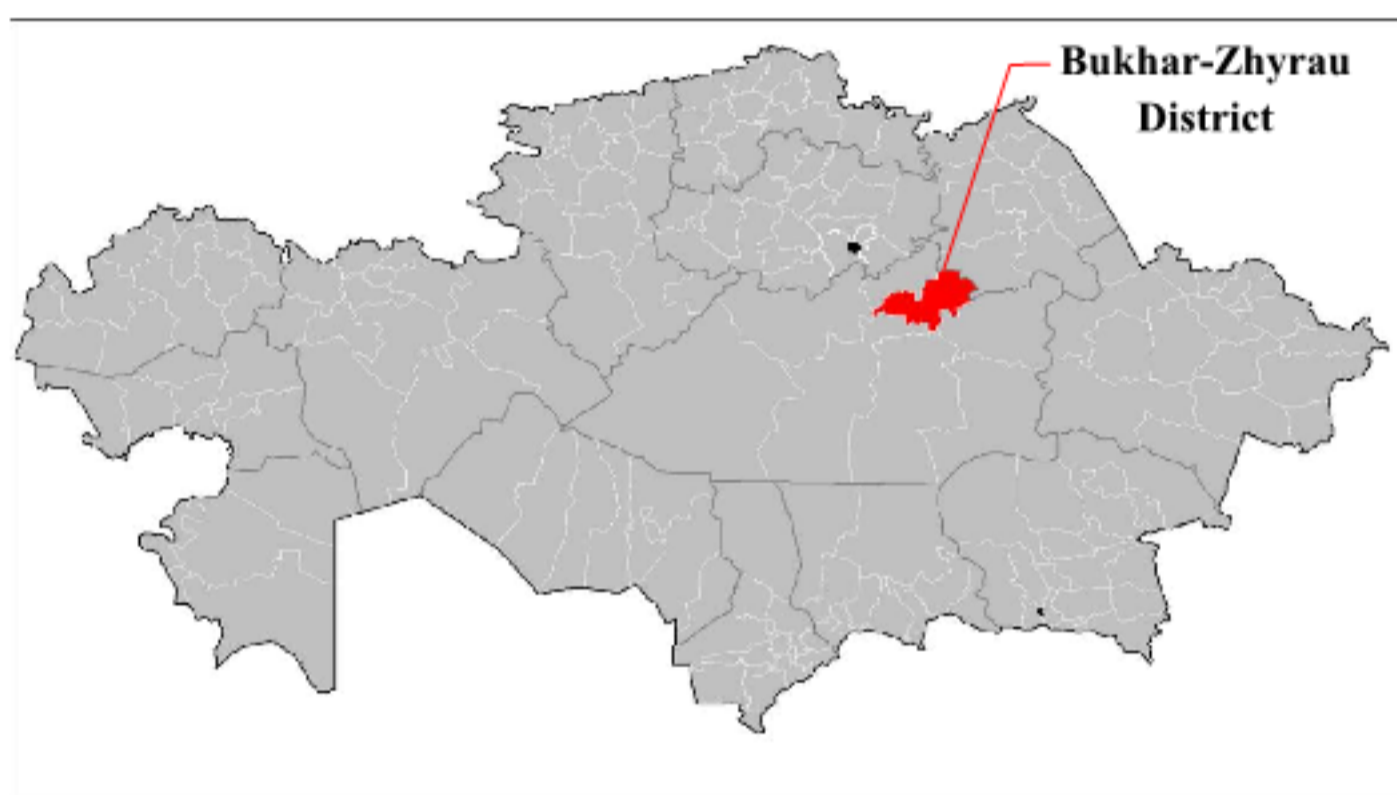
Figure 6 – The study region [226]

2.3 Data collection tools

This information was collected using secondary data provided by the EHCSA of Karaganda Region for information about water supply systems available in the given region as well as data on the water quality and health status from the DQCSGS of Karaganda Region, semi-structured questionnaires (Appendices D, E, F) and in-depth interviews with people.

The questionnaire was developed based on *Core questions on drinking-water and sanitation for household surveys* by the WHO and UNICEF [227] which was adapted to local conditions. The aim of the questionnaire was to assess what water sources the rural population used and how satisfy people were with the quality and quantity of drinking water supply. The questionnaire covered the following topics: type of source mostly used for drinking purposes, reasons for searching for other water sources despite having a tap at home, volume of water consumption, water collection time, additional purchase of bottled water, household water treatment, perceived quality and reliability of water supply systems [20, p. 4].

The priority area in the in-depth interview were public awareness of requirements for the operation of decentralized water sources, maintenance of clean water storage tanks and factors influenced the practice of water supply in society.

2.4   Data quality assurance

The questionnaire was accepted during a session of the Scientific Evaluation Committee (Karaganda State Medical University, Karaganda, Kazakhstan, Protocol No.6 of June 14, 2017). This study was approved and verified by the Akimat of Bukhar-Zhyrau District. To guarantee the quality of data in the study, the English version of the questionnaire was translated into Kazakh and Russian languages, since both Kazakh and Russian speakers reside in the region of interest. After that, translators who had not seen the original questionnaire translated it back into English [20, p. 4].

A pilot study was conducted in the villages not selected by the supervisor Tussupova et al. [228]. The data collected was reviewed and checked for completeness daily. All information was verified, encoded and entered into the computer [20, p. 4].

2.5   Ethical consideration

An ethical approval to undertake the study was obtained from the Bioethics Committee (Karaganda State Medical University, Karaganda, Kazakhstan, Protocol No.110 of October 17, 2016). The respondents were aware that participation therein was voluntary and that they could renounce providing any information at any time without reasons before conducting the survey. To do this, the first page of each questionnaire had an explanation that participation is voluntary and confidential. The respondent's right to refuse a participation in the interview was respected. Identification of the respondent is only possible by identification numbers. Additionally, all the respondents signed an informed data collection consent statement [20, p. 4].

2.6   Sampling

To make a complete pattern of basic advantages and disadvantages of water supply in the region under study, four villages were selected for further investigation (each with the largest percentage of people who use one of three types of water supply): Botakara with mixed (both centralized and decentralized); Dubovka and Karazhar, centralized; Asyl, tankered water supply. The minimum sample size was determined by the formula [229] for the proportion of one population taking into account local assumptions. Based on them, 1369 respondents were identified. Approximately 10% of them (136 people) were chosen for the in-depth interview. These respondents were selected for each of the four villages based on the number of households in each village [20, p. 4].

$$n = \frac{p \times q \times Z_\alpha^2 \times N}{\Delta^2 \times N + p \times q \times Z_\alpha^2}$$

where n is the required sample size;

p and q is a part and its inverse value in each class of the general totality ($p=0.5$; $q=0.5$);

Z_a is a constant (set by convention according to the accepted a *error* and whether it is a one- or two-sided effect) as shown in table 1 [20, p. 4; 229, p. 55]:

Table 1 – Critical values of Z for standardized normal distribution

α error	0.005	0.01	0.012	0.02	0.025	0.05	0.1	0.15	0.2	0.25	0.3
one-sided	2.567	2.326	2.257	2.054	1.96	1.645	1.282	1.036	0.842	0.674	0.524
two-sided	2.807	2.576	2.513	2.326	2.242	1.960	1.645	1.440	1.282	1.150	1.036

N is general totality amount ($N_1=6252$; $N_2=4114$; $N_3=1035$; $N_4=294$);

Δ – the difference in effect of two interventions required (estimated effect size) ($\Delta=5\%$) [20, p. 4; 229, p. 55].

The survey included responses from a single member from each household selected in the villages using systematic random sampling based on the register of each household. The respondents were selected according to the inclusion and exclusion criteria presented in table 2 [20, p. 5]:

Table 2 – Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Male and female gender; Age from 18 to 75 years; Responsible for water use in the household	Living in the village less than a year

2.7 Description of data collection by a survey questionnaire

According to the WHO [6, p. 1], the best way to identify systemic problems of the state so far is a survey questionnaire. Modern literature characterizes the survey as a method of collecting primary information about objective and subjective facts from respondents by contacting them with questions [230, 231]. To collect data on the provision of safe drinking water supply to the population, it was necessary to conduct a survey through each household visiting. *Each household visiting* is a search activity meaning a special conversation with people at their place of residence in order to establish facts of interest to scientific research. It goes together with a visual observation of the respondents' behavior, their reaction to questions, the nature of the answers and the environment. Each household visiting is carried out with the obligatory use of available information about the subject of research [230, p. 19]. The survey was carried out during July-December 2017 and included three stages:

1) preparatory;
2) searching;
3) final.

Preparatory stage. First, to visit each household, a detailed activity plan was drawn up as follows:

– receiving and analyzing source information;

– developing a checklist to be clarified (questionnaire development);
– calculating the number of households surveyed;
– defining a household sampling method;
– briefing the interviewer.

In order to fully clarify all issues and create the best opportunities for the further analysis of the collected materials, a special questionnaire to assess the satisfaction of the rural population with the quality and quantity of drinking water supply was drawn up. Each participant in the visiting received the questionnaire. Its first section included questions about general passport data on the respondents (their age, gender, length of residence in the village and family composition).

The leaders of the scientific work briefed interviewers. During the briefing, the interviewer learned about the immediate tasks of visiting, its general operating procedure and the region being studied. The interviewer's attention was drawn to the need to interview each households of interest. However, the survey was subject to the voluntary consent of respondents notifying a specific person of taking photographs.

Searching stage. The survey of the rural population was carried out by asking questions to be clarified from a specially designed questionnaire. In addition, the interviewer immediately documented any information of interest in the workbook for more thorough verification.

The development of various methods of public interviewing holds a valuable place in each household visiting. There are currently two communication models as follows [230, p. 19; 231]:

– *Symmetric*: when communication subjects alternately act as the source and the recipient of the message and maintain a clear feedback, based on which they give their subsequent statements;

– *Asymmetric:* when one of the subjects assumes primarily the influence functions, i.e., the interviewer acts as the subject asking the questions, and the other party acts as the respondent, who answers them. Communication in an asymmetric survey must be strictly regulated in advance: it is imperative to think through the main questions, their sequence and certain methods of psychological impact.

However, it should be remembered that a formalized survey does not always give positive results, so we tried to bring the survey closer to a less formal symmetrical communication. A number of additional questions arose, their sequence changed, and additional methods of influencing a person were used during the conversation.

From a psychological point of view, the interviewer affects the respondent by various methods and means. Psychological contact with the respondent is a very important stage of the survey, since the reliability and completeness of the information depends on this. Psychological contact is a form of communication between interviewers and respondents, when the latter readily answer the questions, show willingness to participate in the conversation and have confidence in the interviewer. The main methods of psychological contact are good interpersonal skills of the interviewer, removal of negative attitudes and guaranteeing the confidentiality of the conversation [230, p. 19]. Therefore, before embarking on a survey, the interviewer

introduced oneself (gave his/her first name, last name, place of work, and presented a document if necessary), and then asked for help with the research.

After establishing a contact, the respondent was informed about the purpose of the survey. The true goal was directly explained, so that the respondent could immediately understand the idea, start answering questions and provide the necessary information. Creating favorable conditions for the respondent to communicate certain information is an important task of the survey. The interviewer should exert such psychological influence on respondents that their needs are partially satisfied during the survey or in connection with it [230, p. 20]. Therefore, the interviewer emphasized the great importance of the information provided by the respondent for solving water supply problems in the studied villages and noted that the respondent was the one who could help the research team solve these problems due to various circumstances and the respondent's personal qualities. This psychological impact was an effective basis for positive communication and helped to obtain necessary information from people.

Final stage. The interviewer recorded all results of each household visiting in a tabulated form in the MS Excel program. The workbook was viewed to eliminate possible contradictions and clarify some circumstances. Handwritten notes were decrypted and entered into the computer.

2.8   Data processing and analysis

Statistical analysis of the obtained data was performed using the STATISTICA 13.3 software (StatSoft, Tulsa, Oklahoma, USA) [20, p. 4]. Some answers were randomly selected and checked for errors during data entry. Then, a descriptive frequency was used for an outlier test. The data were processed in an appropriate manner and then further analyzed. Odds ratio (OR), 95% confidence interval (95% CI) and p values were determined for each variable sampling study. The data was analyzed at a significance level of $\alpha = 0.05$. Wilson's method was used to calculate 95% CI.

The Kolmogorov-Smirnov test was used to check the normal distribution of quantitative data. The description of quantitative data was based on medians and quartiles (with non-normal distribution) and in the form of $M \pm s$ (for normal distribution of characteristics). Independent samples were compared using Kruskal–Wallis one-way analysis of variance (which is a generalization of Mann-Whitney test) designed to estimate differences simultaneously between three or more samples by the level of any characteristic, as well as Student's t-test for independent samples and the non-parametric Mann-Whitney U-test. In addition, there were a linear regression analysis to establish the dependence of one variable on the other, a correlation analysis to establish the relationship between the variables, as well as a frequency analysis of quality indicators separately for each region.

The reliability and scientific validity of the results were provided by a comprehensive analysis of the problem in determining the initial theoretical and methodological positions, representativeness of the sample, a combination of proven methods adequate to the goals and objectives of the research, a combination of quantitative and qualitative analysis of the material, and correct use of medical statistics.

3 CHALLENGES OF DRINKING WATER PROVISION IN RURAL AREAS OF KARAGANDA REGION

3.1 The availability and status of centralized water supply for the rural population in Karaganda Region

3.1.1 Available drinking water sources in Kazakhstan

Drinking water is water used for both drinking and hygiene purposes [71, p. 35]. It can be supplied from different sources. Figure 7 shows six available sources of such water in Kazakhstan. Centralized water provision is distributed through *taps* and *standpipes*, with water supplied from either surface- or groundwater. This water is usually treated. Standpipes are provided along the pipelines at specified intervals. However, tap water inside a house is available only at the expense of a house owner. The government provides the centralized water supply; therefore, the Akimat shall regularly check it for contaminants. Decentralized water supplies from *boreholes* and *wells* do not have any delivery services to houses and can be both public and individual. The Akimat provides a permit for drilling new boreholes and wells based on prior investigation of the field. They are also intended to test water quality regularly throughout the operation period. However, the population sometimes use unregistered boreholes and wells, which means no control by the Akimat. Other sources of drinking water, such as *tankered water* and *water from open sources*, are not considered safe. However, due to the absence of water supply alternatives, tankered water is included in official statistics and is regarded as a makeshift measure for drinking water supply provision for the population. Water is delivered to villages in a tanker, usually once a week, with paying for each litre on site. A company selected by the Akimat is responsible for a timely delivery and water quality. Finally, open sources are completely absent in the official statistics and are utilized by individuals [20, p. 2-3; 28, p. 336; 232].

CENTRALIZED SOURCES

Tap   Standpipe

Figure 7 – Drinking water sources, sheet 1

DECENTRALIZED SOURCES

Borehole

Well

OTHER SOURCES

Tankered water

Open source

Figure 7 – Sheet 2

Rural people have to use multi-sources due to the lack of a stable water supply system in the villages. Households usually classify them based on their purpose for using water [233]: tap water for drinking, wells for hygiene, rainwater and thawed water for garden irrigation, etc. [20, p. 2].

3.1.2   Provision of the rural population in Karaganda Region with drinking water
The water is supplied to rural residents of Karaganda Region by various water systems, mainly from underground sources. About 98.96% (44,696 people) of population use groundwater. Surface sources of water supply cover 1.04% of inhabitants (471 people). At the same time, 77.71% of water from the surface sources undergoes the preliminary water treatment at water facilities, but 22.29% uses untreated water [36, c. 124].

According to the data on the provision of the rural population in Karaganda Region with drinking water from the EHCSA (figure 8), the majority of inhabitants (250,457 people which makes up 84.55%) have been provided with centralized water supply; 62.16% (155,686 people) among them have a water pipe inside their house, and 37.84% of people (94,771) use communal standpipes. About 15.25% (45,167 people) of rural residents are provided with decentralized water supply. Additionally, 70.73% of them obtains water from boreholes and 25.27% use wells. The number of population consuming tankered water stands at 605 people (0.2%) [36, c. 124].
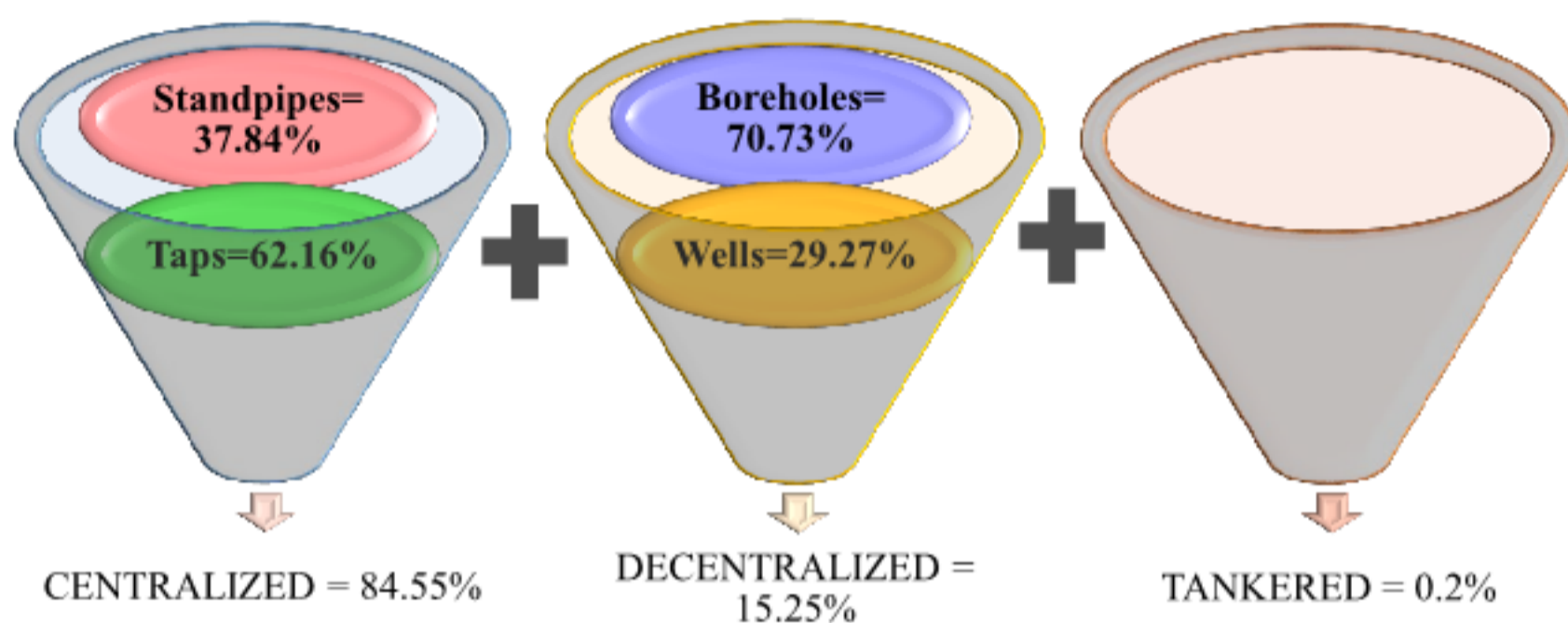
Figure 8 – Water supply systems in rural areas of Karaganda Region

According to the data on epidemiological monitoring of water situation from the DQCSGS of Karaganda Region, 2451 water samples of centralized water systems were analyzed for microbiological indices in rural areas in 2016. Seven of them (0.29%) were inconsistent with the requirements of government standards (figure 9). Two thousand five hundred two samples were tested for chemical indices; there were an estimated 19 water samples (0.76%) inconsistent with standards. In 2015, the percentage of samples that failed to meet the requirements amounted to 0.58% and 0.96% respectively [36, c. 124].

In 2016, the highest exceedance of standards for microbiological indices was observed in Jana-Arka rural district (1.82% of samples). The same index in Aktogay (0.81% of samples), Abay (0.39% of samples) and Shet districts (0.17% of samples) were slightly less than in the previous one [36, c. 125].

Excess of standards for chemical indices has been found in Abay (turbidity from 3.2-3.4 mg/dm^3), Bukar-Zhyrau (nitrates 56.9-90.06 mg/dm^3, oxidizability 8.2-21.6 mg/dm^3, hardness 11.6-12mg/dm^3, solid residue 1156-1504 mg/dm^3), Osakarovka (colour – 25.6), Aktogay and Nura rural districts during 2016. Some accidents, natural hazards and decline in water quality during the seasonal flood have caused the exceedance of standards for these indices [36, c. 125].

Figure 9 – Proportion of water samples from centralized water systems in rural areas of Karaganda Region inconsistent with epidemiological indices from 2012 to 2016

Ninety-nine sources of decentralized water supply of rural residents were monitored by the DQCSGS of Karaganda Region in 2016, and 98 sources, in the previous year. As a part of the verification of water quality of decentralized sources, 42 samples were collected for microbiological investigations in 2016, while seven of them (16.6%) were inconsistent with the requirements of government standards. In the previous year, the proportion of unsatisfactory samples amounted to 15.74% (figure 10) [36, c. 125].

In 2016, 50 samples were analyzed for chemical indices. The percent of inconsistency stood at 28% (14 samples) and 8.26% in 2015. The excess of values of hardness, solid residue and discrepancy of organoleptic indicators were mentioned in boreholes and wells of Jana-Arka, Nura and Shet districts [36, c. 126].

Fifty-one open reservoirs are monitored by the region, including four ones of the first category: Lake Balkhash, canal named after K. Satpayev, Kengir and Karsakpay reservoirs [36, c. 126].

No organized untreated wastewater discharges have been reported over the period of research. There has been some planned discharges of value added industrial wastewater and sewage, which do not exceed the maximum permissible discharge (MPD) from Temirtau, Balkhash, Shahtinsk, Satpayev, Zhezkazgan, Saran and Karaganda cities [36, c. 126].
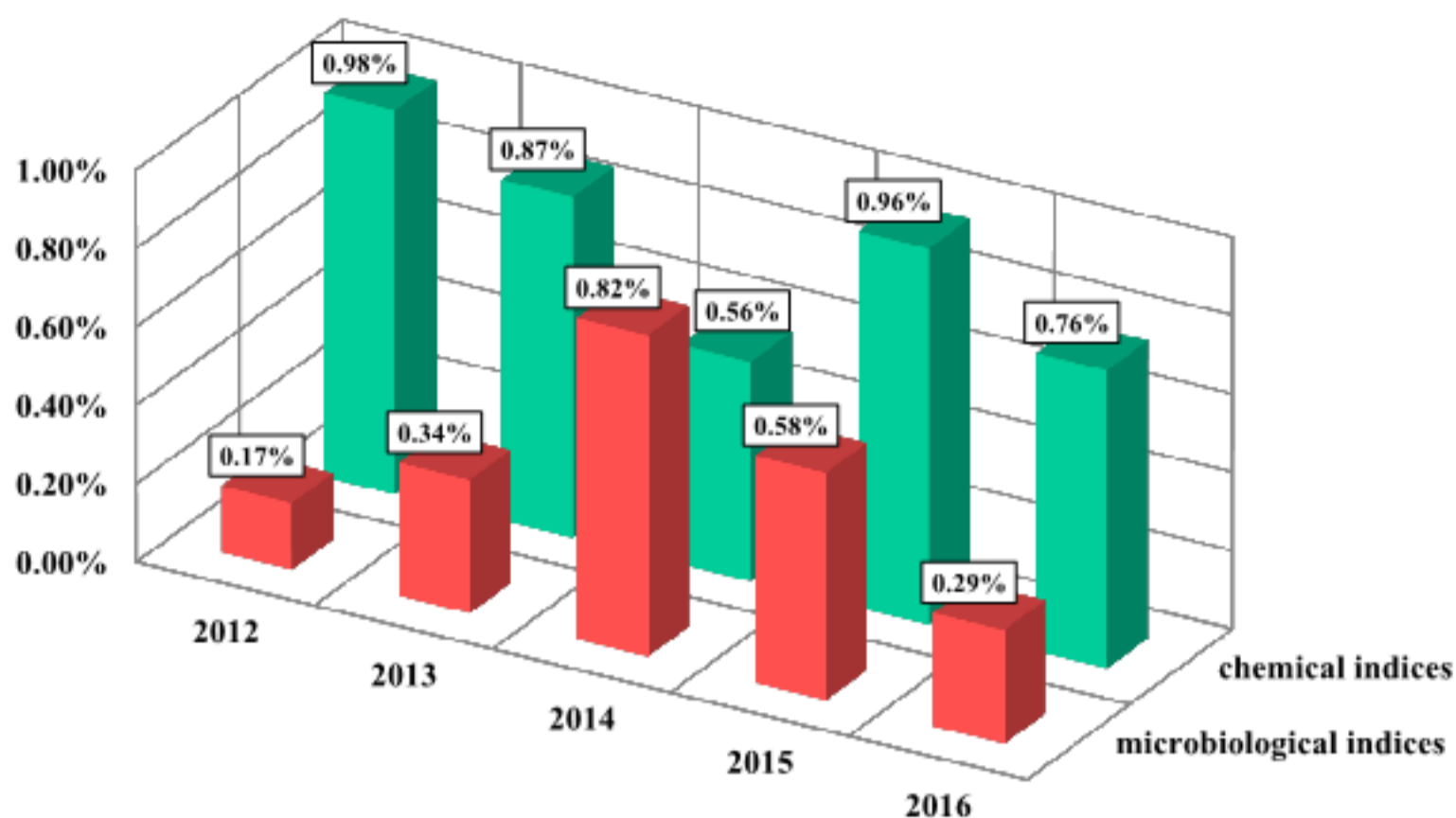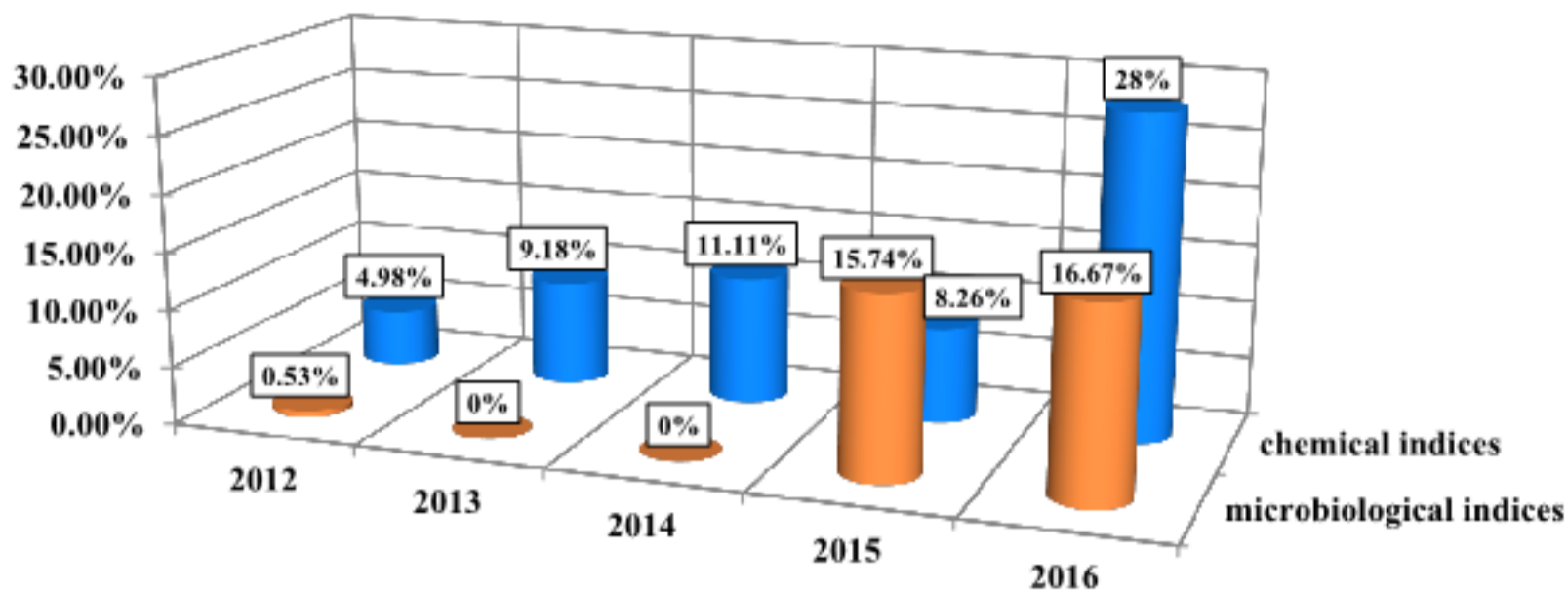
Figure 10 – Proportion of water samples from decentralized water systems in rural areas of Karaganda Region inconsistent with epidemiological indices from 2012 to 2016

In 2016, 12 water samples from the first category reservoirs were analyzed for chemical indices in the places of water usage; the actual concentration of substance was infinitely higher than maximum permissible concentration (MPC) (50%) in six of them. In nine samples selected for microbiological investigations, the standards have not been exceeded [36, c. 126].

One hundred and twenty-seven accidents at the centralized water supply facilities have been reported during 2016, and 102, in the previous year. The number of disinfected centralized water facilities amounted to 892. Decentralized water supply facilities have not been covered by disinfection. Purification of household and drinking water supply facilities included liquid chlorine, bactericidal lamps and calcium hypochlorite. According to data for 2015 and 2016, 26 km of plumbing in the rural areas of Karaganda Region needs repair and reconstruction [36, c. 126].

3.1.3 Assessment of drinking water quality in villages of Bukhar-Zhyrau District

Groundwater is the main water resource in Bukhar-Zhyrau District, and the population there is provided with centralized, decentralized or tankered water (figure 11). About 51,752 people (80.01% of population) use centralized water supply including 6083 standpipe users (11.75%) and 45,669 in-house water conduit users (88.25%). Decentralized water supply is used by 12,431 people (19.22% of population) including 9001 borehole users (72.41%) and 3430 users of wells (27.59%). Finally, 500 people (0.77% of population) use tankered water.
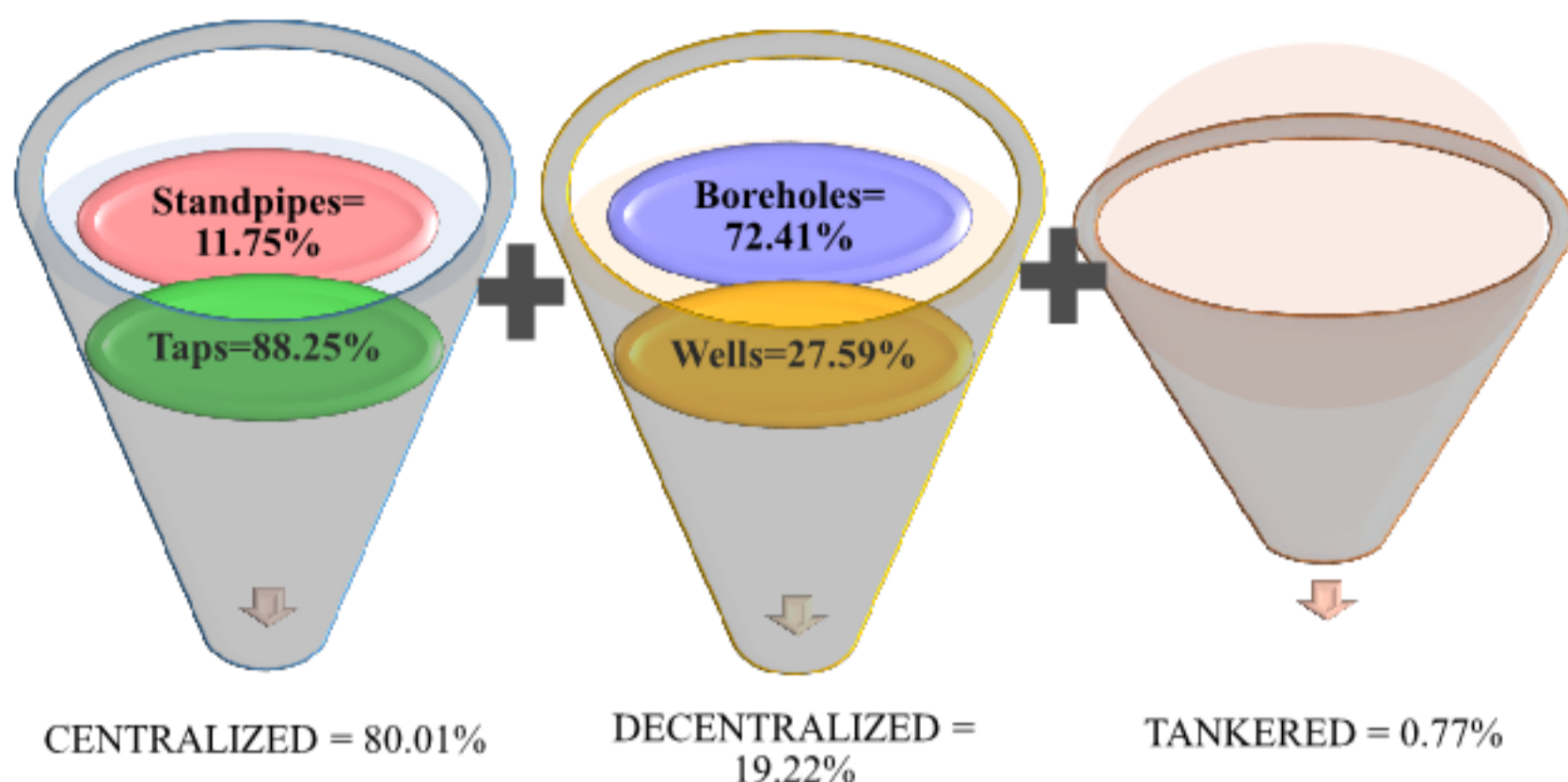
Figure 11 – Water supply systems in Bukhar-Zhyrau District

Table 3 shows the results of analysis on the assessment of drinking water quality in Bukhar-Zhyrau District. At the end of 2017, during the quality control of the centralized water supply, 504 samples were examined for chemical indicators. The proportion of unsatisfactory samples was 1.6% (eight samples). Additionally, 504 samples were selected for compliance with the requirements of government standards for microbiological indicators. Among them, there were no positive results. In the previous year, the proportion of non-conforming samples was 1.9% and 1.4%, respectively.

According to the data, chemical and microbiological studies of water from decentralized sources in that area were not conducted from 2014 to 2017. However, there is an elevated fluorine content, hardness and dry residue in some boreholes and wells, as well as unsatisfactory organoleptic characteristics (turbidity).

A high percentage of pipe deterioration leads to accidents on the water-supply network. Six accidents per year were registered in Bukhar-Zhyrau District from 2013 to 2015, and five accidents per year in 2016 and 2017. According to official data, the timeliness of accident elimination was 100%.

As an additional laboratory analysis, a parasitological study of drinking water for helminth eggs and cysts of pathogenic protozoa was conducted in several villages of Bukhar-Zhyrau District. However, the results were negative.

Table 3 – Drinking water quality indicators in Bukhar-Zhyrau District for 2013-2017

	Proportion of drinking water samples from centralized sources that do not meet epidemiological requirements						Proportion of samples of drinking water from decentralized sources that do not meet epidemiological requirements						Accidents at centralized water supply facilities			Reagents for disinfecting drinking water supply facilities
	on chemical indicators			on microbiological indicators			on chemical indicators			on microbiological indicators						
	examined samples	of them do not match	%	examined samples	of them do not match	%	examined samples	of them do not match	%	examined samples	of them do not match	%	Total registered	Eliminated in a timely manner (on the first day)	Subsequent disinfection	
2013	601	2	0.3	565	2	0.4	58	2	3.5	39	1	2.6	6	6	6	Calcium hypochlorite
2014	577	3	0.5	570	4	0.7	0	–	–	0	–	–	6	6	6	Calcium hypochlorite
2015	290	3	1.1	191	0	–	0	–	–	0	–	–	6	6	6	Calcium hypochlorite
2016	213	4	1.9	213	3	1.4	0	–	–	0	–	–	5	5	5	Calcium hypochlorite
2017	504	8	1.6	504	0	–	0	–	–	0	–	–	5	5	5	Calcium hypochlorite

Thus, the state provided the majority of the rural population in Karaganda region (84.55%) with centralized water supply. This figure in Bukhar-Zhyrau District was 80.01%. Laboratory tests revealed some violations of water quality standards from centralized sources. For 2012-2016, the highest percentage of samples that did not correspond to microbiological indicators was in 2014 (0.82%), and to chemical indicators, in 2012 (0.98%). In Bukhar-Zhyrau District, the highest percentage of non-conforming samples was recorded in 2016 (1.4% and 1.9%, respectively). The DQCSGS of Karaganda Region indicated emergencies, adverse natural phenomena and high-water season as the reasons for these violations. There was a noticeable difference in the ratio of water samples from centralized and decentralized systems that did not meet the standard values for epidemiological indicators. The percentage of water samples with inadequate quality from decentralized sources was significantly higher than from centralized systems (in 2016, on microbiological indicators 16.67% and 0.29%, respectively; on chemical indicators, 28% and 0.76% respectively). A possible reason was that disinfection did not cover the facilities of decentralized water supply. There are no data on the chemical and microbiological studies of water from decentralized sources from 2014 to 2017 in Bukhar-Zhyrau District. Therefore, the problem remains relevant, despite the measures taken to provide the rural population with drinking water of guaranteed quality and insufficient volume [36, c. 126].

3.2 WASH-related health issues in rural areas of Karaganda Region

3.2.1 Global burden of WASH-related diseases

The state of public health is an integral indicator of the environmental influence on the human body [234]. Among the socially significant problems are infectious diseases. They are threatening and destructive factors for humanity and cause enormous economic damage every day [235, 236]. Infectious diseases lie in the 13th place in the structure of the overall incidence of disease in Kazakhstan. In the structure of mortality, this class is inferior to diseases of circulatory system, digestive organs, respiratory organs, neoplasms and others [237]. However, the main cause of a significant part of these diseases are various infectious agents [3, c. 12].

In recent times, doctors have paid particular attention to the consequences of past infectious diseases [238]. It is commonly known that the consequences of acute infectious diarrheal diseases develop some time after the acute phase and lead to gastroenterological, rheumatological, neurological and other diseases. However, these diseases are registered as independent nosological forms due to the lack of clear clinical and laboratory diagnostic criteria. For instance, it was established that intestinal infections preceded the development of reactive arthritis [3, c. 12; 239].

The priority in preventing the risk of intestinal infections is to protect water supply systems from contamination by faeces, which may contain a variety of pathogenic bacteria, viruses, protozoa and helminths [8]. The following segments of population are the most exposed to WASH-related diseases [3, c. 12; 240]:

− infants and young children;
− people with fragile health;

- patients with severe burns;
- patients who underwent surgery;
- people exposed to radiation;
- elderly people.

In 2002, the WHO published the first science-based assessment of the global disease associated with WASH [6, p. 29]. According to these data, WASH-related disease burden hold a specific place in the structure of mortality and disability. In 2012, 6.3% of all deaths in the world were associated with WASH, of which 25% were children under 14 years of age (figure 12) [6, c. 30-53]. This indicator was 16 times higher in developing countries compared to developed ones (8% and 0.5% respectively). In Kazakhstan, the mortality rate associated with WASH in 2012 was 1.6 (0.9% of all deaths in the country), where 18.7% were diarrheal diseases [2, c. 321; 3, c. 12-13].
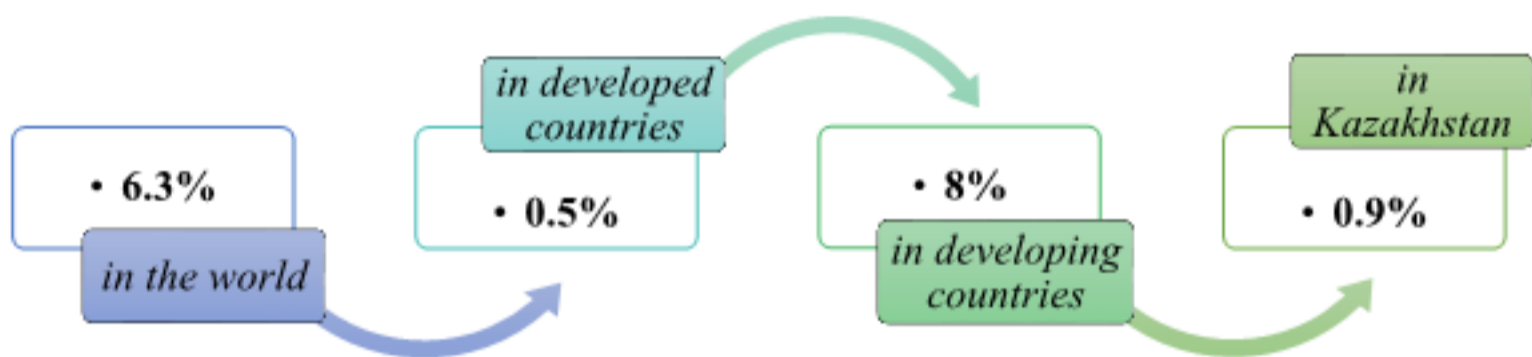
Figure 12 – WASH-related disease burden in the structure of mortality (per cent of the total number)

Over the same year, it was found that 9.1% of disabilities worldwide were associated with WASH-related disease burden, and 22% of them were children under 14 years of age (figure 13) [6, c. 30-53]. This indicator was also much higher in developing countries than in developed ones (10% vs. 0.9%). In Kazakhstan, the disability rate associated with WASH was 55 (1.5%), of which 28.2% were diarrheal diseases [2, c. 322; 3, c. 13].
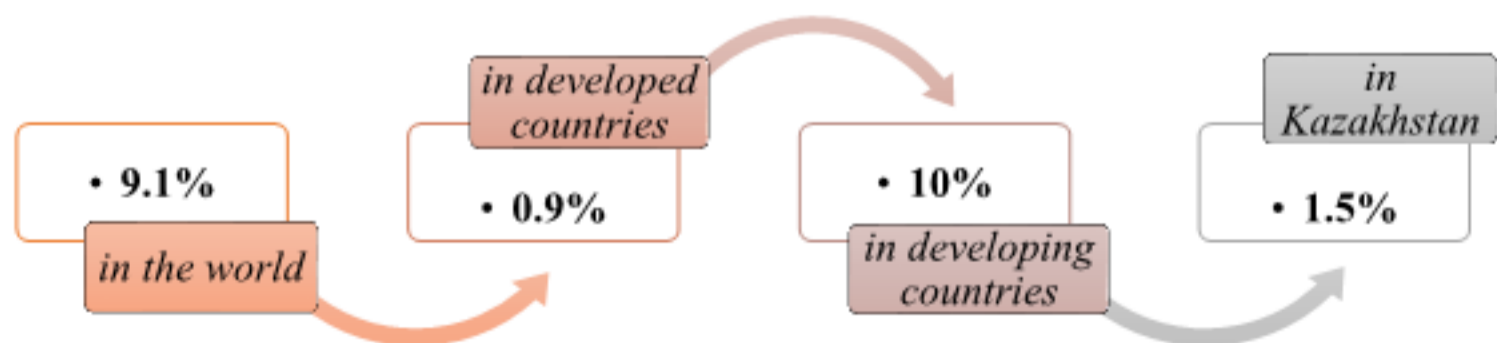
Figure 13 – WASH-related disease burden in the structure of disability (per cent of the total number)

3.2.2 Comparative analysis of the overall incidence of disease in the Republic of Kazakhstan and Karaganda Region for 2007-2017 (epidemiological characteristics)

An analysis of the overall incidence of disease in the Republic of Kazakhstan for 2007-2017 (figure 14) revealed that the peak had been recorded in 2009 and amounted to 60,107.7 per 100,000 people. The incidence rate reached its minimum in 2014 (52,031.5 per 100,000 people) due to a steady decline from 2010 to 2014. However, starting from 2015, the incidence rate among the population began to grow and reached 57,896.9 per 100,000 people in 2017, which may indicate both a deterioration of public health and an improvement in diagnostics level in the country [3, c. 10].
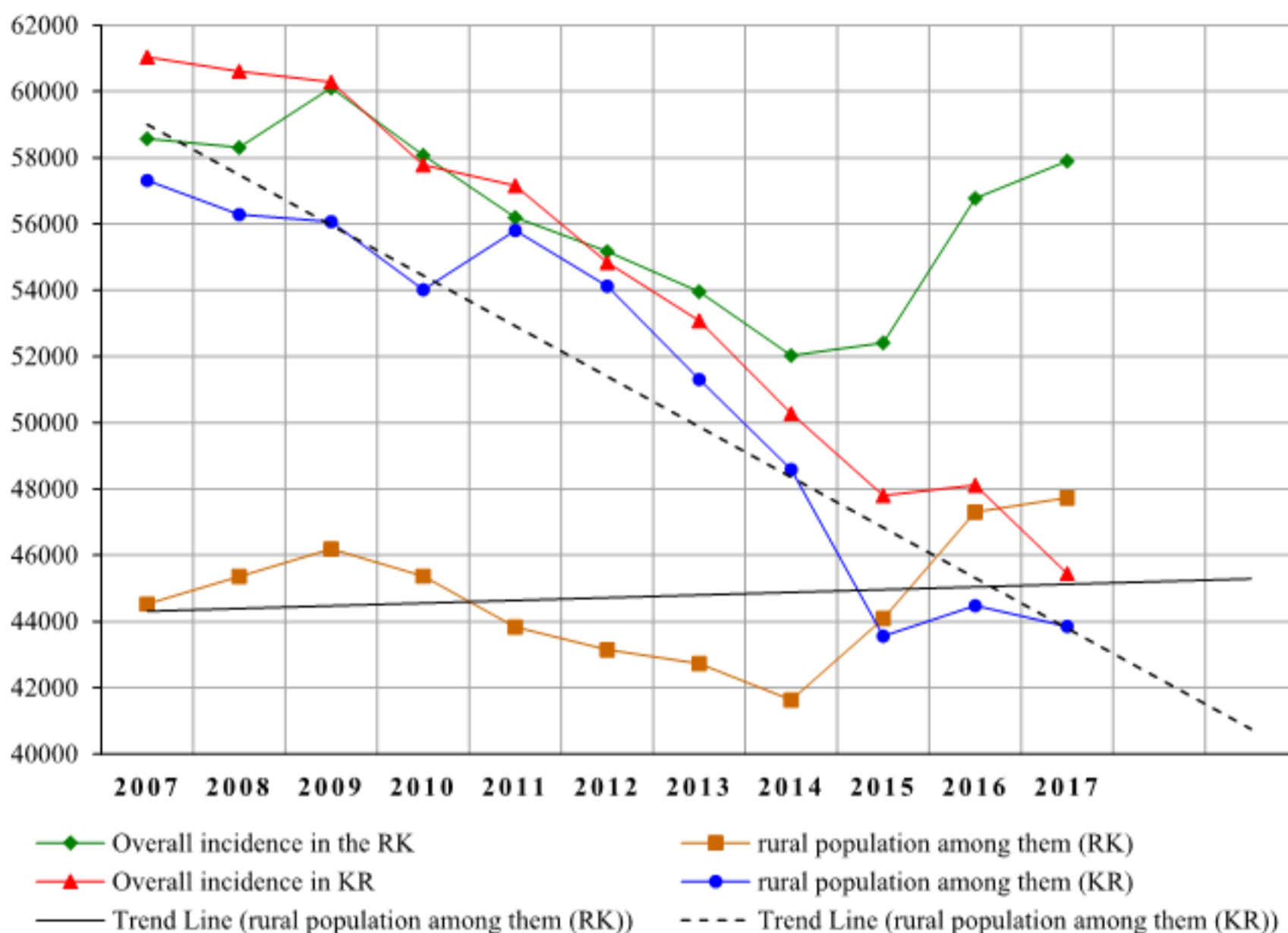
Figure 14 – Long-term dynamics of the overall incidence of disease in the Republic of Kazakhstan and Karaganda Region for 2007-2017 (per 100,000 people)

Karaganda Region was characterized by a reduction in the overall incidence rate among the population for the entire research period. This rate was 61,037.8 per 100,000 people in 2007 and 45,447.3 per 100,000 people in 2017, with a decline of 1.3 times [3, c. 11].

In the Republic, there is a relative stability of the overall incidence of disease among villagers with small fluctuations around the mean ($M=44,717.7$, $s=1896.4$). However, the disease dynamics among the rural population of Karaganda Region is linearly decreasing over the period under review. It was 57,310.6 per 100,000 people

in 2007, and then it decreased to 43,849.7 in 2017 (*M=51,400, s=5372.3*). Therefore, the regional incidence rate is statistically significantly different from the republican one, since *t=3.627, p=0.05* [3, c. 11].

When analyzing the age and gender composition of patients in rural areas of Karaganda Region, it was found that women over the age of 18 became ill more often: for the last analyzed year, the main share was composed of females (54.2%). The adult population prevails in the age structure (18&=53.2%). The proportion of patients from 15 to 17 years old and children under the age of 14 was 7.3% and 39.5% respectively [3, c. 11; 241].

3.2.3 The incidence of disease among the rural population in Bukhar-Zhyrau District of Karaganda Region due to fluctuations in microbiological water quality indicators

We selected all diseases related to water-borne intestinal infections from the number of infectious diseases recorded in the territorial DQCSGS and provided the data to table 4. No Cholera, Typhoid fever, Paratyphoid fever A, B, C and Bacterial carriers of typhoid and paratyphoid fever were registered in the Bukhar-Zhyrau District between 2008 and 2018 [3, c. 11].

Table 4 – Incidence rate of WASH-related intestinal infections in Bukhar-Zhyrau District (per 100,000 people)

	Bacillary dysentery		Bacterial carriers of dysentery		Other intestinal infections of established etiology		Bacterial and viral intestinal infections of unknown etiology		Group of acute intestinal infections	
	Total	*0-14 years old*	*Total*	*0-14 years old*	*Total*	*0-14 years old*	*Total*	*0-14 years old*	*Total*	*0-14 years old*
2008	15.77	51.47	12.62	44.12	45.74	191.18	52.05	198.53	113.56	441.18
2009	10.02	23.62	1.67	7.87	80.13	338.58	46.74	204.72	136.89	566.93
2010	0	–	1.68	0	28.52	128	1.68	8	30.2	136
2011	3.34	7.75	0	–	20.03	77.52	5.01	23.26	28.38	108.53
2012	0	–	0	–	80.7	376	0	–	80.7	376
2013	0	–	0	–	80.52	296	37.14	144	114.66	440
2014	0	–	0	–	99.68	330.99	55.38	204.23	155.06	535.21
2015	0	–	0	–	114.24	467.15	41.39	167.88	155.63	635.04
2016	0	–	0	–	116.32	408.76	9.38	36.5	125.7	445.26
2017	0	–	0	–	103.03	394.72	28.92	98.68	131.95	493.4
2018	1.9	4.61	0	–	140.96	517.35	43.81	152.16	184.77	674.12

Retrospective analysis of the long-term dynamics of WASH-related intestinal infections in Bukhar-Zhyrau District from 2008 to 2018 (figure 15) revealed that there had been a downward trend in the incidence of disease from 2009 to 2011. This figure amounted to 56.8 per 100,000 people in 2011, which was the minimum value for the studied period. The incidence rate began to grow in 2011 and reached its peak in 2018 (371.4 per 100,000 people) [3, c. 11].

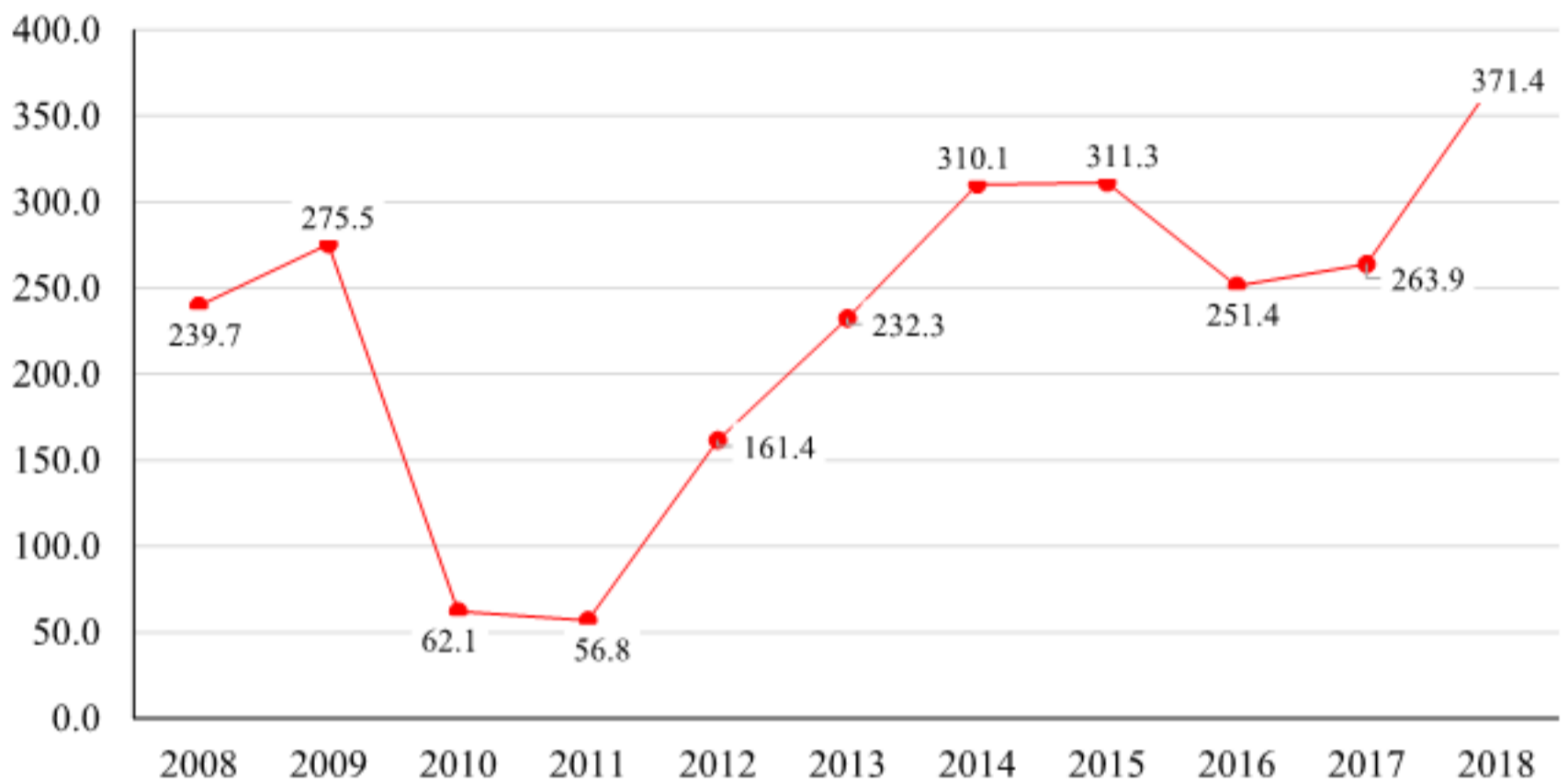Figure 15 – Long-term dynamics of WASH-related intestinal infections in Bukhar-Zhyrau District from 2008 to 2018 (per 100,000 people)

Group of acute intestinal infections was prevalent in the structure of WASH-related intestinal infections and made 49.78% of all registered cases among the population in 2018 (figure 16) [3, c. 11].
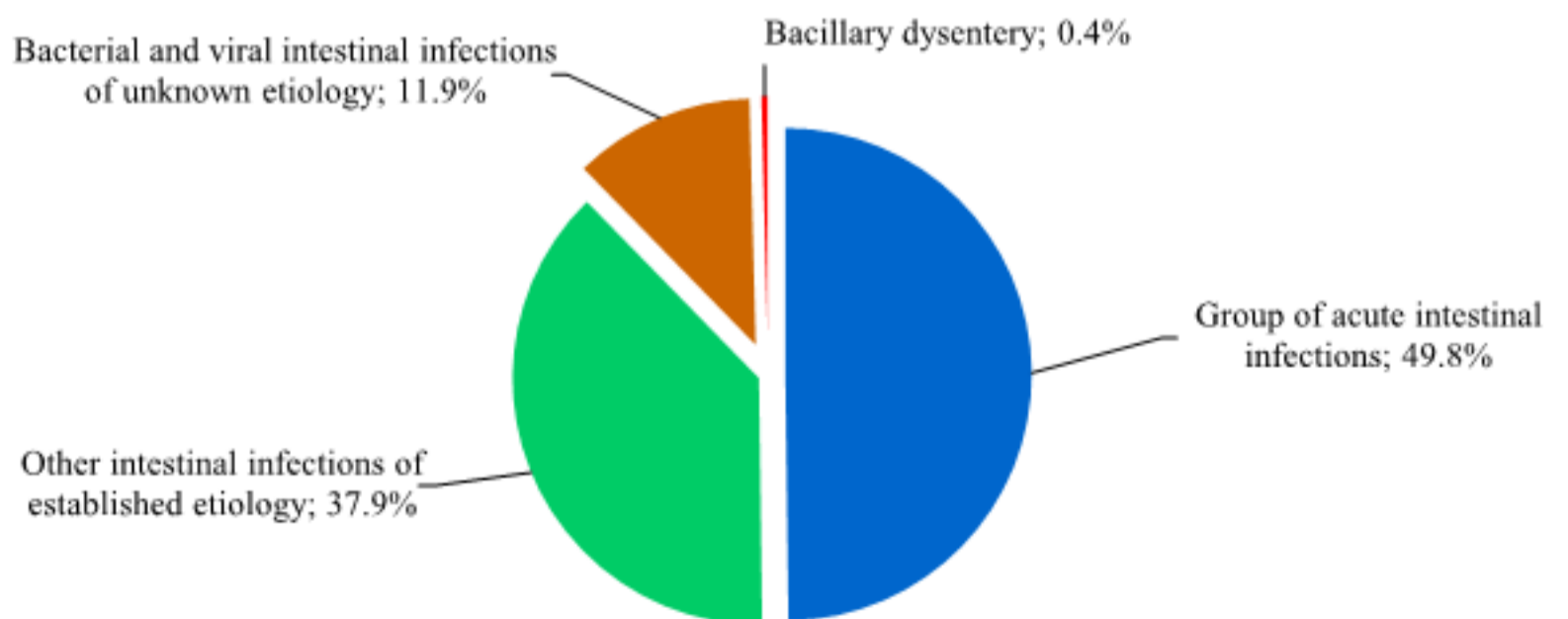

Figure 16 – Structure of WASH-related intestinal infections in the Bukhar-Zhyrau District in 2018

Thus, WASH-related disease burden hold a specific place in the structure of mortality and disability throughout the world. In 2012, 6.3% of all deaths (0.5% in developed versus 8% in developing countries) and 9.1% of disability in the world (0.9% in developed versus 10% in developing countries) were associated with WASH. In Kazakhstan, these indicators were 0.9% and 1.5%, respectively. As for the incidence rate in the Republic of Kazakhstan, this indicator has been growing since 2015 (57,896.9 per 100,000 people in 2017 compared to 52,410.7 per 100,000 people in 2015). Such an unfavorable trend may indicate both a deterioration of public health and an improvement in diagnostics level in the country. It was found that the incidence rate among the rural population of Karaganda Region was statistically significantly different from the republican one (t=3.627, p=0.05). If the regional indicator in 2007 amounted to 57,310.6 per 100,000 people (republican was 44,523.3 per 100,000 people), it had decreased by 2017 to 43,849.7 per 100,000 people, and the republican one on the contrary increased to 47,731.7 per 100,000 people. The epidemiological feature of the overall incidence of disease in Karaganda Region was a high proportion of women over the age of 18 (54.2%). When analyzing the accounting records of the territorial DQCSGS, it was found that they did not register all the infections recognized by WHO as WASH-related diseases. The reported intestinal infections included the following: bacillary dysentery, bacterial carriers of dysentery, other intestinal infections of established etiology, bacterial and viral intestinal infections of unknown etiology and group of acute intestinal infections. The long-term dynamics of above intestinal WASH-related infections in Bukhar-Zhyrau District from 2008 to 2018 had a tendency to rise (239.7 per 100,000 people in 2008 and 371.4 per 100,000 people in 2018). The group of acute intestinal infections predominated in the morbidity patterns and made 49.78% in 2018. No Cholera, Typhoid fever, Paratyphoid fever A, B, C and Bacterial carriers of typhoid and paratyphoid fever were registered in the Bukhar-Zhyrau District between 2008 and 2018. It should be noted that taking into account some fluctuations in microbiological indicators of water quality, the results of assessment of the influence of water factor on health are contradictory, which is due to inadequate control and insufficient number of epidemiological data. This is exacerbated by the lack of data on hygiene factors related to the quality of water supply and their interaction. In general, the greatest bacteriological risk is associated with the use of drinking water that is heavily contaminated with sewage. The risk of microbial contamination cannot be eliminated, since WASH-related diseases can also be transmitted from person to person by other routes. It also contributes to the reservoir of patients and carriers of infection. Chemical pollution of water is a low-intensity factor that does not cause acute effects. Standards for chemicals in water lose all their significance in the face of massive bacterial contamination. Accordingly, the chemical factor has a lower priority in comparison with microbial, the consequences of which can be immediate and large-scale. Another remote effect associated with chemical components is that the recommended values refer to the average exposure levels. Occasional small excesses are acceptable, and the consequences of them must be carefully considered in the light of local conditions. This follows from the definition of recommended values for chemicals [3, c. 13]. Therefore, in Kazakhstan, there are a

number of difficulties with the registration of WASH-related diseases, since it is not always possible to establish a cause-and-effect relation between the lack of access to safely managed drinking water and sanitation or non-observance of personal hygiene and the resulting disease. Consequently, understanding the prevention of disease associated with unsatisfactory or insufficient water supply as well as poor sanitation and hygiene provides the basis for making scientifically grounded decisions on this matter.

3.3 Current access to safe drinking water in villages with various types of water supply

3.3.1 Demographic characteristics of respondents

The total number of respondents was 1369 instead of 1394 (table 5), since 25 people had withdrawn from the investigation: four from Botakara; three from Dubovka; seven from Karazhar, and 11 from Asyl [20, p. 5].

Table 5 – Number of population in the villages of interest by type of water supply according to the official data and sample size

Types of water supply	Villages	Botakara (1)	Dubovka (2)	Karazhar (3)	Asyl (4)
Centralized	tap	2660	4034	650	–
	standpipe	438	80	385	–
	$\sum$	3098	4114	1035	–
Decentralized	borehole	2156	–	–	–
	well	998	–	–	–
	$\sum$	3154	–	–	–
Tankered	$\sum$	–	–	–	294
Sample size		362	353	280	167
Sample size + 20%		434	424	336	200
Surveyed respondents		430	421	329	189
Surveyed sample size		6.9%	10.2%	31.8%	64.3%

$$n_1 = \frac{50 \times 50 \times 1.96^2 \times 6252}{5^2 \times 6252 + 50 \times 50 \times 1.96^2} = 362; n_2 = \frac{50 \times 50 \times 1.96^2 \times 4114}{5^2 \times 4114 + 50 \times 50 \times 1.96^2} = 353;$$

$$n_3 = \frac{50 \times 50 \times 1.96^2 \times 1035}{5^2 \times 1035 + 50 \times 50 \times 1.96^2} = 280; n_4 = \frac{50 \times 50 \times 1.96^2 \times 294}{5^2 \times 294 + 50 \times 50 \times 1.96^2} = 167$$

Provided inevitable loss amongst the participants in the research (for various reasons), the calculated sample size increased by 20% [20, p. 4]:

$$n_1 = 362 + (20\% \times n_1) = 434; n_2 = 353 + (20\% \times n_2) = 424;$$

$$n_3 = 280 + (20\% \times n_3) = 336; n_4 = 167 + (20\% \times n_4) = 200$$

According to the literary source [242], the overall burden of collecting and using water in population is usually much higher in females than males. Our results (table 6) have also confirmed this fact, since 62.97% [95% CI: 60.37-65.48] of respondents were women and the remaining 37.03% [95% CI: 34.52-39.63] were men. The respondents were between 19-70 years old: 25.57% [95% CI: 23.33-27.94] of them under 30 years old, 24.18% [95% CI: 21.98-26.52] aged 31 to 40, 20.31% [95% CI: 18.26-22.52] aged 41 to 40, 17.53% [95% CI: 15.61-19.64] aged 51 to 60 and 12.42% [95% CI: 10.78-14.27] over 61 years old. Regarding the duration of residence in the studied villages, 2.34% [95% CI: 1.66-3.28] lived there less than five years; 3.87% [95% CI: 2.97-5.03], from five to 10 years; 14.02% [95% CI: 12.29-15.97], from 11 to 20 years and 79.77% [95% CI: 77.56-81.81] lived in the villages from their birth. Finally, 40.61% [95% CI: 38.04-43.24] had less than three family members; 49.01% [95% CI: 46.37-51.66], from four to six members and 10.37% [95% CI: 8.87-12.1] over seven members. Since the selection of households was randomized, the level of education within the communities surveyed was not specifically studied [20, p. 5].

Table 6 – Demographic characteristics of respondents

Variables	Responses	Number	Percent	95% CI
Sex of the respondents	male	862	62.97%	60.37-65.48
	female	507	37.03%	34.52-39.63
Age of respondent	<30 years old	350	25.57%	23.33-27.94
	31-40 years old	331	24.18%	21.98-26.52
	41-50 years old	278	20.31%	18.26-22.52
	51-60 years old	240	17.53%	15.61-19.64
	>61 years old	170	12.42%	10.78-14.27
Residence in the studied villages (in years)	<5 years	32	2.34%	1.66-3.28
	5-10 years	53	3.87%	2.97-5.03
	11-20 years	192	14.02%	12.29-15.97
	>20 years	1092	79.77%	77.56-81.81
Number of family members in the household	<3 members	556	40.61%	38.04-43.24
	4-6 members	671	49.01%	46.37-51.66
	>7 members	142	10.37%	8.87-12.1

3.3.2   Selection of drinking water source in the villages
Comparing the official data from table 5 and the collected data from table 7, it was found that the residents often used some alternative water sources, even though they were provided with tap water supply. According to the official data, 42.55% of the population in Botakara village had a water pipe in a house and 7% of them used standpipes outdoors, but only 25.35% [95% CI: 21.47-29.67] of the respondents

indicated taps as a source of drinking water and 51.4% [95% CI: 46.68-56.09], standpipes. In addition, 34.49% of the villagers had registered boreholes, and 15.96% had registered wells in their yards. Nevertheless, our data showed that only 16.51% [95% CI: 13.3-20.31] and 6.74% [95% CI: 4.74-9.52] used this kind of sources [20, p. 5].

Table 7 – Percentage of respondents by drinking water sources according to the collected data

Types of water supply	Villages	Botakara (1)	Dubovka (2)	Karazhar (3)	Asyl (4)
Centralized	tap	25.35%	28.5%	15.5%	–
	95% CI:	21.47-29.67	24.4-32.99	11.99-19.81	
	standpipe	51.4%	15.2%	6.38%	–
	95% CI:	46.68-56.09	12.09-18.95	4.21-9.56	
	$\sum$	76.74%	43.71%	21.88%	–
	95% CI:	72.53-80.49	39.05-48.48	17.76-26.66	
Decentralized	borehole	16.51%	23.52%	28.57%	–
	95% CI:	13.3-20.31	19.72-27.79	23.96-33.68	
	well	6.74%	17.34%	31.31%	–
	95% CI:	4.74-9.52	14.02-21.25	26.54-36.51	
	$\sum$	23.26%	40.86%	59.88%	–
	95% CI:	19.51-27.47	36.26-45.61	54.5-65.03	
Tankered	$\sum$	–	–	–	100%
	95% CI:				98.01-100
Open source	$\sum$	0%	15.44%	18.24%	–
	95% CI:	–	12.3-19.2	14.44-22.77	

The situation was different in Dubovka village. There, 100% of the population was provided with centralized water supply and 98.06% of them had water taps inside their houses (table 5). However, nearly half of the respondents (40.86% [95% CI: 36.26-45.61]) indicated alternative water points as a source of drinking water due to the time limited water service (table 7). Private unregistered boreholes and wells were used by 23.52% [95% CI: 19.72-27.79] and 17.34% [95% CI: 14.02-21.25] of the respondents, respectively. Moreover, 15.44% [95% CI: 12.3-19.2] of villagers preferred to use water from natural open sources [20, p. 6].

A similar situation was observed in Karazhar village. According to the data in table 5, 100% of the population was provided with centralized water supply. Nevertheless, as many as 59.88% [95% CI: 54.5-65.03] of the respondents indicated decentralized water sources: 28.57% [95% CI: 23.96-33.68] of them had unregistered boreholes; 31.31% [95% CI: 26.54-36.51], unregistered wells; and 18.24% [95% CI: 14.44-22.77], independently brought water from natural open sources (table 7). The central water supply in the village was served all year round on a scheduled basis, four hours in the morning and three in the evening. According to the respondents' description, tap water was muddy. Therefore, people had to let water run for a long time, as well as to settle and boil it before each use [20, p. 6].

Consequently, tap water installed in villages by the government was not able to fully satisfy the populations' drinking water demands. There were some constant interruptions in the systems due to technical problems, which in turn worsened the water quality. It was further reduced because the population had underused the system's capabilities. Even though villagers were provided with tap water by the government, a significant number of them used water from alternative sources of an unknown quality. When analyzing the reasons that led to this situation, it turned out that respondents most often indicated in the questionnaire the following: doubts regarding the quality of tap water; use of other sources by habit, as they were accustomed to it during water scarcity and availability of cheaper or free water sources. The villagers also explained that scheduled water supply was the reason of searching for other water sources despite having a tap at home. This was especially the case during summer time, when water consumption increased due to garden irrigation [20, p.10].

Another problem concerned the quality of water supply from unregistered boreholes and wells in the villages. These boreholes and wells were not tested for compliance with the requirements of government standards before and during the operation. Due to acute water supply shortage, the population also had to use water from open sources [20, p. 10].

Additionally, a number of villages in Kazakhstan have an acute water shortage due to the lack of any sources in their territory. It is estimated that the economic condition of the villages is poor. The population is provided with limited volumes of tankered water, the quality of which is doubtful. At the time of this research, there were four similar villages in Bukhar-Zhyrau District. One of them was Asyl, where 294 people lived. All people there used tankered water. The distance of water delivery was 17 km from the water source [20, p. 9].

In Asyl village, the collected data (table 7) coincided with the official ones (table 5), but the reason was the absence of alternative source of drinking water supply in the territory. There was only one tanker (figure 17) for the whole settlement, which brought water once a week according to the schedule (every Friday at midday local time). Therefore, when the transport broke down, the population had no drinking water for two-four weeks. The population had to use brackish water from underground sources recommended only for domestic purposes as well as rain and thawed water. This situation was regarded as highly unsatisfactory. Water tankers must be cleaned and

disinfected before use at least once every three months [243]. According to the interview with the driver, this requirement was not always met [20, p. 10].

Figure 17 – Water delivery tanker

3.3.3   Nature of water consumption among the rural population

A study of water use characteristics was greatly significant for a sustainable development of rural regions, especially in countries with a deficiency of water resources. The person needs 50 to 100 litres of water per day to meet physiological and hygienic needs [244-246]. People facing a limit of 20 litres per capita per day will therefore be exposed to a high level of health concerns. Rural residents usually live in worse economic conditions than urban ones, which affects the volume of water use [20, p. 11; 247, 248].

When drinking water is not available in the home, the time required for water collection is an important factor that determines whether a household can receive a sufficient amount of water for domestic use [166, 249, 250]. When the time required to collect drinking water is five to 30 minutes, the amount of water is constant and is suitable to meet the basic needs [166, p. 1587]. Early studies have shown that if the total time spent on water collection exceeds 30 minutes, people tend to collect less water to the detriment of their basic needs [249, p. 63; 250, p. 3]. In terms of time or distance, access to water has influence on the risk of disease. A study conducted by Wang and Hunter [251] showed a significant increase in gastrointestinal diseases in people living far away from the water source (OR=1.45 [95% CI: 1.04-1.68]) [20, p. 11].

The results of our regression analysis are consistent with the published data and confirm that the amount of used water depended on the source of water supply used by households and the time required to transport water from the source to the house. The linear regression between the volume of water consumption, a water supply source and the time spent on water collection was moderately negative ($R=-0.691; p=0.01$) (figure 18). This relationship showed that in 99% of cases with increasing time of water

transporting, its consumption decreased. A type of water source and the time for water transportation to the house explained 47.8% of the variation in water consumption among respondents; the remaining 52.2% of the variation was caused by influence of other unaccounted factors [20, p. 6].
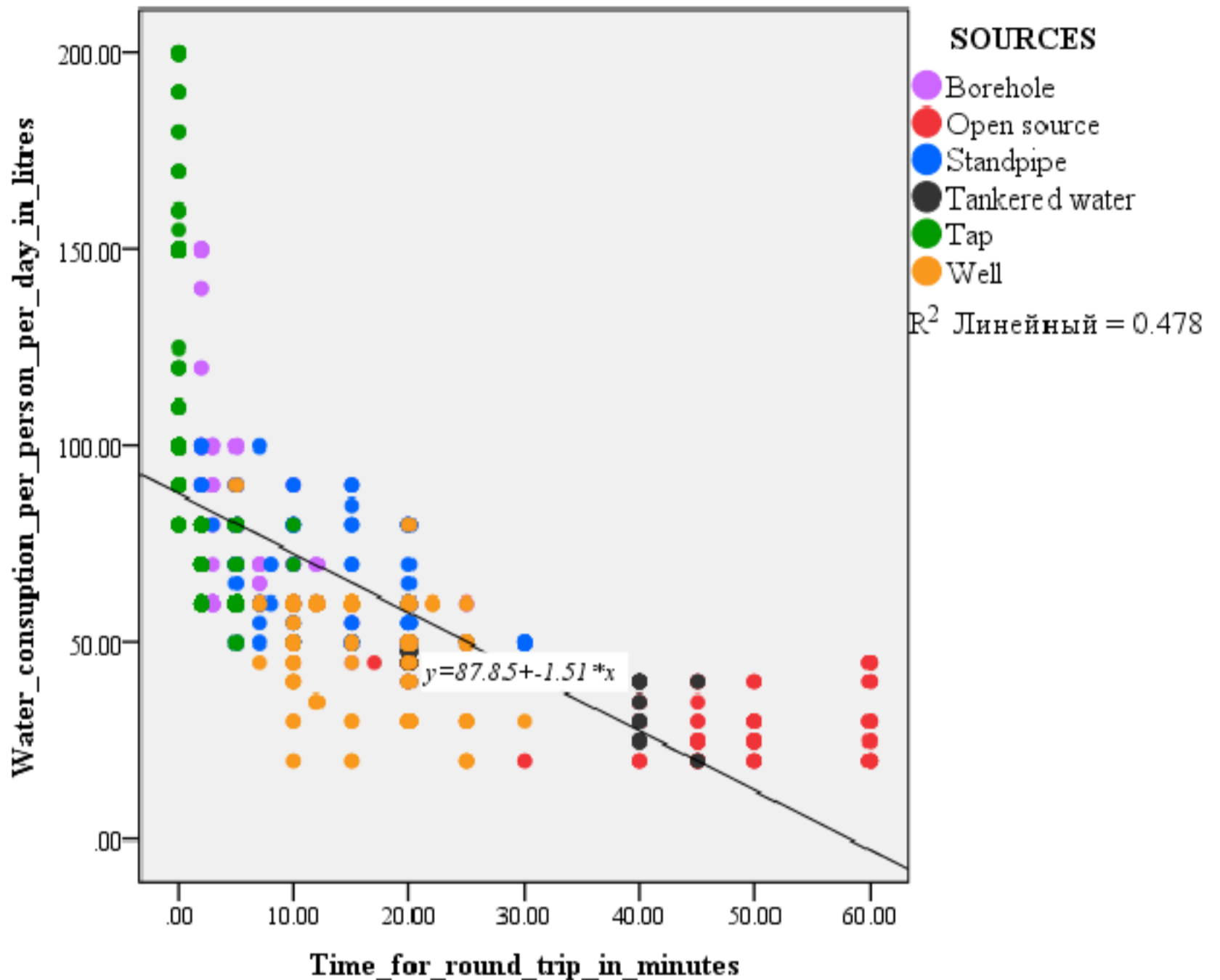
Figure 18 – Water consumption in terms of the water supply source used by households and water collection time

In this case, the volume of water consumption per person per day was calculated as follows [20, p. 5]:

– households that use the tap pay for each m³ of water according to the meter readings. The respondents indicated the volume of water consumption (x) according to the payment receipts for the last month. Thus, water consumption per person per day (L) was calculated by the following formula [20, p. 5]:

$$Water\ consumption\ per\ person\ per\ day\ (l) = \frac{x\ (m^3) \times 1{,}000(l)}{number\ of\ people\ in\ the\ house \times 30\ (days)};$$

– households that use sources without any delivery services collect and store water in tanks. During the interview, the respondents indicated the volume of tanks (x) and how often they had to fetch water. According to the findings, water consumption per person per day (l) was calculated as follows [20, p. 5]:

$$Water\ consumption\ per\ person\ per\ day\ (l) = \frac{x\,(l)}{number\ of\ people\ in\ the\ house \times days\ of\ use}$$

Consequently, the more time people spent on water transportation from the source to the house, the less water they consumed to the detriment of their physiological and hygienic needs. Moreover, the amount of water used dropped sharply with decreased quality or inconvenience related to the source of water supply used by households. Water consumption among taps, standpipes and boreholes users was found to be 50 to 200 litres per person per day, while this number among open sources and tankered water users did not reach 50 litres per day. The average water consumption in Asyl was 41.85 litres [95% CI: 41.3-42.4] per person per day. Some residents stated that they spent an average of 31.43 minutes (a round trip) [95% CI: 30.7-32.16] for self-delivery of water from alternative sources to their houses (figure 19). Other factors affecting the amount of water consumption included religious obligations, water price, family income and climate condition, as well as relations and intentions concerning preservation of water resources [20, p. 11; 252-255].

Figure 19 – A device for self-delivery of water to the house

The interview provided additional information on hygiene of water use among Asyl residents and showed that more than half of the respondents (50.26% [95% CI: 43.2-57.32]) used various plastic containers from five to 80 liters in capacity to store drinking water (figure 20). These containers were covered in almost all households (97.35% [95% CI: 93.96-98.86]). As for tank cleanliness, almost half of the respondents (48.68% [95% CI: 41.65-55.76]) cleaned their tanks twice a week. As a

cleaning agent for drinking water containers, the population used water with soap or dishwashing detergent (74.6% [95% CI: 67.95-80.28]) and just water (25.4% [95% CI: 19.72-32.05]) [20, p. 10].

Figure 20 – Water storage tanks

3.3.4 The subjective assessment of drinking water quality and reliability of water sources

Multiple *p-level* comparisons by the Kruskal-Wallis test showed that water from taps in houses, outdoor standpipes and boreholes was no different in satisfaction with the quality of drinking water and reliability of sources according to the respondents (table 8). Quality and reliability are dependent factors. System breakdown affects both of them, as the water is frequently of poor quality after such an event. Thus, *reliability* was essentially a measure of how often there was a problem concerning the delivery of water of acceptable quality [20, p. 7].

In Dubovka and Karazhar villages, there were statistically significant differences in the quality of water taken from wells and open sources, in contrast to water from other sources. Those Dubovka's villagers who used wells and open sources were not satisfied with its quality and reliability, as they rated them as "poor" (81% [95% CI: 76.98-84.46] and 71.73% [95% CI: 67.25-75.82] respectively) and "unreliable" (94.06% [95% CI: 91.38-95.95] and 86.7% [95% CI: 83.12-89.61] respectively). Almost the same situation was observed in Karazhar: 66.87% [95% CI: 61.61-71.73] of villagers were not satisfied with the quality of water from wells and 74.77% [95% CI: 69.81-79.16] from open sources. In addition, 76.6% [95% CI: 71.73-80.85] and 85.11% [95% CI: 80.85-88.55] of the respondents considered the use of wells and open sources respectively to be unreliable. In Asyl village, the level of satisfaction with the quality of water and reliability of the source was also very low. Since 77.78% [95% CI: 71.33-83.12] of residents believed that, its quality was "poor", and 98.94% [95% CI: 96.22-99.71] estimated the reliability of tankered water supply as "unreliable" [20, p. 7].

Table 8 – Level of satisfaction with the quality of drinking water and reliability of sources according to the respondents

Villages		Botakara (1)				Dubovka (2)					Karazhar (3)					Asyl (4)
Sources of water supply		tap	standpipe	borehole	well	tap	standpipe	borehole	well	open source	tap	standpipe	borehole	well	open source	tankered water
SATISFACTION = Turbidity + Odor + Taste	good	65.35%	70.7%	86.74%	46.28%	81.24%	60.1%	51.07%	0%	1.66%	33.74%	46.5%	19.45%	2.13%	0%	6.88%
	95% CI:	60.73-69.69	66.23-74.8	83.21-89.63	41.62-51	77.23-84.68	55.35-64.66	46.31-55.81	-	0.81-3.39	28.84-39.01	41.19-51.9	15.54-24.07	1.03-4.33	-	4.06-11.41
	average	27.91%	28.84%	10.23%	53.72%	4.51%	18.05%	31.83%	19%	26.6%	36.78%	50.15%	60.49%	31%	25.23%	15.34%
	95% CI:	23.88-32.33	24.76-33.29	7.71-13.46	49-58.38	2.91-6.94	14.67-22.01	27.56-36.43	15.54-23.02	22.61-31.02	31.75-42.11	44.78-55.52	55.11-65.62	26.25-36.2	20.84-30.19	10.9-21.17
	poor	6.74%	0.47%	3.02%	0%	14.25%	21.85%	17.1%	71%[1]	71.73%[1]	29.48%	3.34%	20.06%	66.87%[1]	74.77%[1]	77.78%
	95% CI:	4.74-9.52	0.13-1.68	1.78-5.1	-	11.24-17.91	18.17-26.05	13.81-20.99	76.98-84.46	67.25-75.82	24.82-34.62	1.88-5.89	16.09-24.72	61.61-71.73	69.81-79.16	71.33-83.12
RELIABILITY	reliable	42.33%	43.49%	76.51%	42.79%	73.62%	39.9%	52.26%	0%	0%	17.63%	28.57%	13.07%	0%	0%	0%
	95% CI:	37.74-47.04	38.88-48.21	72.28-80.27	38.2-47.51	74.46-82.27	35.34-44.65	47.49-56.99	-	-	13.89-22.11	23.96-33.68	9.85-17.14	-	-	-
	not always	50%	54.65%	17.67%	57.21%	0%	26.6%	21.62%	5.94%	13.3%	35.26%	14.29%	64.13%	23.4%	14.89%	1.06%
	95% CI:	45.3-54.7	49.93-59.29	14.36-21.56	52.49-61.8	-	22.61-31.02	17.95-25.79	4.05-8.62	10.39-16.88	30.29-40.56	10.92-18.48	58.82-69.13	19.15-28.27	11.45-19.15	0.29-3.78
	unreliable	7.67%	1.86%	5.81%	0%	21.38%	33.49%	26.13%	94.06%[1]	86.7%[1]	47.11%	57.14%	22.8%	76.6%[1]	85.11%[1]	98.94%
	95% CI:	5.52-10.58	0.95-3.63	3.97-8.44	-	17.73-25.54	29.15-38.13	22.16-30.53	91.38-95.95	83.12-89.61	41.78-52.51	51.74-62.38	18.59-27.63	71.73-80.85	80.85-88.55	96.71-99.71
[1]Significant at p < 0.05																

Consequently, people in Botakara were the most satisfied with the quality of used drinking water and reliability of sources because they did not use water from open sources, and it was in this area where the majority of boreholes and wells had been registered. The less satisfied people lived in Dubovka and Karazhar due to low quality of water from wells and open sources, and in Asyl because of tankered water. People gave a poor estimate to reliability of these sources, although they still consumed water from them [20, p. 11].

Figure 21 shows the subjective assessment of the price and quality of drinking water given by the respondents depending on the used water source on a scale from one to ten. They stated the quality of drinking water in points in accordance with their impression, where one point was low and ten points was good quality. The price was converted into points based on the impression of drinking water cost, where one point was acceptable and ten points was expensive. The ratio of quality and price was calculated as follows [20, p. 9]:

$$Quality - price\ ratio = \frac{Quality}{Price}$$

The assessment given by the respondents fell in the following sequence depending on the water source: tap > standpipe > borehole > well > open source. Even while there was one source of water for taps and standpipes in each village, satisfaction with its quality and reliability varied due to technical problems in water supply plants. Upon their assessment of the price and quality of drinking water subject to the water source, the respondents gave more points to tap water than to standpipe in all villages of interest. This was because in this case they estimated the quality of the water as well as the convenience service [20, p. 9].
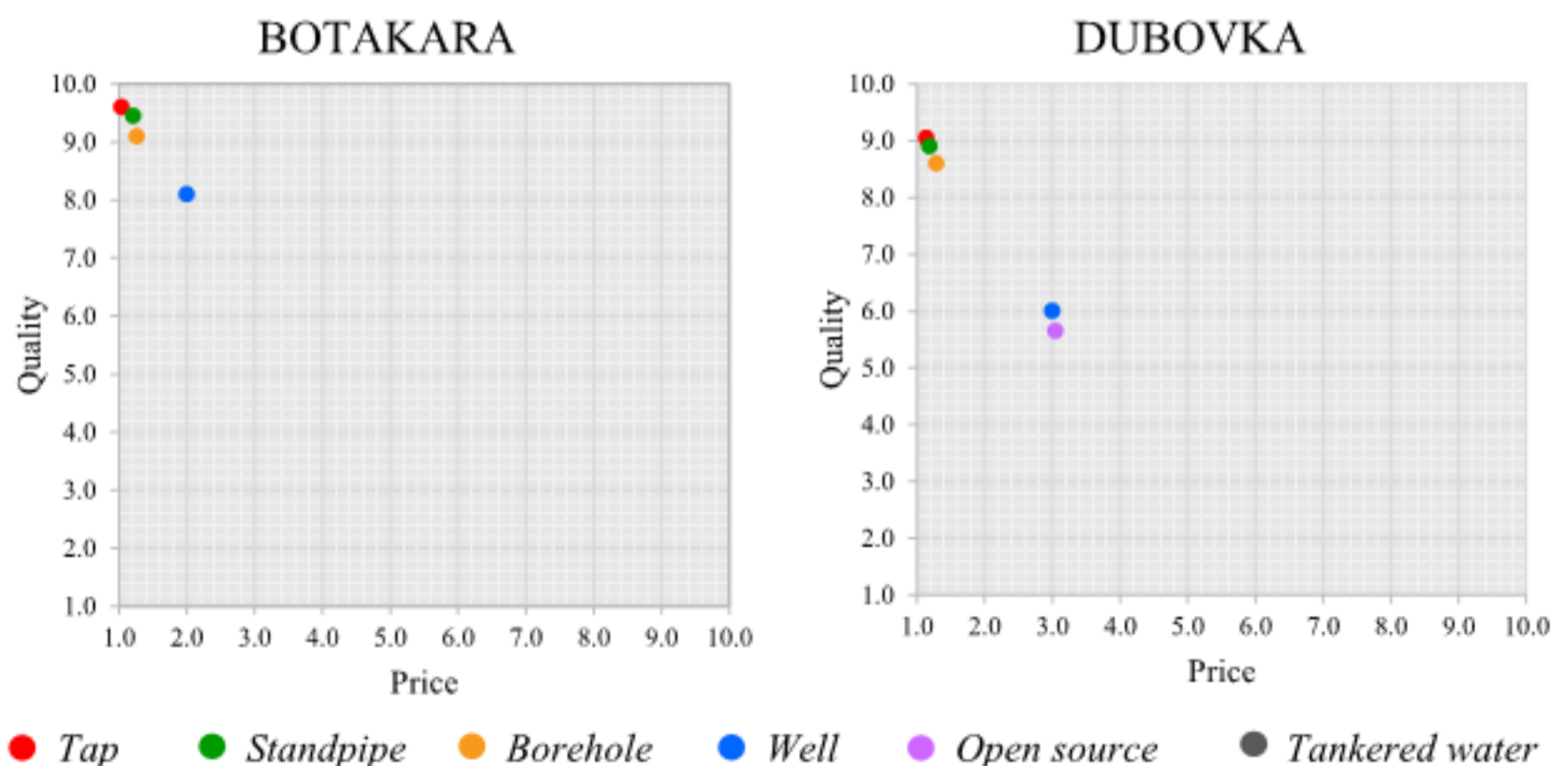

Figure 21 – Subjective assessment of quality-price ratio on drinking water by the respondents, sheet 1

KARAZHAR   ASYL

● *Tap*   ● *Standpipe*   ● *Borehole*   ● *Well*   ● *Open source*   ● *Tankered water*
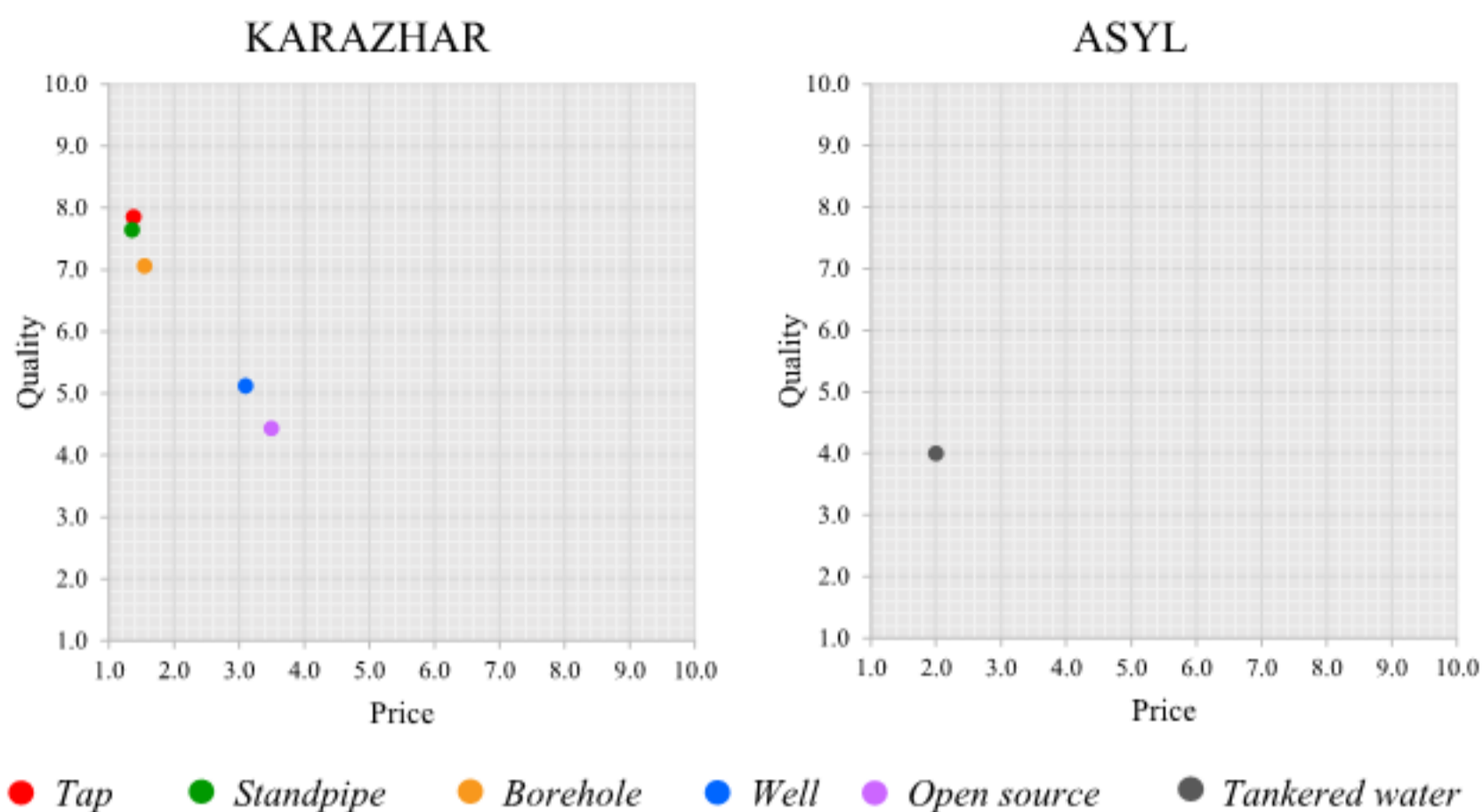
Figure 21 – Sheet 2

Furthermore, the villagers thought that the costs of an agreement with a third party for drilling a well and independent water transportation from open sources as well as the price of tankered water were not in line with its quality. This number for water from wells in Botakara was estimated at 4.1 points; in Dubovka, at two points; in Karazhar, at 1.7 points. The residents of Dubovka and Karazhar also used open sources and rated them at 1.9 and 1.3 points respectively. Villagers from Asyl assessed the quality-price ratio of tankered water at only two points [20, p. 9].

3.3.5   Additional measures to improve the quality of drinking water

As shown in figure 22, 27.21% [95% CI: 23.22-31.6] of respondents in Botakara, 27.55% [95% CI: 23.5-32.01] in Dubovka and 17.63% [95% CI: 13.89-22.11] in Karazhar bought bottled water. However, Karazhar village differed from the other two in the frequency and quantity of such water. Among those who was buying bottled water, 50% [95% CI: 45.3-54.7] of people in Botakara and 50.12% [95% CI: 45.36-54.87] in Dubovka did this irregularly, while Karazhar villagers had to purchase it two or three times a week. Residents of Botakara and Dubovka bought an average of 5.1 [95% CI: 5.08-5.12] and 4.97 litres [95% CI: 4.42-5.52] at a time respectively. In Karazhar, this number was 7.05 litres [95% CI: 6.66-7.44]. The data showed that an additional purchase of bottled water was more popular among the Asyl population. The reason for this was both an acute shortage of tankered water and its low quality. In Asyl, 68.78% [95% CI: 61.86-74.96] of respondents bought an average of 12.2 litres [95% CI: 12.14-12.26] of bottled water at a time, which was about 2.5 times higher than in other villages. However, they use it as needed for drinking and cooking only. In case of water shortage or lack of delivery, most villagers used rainwater and thawed water for hygiene purposes [20, p. 7].

BOTAKARA

27.21%

72.79%

DUBOVKA

27.55%

72.45%

KARAZHAR

17.63%

82.37%

ASYL

31.22%

68.78%

● *Buy*   ● *Do not buy*
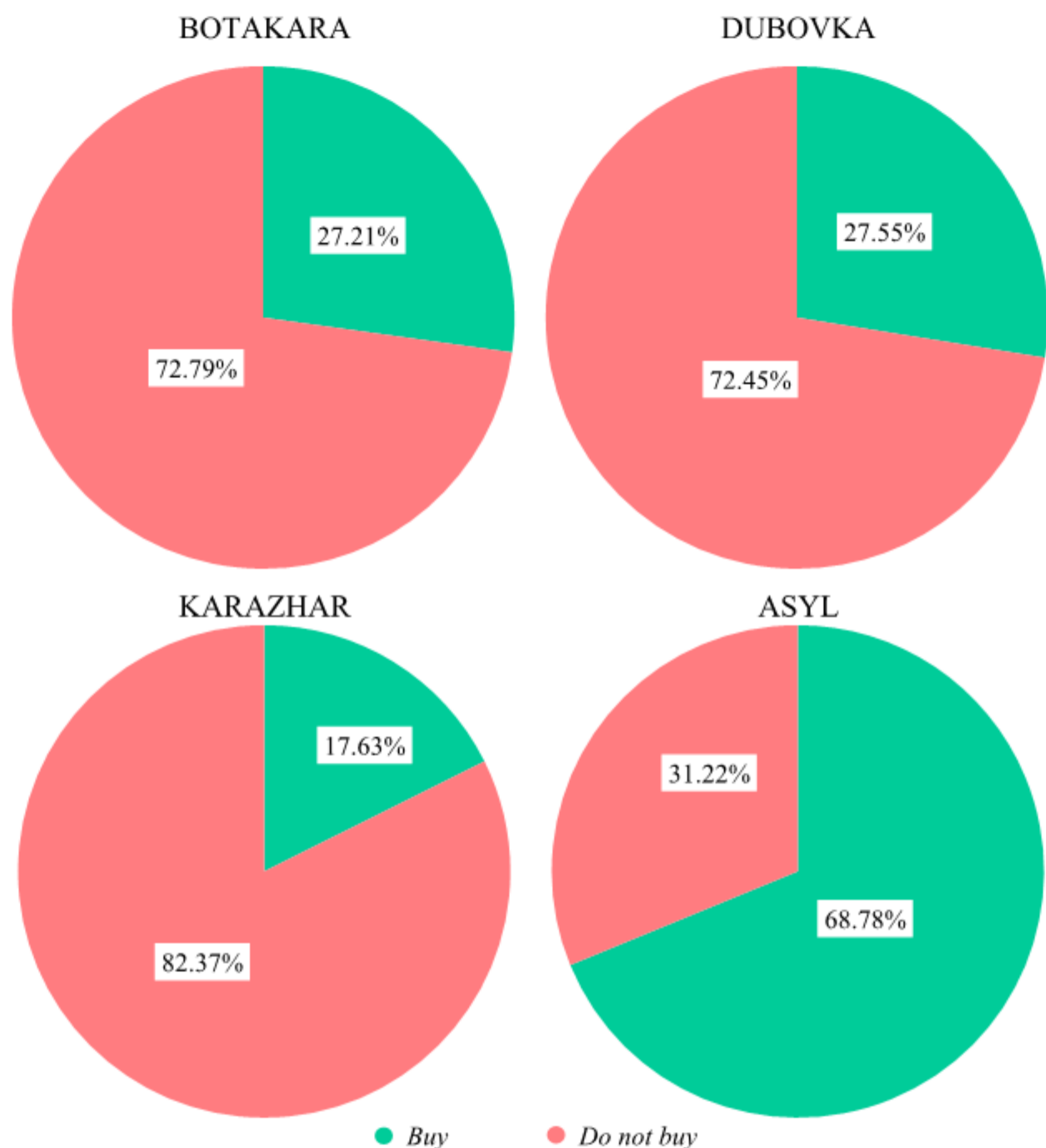
Figure 22 – Additional purchase of bottled water

Some households treated drinking water at household level (figure 23). In Karazhar 49.54% [95% CI: 44.18-54.92] of the respondents used some methods of household treatment, while this number in Botakara and Dubovka was 26.28% [95% CI: 22.34-30.64] and 25.42% [95% CI: 21.49-29.78] respectively. For this treatment, 76.29% [95% CI: 71.41-80.57] of the respondents who purified water in Karazhar said that they used a factory filter. More than half of them (55.93% [95% CI: 50.52-61.19]) changed a filter once a month and spent an average of 880 tenge [95% CI: 820.81-939.19] (US $2.47 as on August 31, 2018) on each piece [20, p. 7].
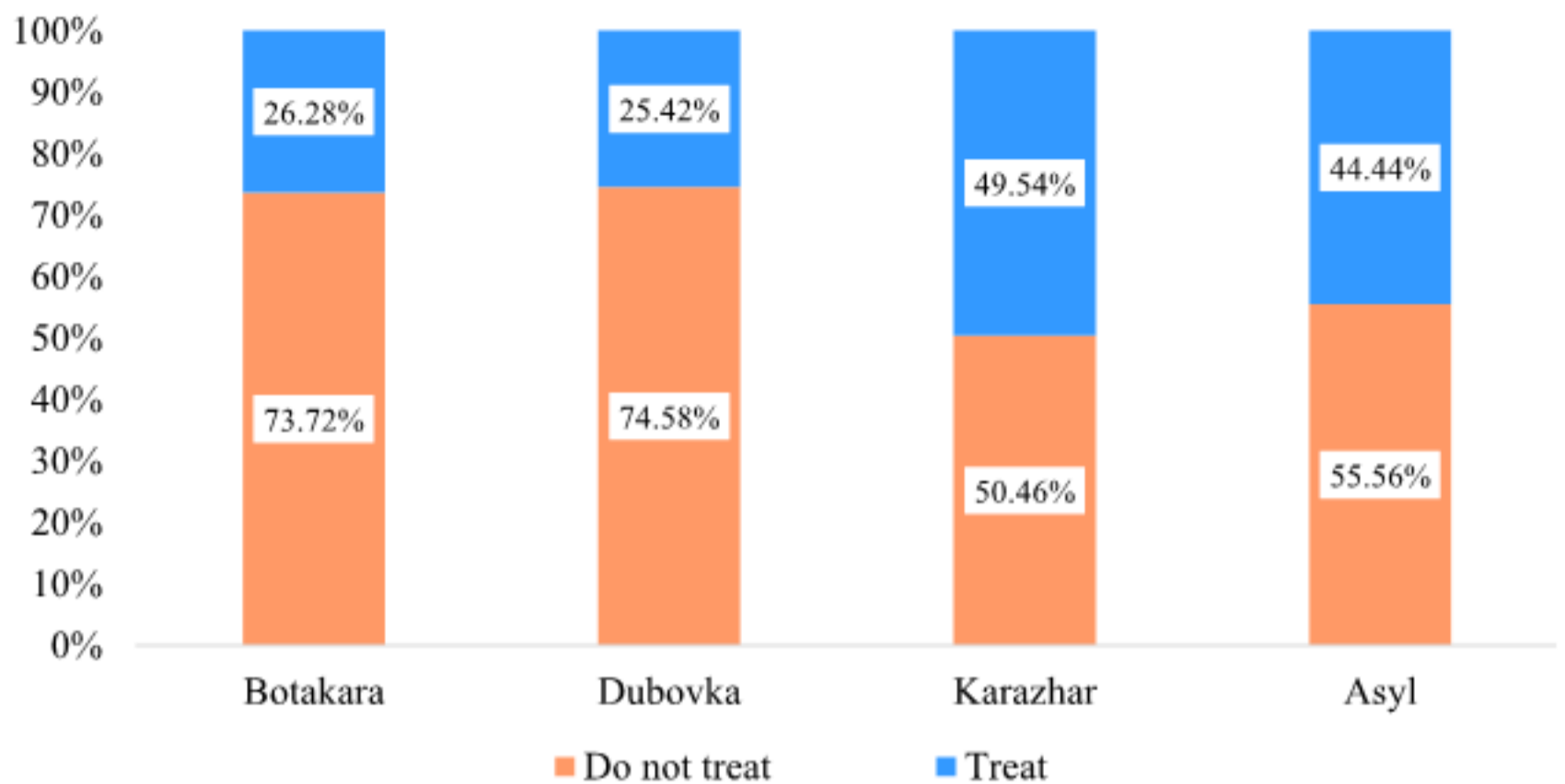
Figure 23 – Household water treatment methods in villages

In Asyl, 44.44% [95% CI: 37.54-51.57] of residents indicated that they regularly treated drinking water at home; 24.87% [95% CI: 19.25-31.49] of them boiled water before consumption, 7.41% [95% CI: 4.46-12.05] pass water through gauze, and 67.72% [95% CI: 60.76-73.98] used a factory filter (figure 24). However, the issue was that the population did not know how to operate it properly. This was evident from the fact that slightly more than half of those who used filters at home (34.39% [95% CI: 27.99-41.41]) had not changed them it from the moment of purchase [20, p. 7].
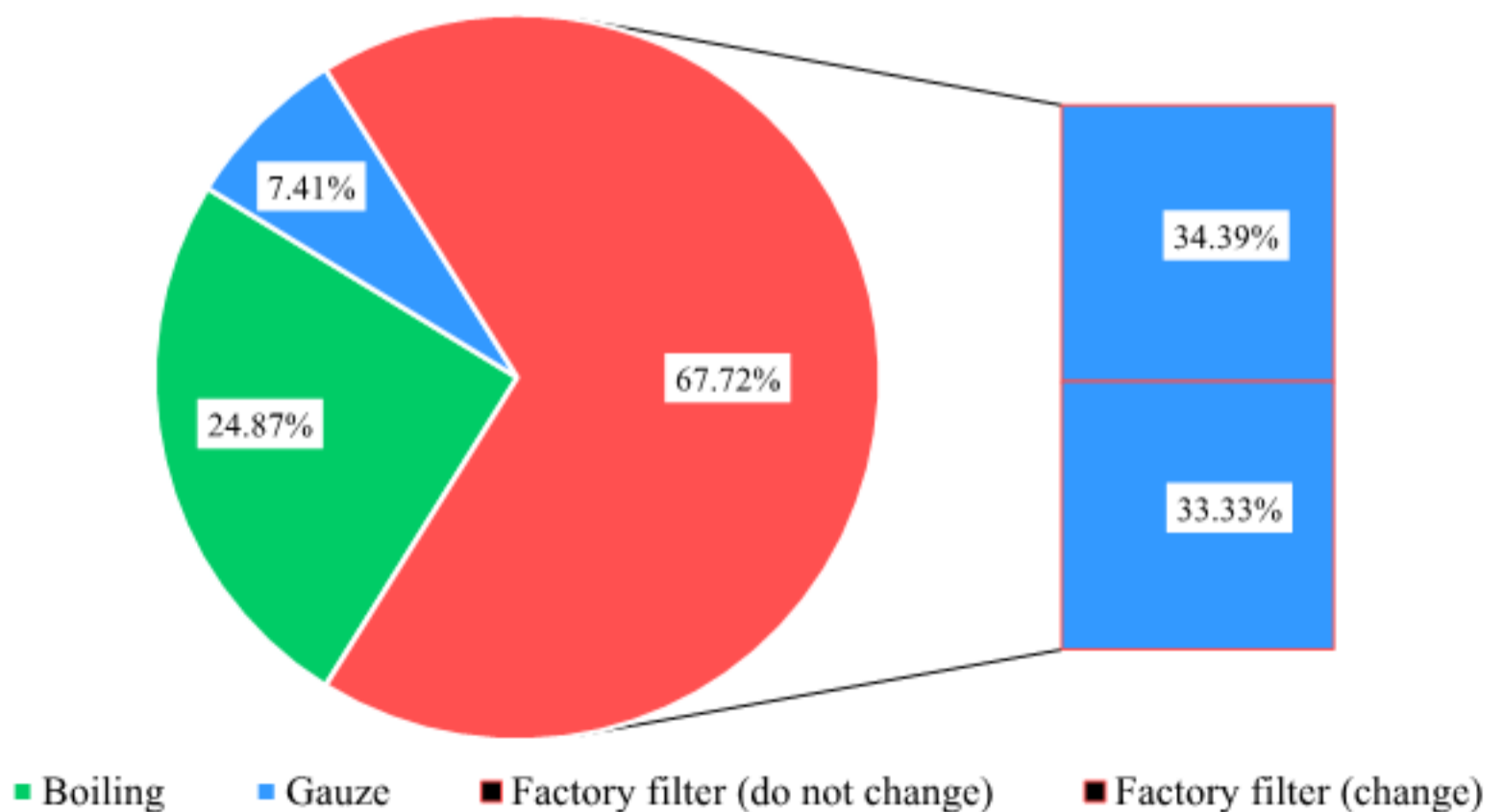
Figure 24 – Household water treatment in Asyl

Thus, 76.74% [95% CI: 72.53-80.49] of respondents in Botakara, 43.71% [95% CI: 39.05-48.48] in Dubovka and only 21.88% [95% CI: 17.76-26.66] in Karazhar actually used centralized water supply provided by the state. The rest consumed water from unregistered boreholes, unprotected wells dug manually, open sources, as well as tankered water. However, the villagers have no other option, since most of them have never had access to safe drinking water supply due to lack of infrastructure (in villages with tankered water) or technical problems with infrastructure, which leads to regular suspension of water supply. It was also found that the selection of household water supply source affected the volume of water consumption. Water consumption among users of taps, standpipes and boreholes was found to be 50 to 200 litres per person per day, while this number among users of open sources and tankered water did not reach 50 litres per day. The linear regression between the volume of water consumption, a water supply source and the time of water collection was moderately negative ($R=-0.691; p=0.01$). The subjective assessment of the quality of drinking water and reliability of sources showed that the highest level of satisfaction had been observed in Botakara, where 65.35% [95% CI: 60.73-69.69] of the respondents rated as "good" the quality of tap water; 70.7% [95% CI: 66.23-74.8], of standpipes; 86.74% [95% CI: 83.21-89.63], of boreholes; 46.28% [95% CI: 41.62-51], of wells. Nevertheless, the population in Botakara recognized the borehole to be the most reliable water source (76.51% [95% CI: 72.28-80.27]). Dubovka and Karazhar villages revealed statistically significant differences in the level of satisfaction with the quality of water from wells and open sources and their reliability, since 81% [95% CI: 76.98-84.46] of respondents in Dubovka and 66.87% [95% CI: 61.61-71.73] in Karazhar rated the quality of water from wells as "bad" and from open sources 71.73% [95% CI: 67.25-75.82] and 74.77% [95% CI: 69.81-79.16], respectively. Wells were also recognized as unreliable by 94.06% [95% CI: 91.38-95.95] of respondents in Dubovka and 76.6% [95% CI: 71.73-80.85] in Karazhar; open sources by 86.7% [95% CI: 83.12-89.61] and 85.11% [95% CI: 80.85-88.55], respectively. However, the most unreliable source of water supply is tankered water (according to 98.94% [95% CI: 96.22-99.71] of respondents in Asyl), since it is not available on the premises and if needed. Most of the population (77.78% [95% CI: 71.33-83.12]) also rated its quality low. In addition, the villagers were not satisfied with the price of such poor-quality water from the most unreliable sources. Value for money of water from wells was rated at 4.1 points in Botakara, 2 points in Dubovka and 1.7 points in Karazhar; water from open sources at 1.9 points in Dubovka and 1.3 points in Karazhar; tankered water at 2 points in Asyl. The population considered additional purchase of bottled water and treating water at home to be a desperate measure. Bottled water was needed in periods of acute shortage, when percentage of purchase was especially high in the village with tankered water (68.78% [95% CI: 61.86-74.96]). Water was treated at home in those villages where residents doubted the water quality and took responsibility for its additional treatment. In Karazhar and Asyl villages, household water treatment methods were used almost twice more often than in Botakara and Dubovka (49.54% [95% CI: 44.18-54.92] and 44.44% [95% CI: 37.54-51.57] versus 26.28% [95% CI: 22.34-30.64] and 25.42% [95% CI: 21.49-29.78]). The most common method in Asyl is the use of a factory filter

(67.72% [95% CI: 60.76-73.98]), but the population does not know the rules for operating these filters. An important factor directly affecting the water quality is water hygiene. According to the results of an additional interview among the Asyl population, plastic containers (50.26% [95% CI: 43.2-57.32]) are very popular because of their convenience, diversity and affordability. About 97.35% [95% CI: 93.96-98.86] of all containers were covered, but more than half of the respondents (51.32% [95% CI: 44.24-58.35]) did not clean them regularly. Therefore, providing safely managed drinking water to rural Kazakhstan is a tremendous challenge that the government needs to tackle as soon as possible [20, p. 11-12].

4 WAYS TO IMPROVE ACCESS TO SAFE WASH FACILITIES AND PRACTICES IN RURAL AREAS

4.1 Estimation of drinking water supply coverage

Despite some progress in improving water access, our research has shown that it is overestimated on a global scale due to how this access has been currently measured. Almost all water supply studies report water access at a specific point in time or a distance to the nearest water source. In fact, water access is a dynamic process that often changes depending on the season [256], water availability [257], infrastructure failure [258, 259] or eco-social aspects [260]. Such inaccessibility can lead to changes in the type of water source with some health consequences. Far fewer people have easy access to safe and reliable water than global estimates suggest [261]. Therefore, to improve water access globally, we must first understand the real picture of safe drinking water provision in rural areas.

The number of people who have a specific centralized water supply is determined by the data from executive authorities, local government bodies and water supply providers. In the regional development program, the indicator of centralized water supply provision in rural areas is calculated by the number of villages connected to this service. However, this research revealed a gap in the official data on the access of the rural population in Karaganda Region to drinking water with the actual situation due to the difference in the methodology of data collection. This is because centralized water supply does not always meet the requirements of SDG 6.1 for safely managed drinking water, i.e., "located on premises", "availability when needed" and "free of contamination". Therefore, it would be more appropriate to calculate "proportion of population using safely managed drinking water from centralized water supply systems." This indicator should be calculated as follows:

$$N = \frac{A_1}{A} * 100$$

N – proportion of population provided with safely managed drinking water from centralized water supply systems, %;

A_1 – population using drinking water from centralized sources;

A – total population provided with drinking water supply.

To calculate A_1, it is necessary to conduct a population survey by means of each household visiting (figure 25) using the example of our research (see Subsections 2.7 in "Materials and Methods" and 3.3 in "Challenges of Drinking Water Provision in Rural Areas of Karaganda Region").

Figure 25 – Population survey by means of each household visiting in Asyl village

4.2   Systems approach to ensure improved WASH

The provision of clean water and sanitation for all is one of the SDGs, otherwise known as the Global Goals [27]. SDG 6 comprises six technical targets for the period until 2030 relating to drinking water, sanitation and hygiene, wastewater management, water efficiency, integrated water resource management and protection of aquatic ecosystems [22]. We should mention the first three of them. Target 6.1 of SDG is to achieve universal and equitable access to safe and affordable drinking water for all, which is located on the premises, available when needed and free of fecal and harmful chemical contamination. Target 6.2 is to achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations. Access to safely managed sanitation is crucial and implies a basic sanitation facility, which is not shared with other households and where excreta are safely disposed in situ or treated off-site. Target 6.3 is to improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally [22]. Universal SDG targets can only be considered achieved when met for all sub-groups within the population, which implies progressive disaggregation of data by income, gender, age, race, ethnicity, migratory status, disability, geographic location and other characteristics relevant in national contexts [8].

The USA has set up some organizations like the Center for Disease Control and Prevention (CDC) and the US EPA, which have monitored the outbreaks of WASH-related diseases since 1971. Sweden and Japan (in 1980 and 1981, respectively) established the system of National Epidemiological Surveillance of Infection Diseases (NESID) [123, p. 1380]. The National Notifiable Diseases Surveillance System (NNDSS) was created in Australia in 1990. The Health Protection Agency (HPA) was founded in the UK in 2003. The Public Health Agency of Canada (PHAC) was established in 2004. Following the USA, in 2005 some European countries organized the European Centre for Disease Prevention and Control (ECDC) [12, p. 6610]. These organizations monitor and evaluate the quality of environmental medium including water sources due to their impact on public health and develop recommended practices for reducing any adverse impacts. Monitoring of the environmental condition and public health is carried out at the government level. One of the most significant aspects of this activity is the study and analysis of WASH-related morbidity. Numerous departments and research laboratories are used to collect and analyze data [123, p. 1380]. Relevant information and documentation on outbreaks caused by pathogens in water are available from most of these centers [8, p.9-10; 12, p. 6610].

Most developing countries do not have any governmental systems for recording the incidence and prevalence of WASH-related infections or outbreaks [9, c. 108]. Therefore, there is a lack of documentation on cause-and-effect relations between consumption of water from a particular source and a disease [12, p. 6614], which may have led to underestimated rates of WASH-related infections in developing countries. About 600 million people in Latin America, Asia, and Africa live under unsanitary conditions [132, p. 256]; 1.1 billion people lack access to improved sources of drinking water and 2.6 billion people have no adequate sanitation [262]. Therefore, a high prevalence of WASH-related diseases can be expected in developing countries. For example, most outbreaks of giardiasis occur in Latin America, Africa, and Asia, about 5100 new cases each year [263]. The prevalence of *Cryptosporidium* in fecal samples from patients with gastroenteritis is 1-4% in Europe and North America, while the figure in Africa, Asia, Australia, and South America ranges from 3-20% [264]. Also, there are high rates of asymptomatic carriage of *Cryptosporidium* (10-30%) in developing countries, as compared to developed ones (<1%). Higher prevalence rates in developing countries can also be estimated for other waterborne pathogens. However, the prevalence of WASH-related infections are studied mostly in developed countries, where the health infrastructure and laboratory tests are more affordable than in the developing countries [8, 12, p. 6614; 265].

Although developed countries have established epidemiological surveillance systems, there is still no international agreement on the reporting structure. Hormann et al. [266] criticized the fact that the surveillance and reporting systems vary widely between different countries and comparison of data is not always possible. Although the CDC records each waterborne outbreak by agent, location and number of cases, European epidemiological surveillance systems are used to determine national infection rates and incidents, thus neglecting the details of WASH-related outbreaks. In addition, Craun et al. [267] found that these epidemiological surveillance systems

often failed to identify the cause and source of infection. Therefore, even those countries that already support the surveillance system for waterborne outbreaks should improve their methods of detecting and diagnosing diseases [8].

The introduction of epidemiological surveillance systems in developing countries will be useful in detecting and combating pathogens in water, which can help to improve the public health. Therefore, it is necessary to develop reliable and affordable diagnostic instruments to identify these pathogens, especially in developing countries. A further study of new methods is required in order to obtain more results on WASH-related diseases. In addition, all countries should establish an international standard reporting system leading to standardized databases and a successful cooperation in the control of waterborne pathogens [8, 12, p. 6614].

Clean water, proper disposal of bio-waste and improved hygiene behavior are important factors in preventing the transmission of waterborne pathogens [268]. Protection of drinking water from these pathogens is a serious problem for water supply organizations around the world. Despite the fact that great success has been achieved in water treatment, good understanding of the mechanisms is required for adequate control of waterborne pathogens. There is also a need for new and innovative water treatment methods that can be used in both developing and developed countries. This can only be achieved through integrated studies that examine the sources, concentrations, survival and transmission of WASH-related pathogens, the environmental exposure, and, finally, the ability of treatment systems to reliably reduce the risk of transmitting the disease through water [9, c. 108; 163]. For achieving sustainable results in safe drinking water provision in rural areas, we propose to introduce the institutional and systems approach to ensure improved WASH (figure 26) [8].
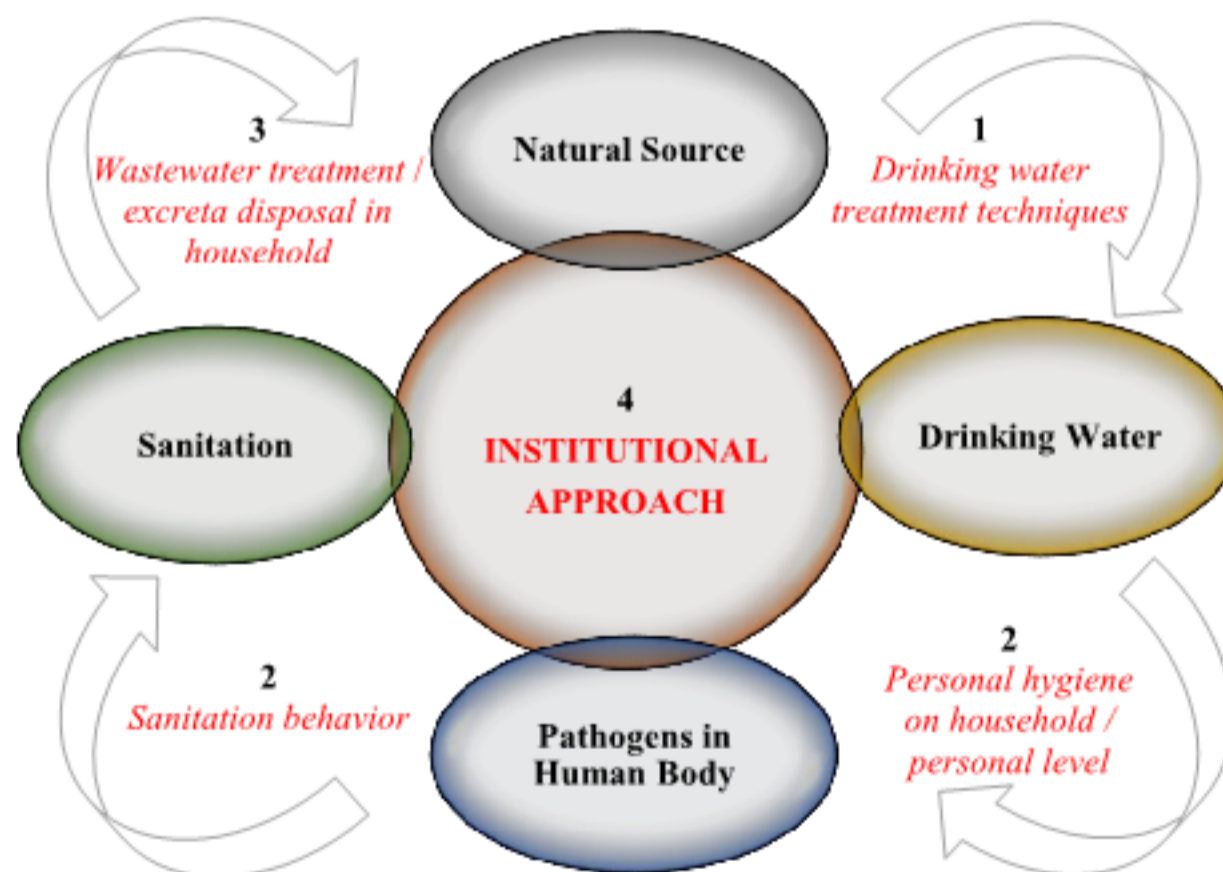

Figure 26 – Schematic of institutional and systems approach to ensure improved WASH

The schematic of institutional and systems approach to ensure improved WASH covers the entire chain from water intake to water discharge:

1) proper *drinking water treatment methods* is necessary to ensure access to safely managed drinking water. The guiding principle for providing safe water is the concept of a multiple barrier, which includes protection of the water source (surface and groundwater), optimization of water treatment, and proper maintenance of distribution systems. In addition, a multiple barrier approach should be applied in water treatment. The treatment of drinking water, which includes a combination of different disinfectants and filtration technologies to remove and inactivate various microbial pathogens, will guarantee a lower risk of microbial contamination [8, 163];

2) *hygiene on a household and personal level* is required to prevent the penetration of waterborne pathogens into the human body, while good *sanitation behavior* is able to protect our body from reinfestations. Besides improving water supply and sewerage systems to prevent or minimize the risk of spreading waterborne pathogens, measures should be focused on the hygienic behavior of people [268, p. 794]. People should feel their share of responsibility for health and undertake some activities such as hand washing, boiling tap water or installing additional filters for water purification, safe disposal of human waste and health education [8, 9, c. 108];

3) proper *wastewater treatment* and *excreta disposal in the household* is significant in order for pathogens in faeces do not enter the water supply sources [9, c. 108]. Some treatment facilities use only primary treatment. Resistant pathogens such as *Giardia* cysts and *Cryptosporidium* oocysts have not been completely eliminated even after secondary treatment. Therefore, the efficiency of such installations is minimal [161, p. 3528]. Throughout the world, there is a big difference in the coverage of toilets. Approximately 1.77 billion people around the world use pit latrines as the primary means of sanitation. The toilet type, design, materials and quality of construction also affect the localization of contamination from pit latrines. Therefore, great efforts are needed to develop more reliable but viable approaches to the placement of pit latrines and water sources. The proposed guidelines must ensure the protection of groundwater from the entry of any pathogens [8, 205, p. 521];

4) today, there is no body that controls the entire chain of water supply system from intake to the consumer and wastewater discharge from the consumer to natural sources. Therefore, it is necessary to implement an *institutional approach* to ensure the efficient measures to accomplish the above targets. This is to say that a monitoring body for waterborne pathogens is essential in developing countries. This body will have the following functions [8, 9, c. 108]:

– to determine the required method of water treatment
– to assess public risks along with reliability and effectiveness of a full-scale water treatment system
– to provide training on the requirements for digging and operating decentralized sources and pit latrines as well as for the proper treatment and storage of drinking water at home
– to assist in the study of WASH-related outbreaks and epidemics.

Some parts of the schematic can overlap with water safety plans (WSPs) recommended by the WHO. WSPs encompasses the water supply from catchment to consumer and have three components, which are the responsibility of suppliers: a system assessment, effective operational monitoring, and management and communication [269]. However, the penetration of pathogens into the human body is heavily dependent on people's behavior, which should be targeted at the prevention of the ingestion of pathogenic microorganisms with water and its transfer into water sources. Therefore, the division of responsibility between monitoring bodies and consumers is essential for the implementation of targets regarding safe drinking water provision in rural areas. Consequently, the institutional and systems approach to WASH is necessary to solve health problems caused by waterborne pathogens [8].

4.3   Capacity building in the field of WASH

Capacity building in the field of WASH is essential for achieving the SDG 6 aimed at ensuring accessibility and sustainable management of water and sanitation for all. Capacity building is not an end in itself but the basis for achieving SDG 6. Therefore, effective capacity building for WASH should lead to the transfer of knowledge, development of skills and change in behavior, the result of which will be people who have and use safely managed water and sanitation [270-272].

Investing in people brings long-term and sustainable profit, as capacity building leads to changes in actions and behavior. That is why the WASH sector in modern conditions should be aimed at training of people and building their capacity. Access to safely managed drinking water and sanitation cannot be a comprehensive solution to WASH-related health issues among the population, since the proper operation of water supply and sanitation facilities as well as hygiene on a household and personal level will be crucial. Therefore, training and capacity building are essential components of global policies, strategies and programs for WASH (figure 27) [270, p. 1; 272].

Capacity building is primarily a global concept and a strategic element of sustainable development in the field of WASH. This is a long-term continuous process by which people, organizations and societies mobilize, support, adapt and expand their capabilities to manage their own sustainable development. Thus, capacity building requires a long-term strategy and is as important as the financial, economic, technical, environmental and medical aspects [270, p. 1; 271, p. 66; 272, p. 502; 272].

Capacity building activities are essential for the long-term sustainability of water resources. The best custodians of water and the environment are people who work together with institutions. Water suppliers and users must coexist and mutually reinforce each other. Capacity building programs in countries include improving the "political environment" and, most importantly, institutional and human development at the national and local levels, with a focus on local community organization [270, p. 1; 271, p. 66; 272, p. 502; 273].
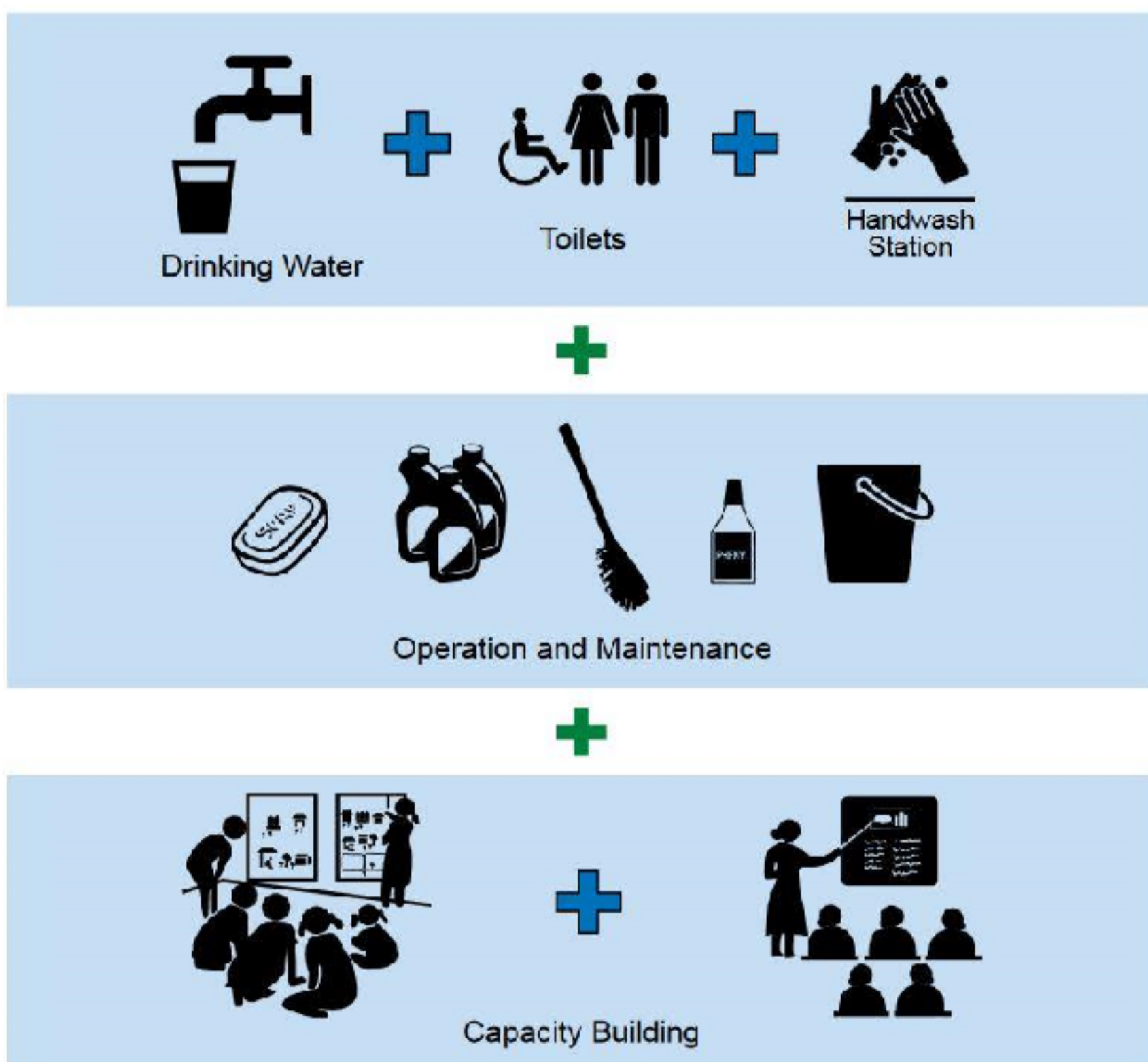
Figure 27 – Integral components of WASH [270]

Capacity building depends on the following interconnected concepts:

1) strengthening institutions at all levels for more effective and efficient addressing all issues of sustainable development of WASH including creating favorable political conditions, assessing water resources, planning and managing, as well as developing programs and implementing them [270, p. 2; 271, p. 67; 272, p. 503; 273];

2) developing human resources at all levels with a focus on hygienic education of the population and creation of conditions for the proper use of safely managed drinking water and sanitation in rural areas [270, p. 2; 271, p. 67; 272, p. 503; 273].

An ideal institutional structure with an untrained population has less capacity than a poor structure with well-trained people. Reliable institutions and skilled human resources are the best guarantee for achieving the cost-benefit and cost-effectiveness results for improving access to safe WASH facilities and practices in rural areas [270, p. 2; 271, p. 67; 272, p. 503; 273].

Our research showed that institutional weakness and malfunctioning of the system were one of the main causes of inefficient and unstable water supply. Therefore, now it is necessary to pay attention to institutional capacity building at all levels. The need for more efficient delivery of water services at the local level suggests that institutional capacity building should better meet the public demands. The most important institutional task is to develop policies, rules, organizations and managerial skills that satisfy both needs at the same time, without limiting the main goals of each of them. It should be noted that each country and region has its own specific features and requirements in the field of WASH and institutional structure. Therefore, any operational strategies for capacity building in this area should be individual and long-term, aiming at improving the quality of decisions, sectoral effectiveness of management in the planning and implementation of programs and projects in water supply and sanitation [270, p. 3; 271, p. 68; 272, p. 504; 273].

The objectives of the institutional segment should be in the following key areas [270, p. 3; 271, p. 68; 272, p. 504; 273]:

1) conceptual development of laws and regulations for implementation of policies and development of comprehensive legislation covering basic aspects of WASH such as planning, distribution and use of water, as well as the prevention and control of pollution;

2) designing government agencies with particular emphasis to ensure consistency, direction and purpose in all aspects of WASH;

3) implementation and enforcement of laws and regulations, with particular attention to planning procedures in the water sector, management of water rights and control of emissions;

4) a systematic survey of common practices in the field of water use among the rural population;

5) collection and dissemination of information on water laws and regulations, as well as raising public awareness of their rights and obligations regarding the use and protection of water resources.

These institutions should perform the following functions [270, p. 3; 271, p. 68; 272, p. 504; 273]:

− to assist relevant authorities in identifying and solving sociological problems of water supply and sanitation, as well as in understanding the needs of people;

− to ensure the correct use of water supply and sanitation facilities;

− to promote self-help and independence of the population in the use of water supply and sanitation facilities;

− to direct and train local employees from the relevant government departments in health education, environmental sanitation and control of diseases related to water supply and sanitation.

As mentioned earlier, each region has its own specific features and requirements in the field of WASH, so it is necessary to assess the expedience of teaching the basics of hygiene in water supply and sanitation in villages, especially of those priority steps that reduce hygiene risks and behavioral factors, as well as of measures to improve

sanitary amenities. To this end, it is necessary to study the existing practice in the following key areas [270, p. 4; 271, p. 69; 272, p. 505; 273]:

- water sources used by households;
- collection, transportation and storage of drinking water;
- use of drinking water treatment methods at home;
- use and maintenance of sanitary facilities (toilets, pit latrines, etc.);
- the most common defecation procedures and the existing practice of cleansing the anal region;
- hand washing after defecation and before cooking;
- bathing / washing areas and existing regulations.

It is also necessary to take into account the level of knowledge among the people, their beliefs, cultural characteristics and taboos, as well as an understanding of the transmission of WASH-related diseases.

Capacity building includes training the population in design, construction, operation and maintenance of water supply and sanitation facilities. It would be advisable to distribute some leaflets with brief information about the requirements for digging and operating decentralized sources and pit latrines, as well as the proper treatment and storage of drinking water at home and why it is so important to know about it.

The study by Ljungkvist V. [274] showed that the rural population was ready to take responsibility for their hygienic behavior and wanted to learn how to improve conditions directly in their households and develop hygiene skills both at home and in their children.

According to the survey (see Subsections 3.3 in "Challenges of Drinking Water Provision in Rural Areas of Karaganda Region"), most of the population did not know the rules for operating decentralized water sources. Basic knowledge in this area is the following [275]:

1) it is necessary to hire a certified driller for construction, modification or liquidation of new boreholes/wells;

2) there should be no residential and household buildings directly at the borehole/well in the area of at least 4x4 m;

3) no industrial enterprises, large roads, landfills, burial grounds for cattle or cemeteries should be located within a radius of at least 300 m;

4) there should be no garden crops irrigated with chemical fertilizers in a radius of at least 20 m;

5) the borehole/well should be as far away as possible from cesspools, sewer septic tanks, compost heaps and similar objects located not only on the owner's site, but also in the neighbourhood;

6) the borehole/well should be protected from the penetration of surface water, which occurs due to poor construction or damage of the source;

7) the area around the borehole should have a slope to divert surface runoff;

8) the borehole/well should have a cover or sanitary seal to prevent unauthorized use or penetration of foreign substances, insects, rodents, etc.;

9) it is necessary to regularly check the borehole/well casing, cover or seal for cracks, corrosion or damage;

10) no pesticides, fertilizers, herbicides, degreasers, fuels and other pollutants are allowed near the borehole/well;

11) it is prohibited to dispose waste in dry or unused boreholes/wells;

12) it is necessary to regularly pump and inspect septic systems;

13) it is prohibited to throw hazardous materials into the septic system;

14) it is recommended to analyze the quality of water from a borehole/well annually; the basic analyzes include the following:

- total coliform bacteria;
- pH, color and turbidity;
- iron and manganese;
- nitrite or nitrate;
- sodium;
- hardness;
- chloride;
- sulfate.

Thus, the sustainable use and development of WASH requires an integrated and coordinated approach taking into account the interests of all relevant WASH-related subsectors and capacity of the water system within the required multilayer institutional environment. Therefore, there is a need for a coordinating body under the patronage of a high level to conclude good mutual agreements on the distribution of responsibilities for each subsector. WASH management can be seen as a closed system in which demand and demand-related interest justify the distribution of resources. Local authorities and communities should be involved in capacity building at most. Consequently, the policy aimed at building capacity in this area is critical to ensure that this process is tailored to the complex needs of the WASH sector.

CONCLUSION

This work presented the results of assessing the availability of safe drinking water in rural areas of Karaganda Region. In spite of the fact that the government tries to provide rural regions with tap water supply, the findings of our research have revealed various challenges in this endeavour. Consequently, implementation of SDG 6 aimed at availability and rational use of water and sanitation for all in rural Kazakhstan is a tremendous challenge that the government needs to tackle as soon as possible. Problems with access to safely managed drinking water and sanitation entail a deterioration in both the social and economic situation in the country and health and well-being of the population, since unsafe water supply, inadequate sanitation and poor hygiene are considered as public health risks. It is commonly known that SDG 3 aims to ensure a healthy lifestyle and promote well-being for all at all ages. The rural population is in greater need of both affordable and accessible medical services and training to improve health and prevent disease using safe WASH. Every year the situation is aggravated with the growth of the population and the irrational use of fresh water reserves. Outbreaks and fatal epidemics will continue unless WASH infrastructure and management are improved. Thus, the full achievement of SDG 6 targets by 2030 will also mean the implementation of SDG 3. Therefore, the results of our research can contribute to more effective WASH planning and, thereby, support a sustainable development of rural regions in Kazakhstan.

Based on the research, one can *conclude* as follows:

1) according to the findings, it was found that 84.55% of the rural population in Karaganda Region was provided with centralized water supply by the state; in Bukhar-Zhyrau District this figure was 80.01%. However, 76.74% of respondents in Botakara, 43.71% in Dubovka and only 21.88% in Karazhar actually used it. There were four reasons for this: residents' doubts regarding the tap water quality; use of other sources out of habit, as they were accustomed to it during water scarcity; availability of cheaper or free sources; and scheduled water supply;

2) the obtained data revealed that the long-term dynamics of WASH-related intestinal infections in Bukhar-Zhyrau District from 2008 to 2018 had a tendency to rise (239.7 per 100,000 people in 2008 and 371.4 per 100,000 people in 2018). The group of acute intestinal infections predominated in the morbidity patterns and made 49.78% in 2018. It should be noted that taking into account some fluctuations in microbiological indicators of water quality, the results of assessment of the influence of water factor on health are contradictory, which is due to inadequate control and insufficient number of epidemiological data. This is exacerbated by the lack of data on hygiene factors related to the quality of water supply and their interaction;

3) the findings of this research indicate that due to acute water supply shortage, the population had to use water from unregistered boreholes (23.52% in Dubovka and 28.57% in Karazhar), unprotected wells dug manually (17.34% in Dubovka and 31.31% in Karazhar), and open sources (15.44% in Dubovka and 18.24% in Karazhar), as well as tankered water (100% in Asyl). However, the villagers have no other option, since most of them have never had access to safe drinking water supply due to lack of

infrastructure (in villages with tankered water) or technical problems with infrastructure, which leads to regular suspension of water supply;

4) the obtained data allow us to state that the lowest level of dissatisfaction with the quality of tap water and its reliability was observed in Botakara (6.74% and 7.67%, respectively). These rates in Dubovka were almost three times higher (14.25% and 21.38%, respectively). The highest proportion of residents dissatisfied with the quality and reliability of this source was observed in Karazhar (29.48% and 47.11%, respectively). However, the borehole was recognized as the highest quality and most reliable source (according to 86.74% and 76.51% of the respondents in Botakara, respectively), and the tankered water was recognized as poor-quality and unreliable (according to 77.78% and 98.94% of the respondents in Asyl, respectively), since it should be considered only as a temporary solution during an emergency and should not be a permanent and sole source;

5) based on the results of this thesis, to improve access to safe WASH facilities and practices in rural areas, the following is recommended:

– to calculate the indicator of centralized water supply provision as a "proportion of population provided with safely managed drinking water from centralized water supply systems" instead of number of villages connected to this service;

– to introduce a systematic approach that will cover the entire chain of the water supply system from the intake to the consumer and the discharge of wastewater from the consumer to natural sources to implement of measures for the organization of water supply, control and monitoring of their completeness and effectiveness;

– to build capacity among the rural population for transferring knowledge and developing skills in the field of WASH, as well as changing people's attitude to safe water supply and sanitary and hygienic rules.

Based on the findings of this research, *the following recommendations* were formulated:

1) decentralization of water management, monitoring of both water supply and water use and a tailor-made approach to each village are necessary to achieve the SDGs of providing the rural population with safely managed drinking water. Only in cooperation with the local community, government bodies can identify systemic sustainability problems as well as to develop and implement policies for water access in premises; water that is available as needed and free from contamination. This cooperation will also ensure sustainable public health and bring economic benefits to villages [20, p. 11];

2) decentralization of water management, monitoring of both water supply and water use and a tailor-made approach to each village are necessary to achieve the SDGs of providing the rural population with safely managed drinking water and sanitation. Only in cooperation with the local community, government bodies can identify systemic sustainability problems as well as to develop and implement policies for access to safe WASH facilities and practices. This cooperation will also ensure sustainable public health and bring economic benefits to villages [20, p. 11];

3) an indicator of centralized water supply provision would be more appropriate to calculate on the basis of "proportion of population provided with safely managed drinking water from centralized water supply systems" instead of the number of villages connected to this service. Thus, we will be able to obtain data reflecting actual situations regarding the coverage of the population with drinking water supply in rural areas;

4) to implement the institutional and systems approach to ensure improved WASH, which will cover: proper drinking water treatment methods, personal hygiene on a household and personal level, good sanitation behavior, proper wastewater treatment and excreta disposal in household. A monitoring body should also be established to control the entire chain of the water supply system from intake to the consumer and wastewater discharge from the consumer to natural sources [8, p. 12];

5) to build capacity in the field of WASH for raising public awareness of the requirements for digging and operating decentralized sources and pit latrines and methods of the proper treatment and storage of drinking water at home, as well as to develop skills and to change people's behavior in the use of safe water supply and compliance with sanitary rules. To do this, it is necessary to determine the authority responsible for efficient and hygienic training of the population [8, p. 12];

6) there is a need for a more effective management and implementation of water preservation as well as improvement of the technical conditions of water supply lines and sewage facilities to reduce the stress on limited water resources [20, p. 12];

7) it is necessary to find a balance between the quantity and quality of water [20, p. 12]:

– in villages where there is a need to prioritize access to *sufficient water quantity*, the water consumption can be increased by means of timely repair and maintenance of the system, which is in turn a guarantee of uninterrupted supply of drinking water;

– in villages where *the water quality* is the dominant factor, priorities should be directed to appropriate drinking water treatment methods and training to encourage the population to select the right water source. To this end, there should be an emphasis on making the healthy benefits of tap water associated with its high microbiological quality widely known;

7) an effective epidemiological monitoring requires data on estimation of WASH-related diseases at both the state and local levels and accessible to the public. It is also necessary to develop an online research database on the relationship between environmental factors and human health as exemplified by WHO. This database will be an important tool for deciding how to prevent the disease at the state level [2, c. 322; 3, c. 13].

Further research into the problem of providing the rural population with safe drinking water is a promising direction for many developing countries including Kazakhstan.

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APPENDIX A

Акт внедрения результатов научно-исследовательской работы

«УТВЕРЖДАЮ»
Аким Бухар-Жырауского района
Карагандинской области
_____ Сатаев С.К.
(подпись, фамилия и инициалы)
_____ 2019 г.

АКТ

внедрения результатов научно-исследовательской работы
Акимат Бухар-Жырауского района Карагандинской области
(наименование учреждения, где внедряется работа)

Наименование предложения: «Совершенствование системы обеспечения сельского населения питьевой водой»

Работа включена из диссертационной работы А.О. Омаровой на соискание степени доктора философии (PhD) на тему: "Providing the rural population with drinking water: A case study from Bukhar-Zhyrau district of Karaganda region"
внедрение в инициативном порядке

(союзного республиканского, областного планов внедрения; планов внедрения научно-исследовательских, учебных институтов; внедрения в инициативном порядке; заимствована из методических рекомендаций журнальных статей, диссертаций, монографий – указать)

Форма внедрения: рекомендации по совершенствованию системы питьевого водоснабжения сельского населения

Ответственные за внедрения и исполнители: А.О. Омарова, К.М. Тусупова, М.Г. Калишев, А.Д. Ефимова, Н.Т. Жакетаева, С.И. Рогова

Эффективность внедрения: социальная – снижение заболеваемости населения, связанной с качеством питьевой воды

Предложения, замечания учреждения, осуществляющего внедрение:
нет

Сроки внедрения: май 2019 г.

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Авторлық құқықпен қорғалатын объектілерге құқықтардың мемлекеттік тізілімге мәліметтерді енгізу туралы куәлік

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ   РЕСПУБЛИКА КАЗАХСТАН

АВТОРЛЫҚ ҚҰҚЫҚПЕН ҚОРҒАЛАТЫН ОБЪЕКТІЛЕРГЕ ҚҰҚЫҚТАРДЫҢ
МЕМЛЕКЕТТІК ТІЗІЛІМГЕ МӘЛІМЕТТЕРДІ ЕНГІЗУ ТУРАЛЫ

КУӘЛІК

2019 жылғы « 6 » наурыз   № 2151

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ОМАРОВА АЛУА ОРАЛОВНА

Авторлық құқық объектісі: әдеби туынды

Анкета по оценке удовлетворенности сельского населения качеством и количеством

Объектінің атауы: питьевого водоснабжения

Объектіні жасаған күні: 03.05.2017

СВИДЕТЕЛЬСТВО

О ВНЕСЕНИИ СВЕДЕНИЙ В ГОСУДАРСТВЕННЫЙ РЕЕСТР
ПРАВ НА ОБЪЕКТЫ, ОХРАНЯЕМЫЕ АВТОРСКИМ ПРАВОМ

№ 2151 от « 6 » марта 20 19 года

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Подписано ЭЦП   Баталова К. О.

APPENDIX C

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫ   **РЕСПУБЛИКА КАЗАХСТАН**

АВТОРЛЫҚ ҚҰҚЫҚПЕН ҚОРҒАЛАТЫН ОБЪЕКТІЛЕРГЕ ҚҰҚЫҚТАРДЫҢ МЕМЛЕКЕТТІК ТІЗІЛІМГЕ МӘЛІМЕТТЕРДІ ЕНГІЗУ ТУРАЛЫ

КУӘЛІК

2019 жылғы «24» қазан № 6038

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Авторлық құқық объектісі: **әдеби туынды**

Объектінің атауы: **Schematic of institutional and systems approach to ensure improved water, sanitation and hygiene (WASH)**

Объектіні жасаған күні: 12.03.2018

Подписано ЭЦП   Степанов Е. К.

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫ   РЕСПУБЛИКА КАЗАХСТАН

СВИДЕТЕЛЬСТВО

О ВНЕСЕНИИ СВЕДЕНИЙ В ГОСУДАРСТВЕННЫЙ РЕЕСТР ПРАВ НА ОБЪЕКТЫ, ОХРАНЯЕМЫЕ АВТОРСКИМ ПРАВОМ

№ 6038 от «24» октября 2019 года

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Название объекта: **Schematic of institutional and systems approach to ensure improved water, sanitation and hygiene (WASH)**

Дата создания объекта: **12.03.2018**

Подписано ЭЦП   Оспанов Е. К.

APPENDIX D

Questionnaire to assess the satisfaction of rural population with the quality and quantity of drinking water supply

Dear respondent,

The aim of the questionnaire is to assess what sources are used by the rural population and their satisfaction with the quality and quantity of the drinking water supply. Your opinion will allow us to identify problems related to water supply in rural areas, assess the quality of drinking water supply and contribute to its improvement.

We kindly ask you to answer all the questions by *circling the appropriate option or writing the answer in the specially designated space*. Participation is voluntary and you can renounce providing any information at any time without reasons. Anonymity is guaranteed; all data will be published in general.

Researcher:

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Phone: +7 (7212) 503930 (1615), +7 778 867 66 00, *Email:* alua_1912@mail.ru

1. Your gender:
A. male
B. female

2. Your age: _____

3. How long have you lived in this village?
A. Up to 5 years
B. 5-10 years
C. 11-20 years
D. More than 20 years

4. How many people live in your house? _____
   How many of them are:
   children under 5 years old   _____
   children aged 5-12 years   _____
   teenagers (13-18 years old)   _____
   adults (over 18 years old)   _____
   retirees   _____

5. Which sources do you mainly use for drinking?
A. Water tap inside the house
B. Outdoor standpipe
C. Borehole
D. Well
E. Tankered water
F. Open source
G. Other *(please specify)* _____

6. If you have access to tap water, but you do not use it, what is the reason for this *(if you use tap water, please go to question No. 7)*?
   A. Doubts regarding its quality
   B. Availability of cheaper or free water sources
   C. Its scarcity due to scheduled water supply
   D. Use of other sources by habit
   E. Other *(please specify)* _____

7. How much water is consumed in your house on average?
   ➢ _____ m^3 / 30 days *(for tap water users)*
   ➢ _____ water tank capacity / days of use *(for users of other sources)*

8. How much time do you need on average for self-delivery of drinking water from sources to your house? _____ **minutes**

9. Do you pay for water?
   A. Yes
   B. No *(please go to question No. 11)*

10. If "Yes", how much do you pay per month in tenge? _____

11. If you have your own borehole/well, how much did it cost you in tenge? _____

12. If you have your own borehole/well, how many years have you been using it? _____

13. Do you buy bottled water?
    A. Yes
    B. No *(please, go to question No. 17)*

14. If "Yes", what do you use the bottled water for?
    A. For drinking
    B. For cooking
    C. Other *(please specify)* _____

15. Please write how often you buy bottled water: _____

16. How many liters of bottled water on average do you use per day? _____

17. Do you purify drinking water?
    A. Yes
    B. No *(please go to question No. 21)*

18. If "Yes", what do you use for water purification?
    A. Factory filter
    B. Gauze
    C. Boiling
    D. Other *(please specify)* _____

19. If you use a factory filter, how often do you replace it? _____

20. If you use a factory filter, how much do you spend on replacing it in tenge? _____

21. Evaluate the following organoleptic indicators of water quality *(please put a "+" sign opposite the indicator in the corresponding column)*:

Indicators	POOR	AVERAGE	GOOD
COLOUR			
SMELL			
TASTE			
TURBIDITY			

22. How would you rate the reliability of the drinking water source used?
A. Reliable
B. Not always reliable
C. Unreliable

23. How many points on a scale from one to ten would you rate the quality of drinking water *(please circle a point, where one is low and ten is good quality):*

24. How many points on a scale from one to ten would you rate the *cost* of drinking water *(please circle a point, where one is acceptable and ten is expensive):*

**THANK YOU
FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE**

Ауыл тұрғындарының ауыз сумен қамтамасыз ету сапасы мен мөлшеріне қанағаттану деңгейін бағалау бойынша сұраунама

Құрметті респондент,

Сұраунаманың мақсаты ауыл тұрғындары қандай су көздерін пайдаланатындығын және олардың ауыз сумен қамтамасыз ету сапасы мен мөлшеріне қанағаттануын бағалау болып табылады. Сіздің пікіріңіз ауылдық жерлерде сумен жабдықтауға қатысты мәселелерді анықтауға, ауыз сумен қамтудың сапасын бағалауға мүмкіндік береді және оны жақсартуға ықпал етеді.

Сізден барлық сұрақтарға *сәйкес опцияны дөңгелектеу немесе жауапты тағайындалған орынға жазу арқылы* жауап беруіңізді сұраймыз. Қатысу ерікті болып табылады және кез-келген уақытта ешқандай себепсіз кез келген ақпаратты беруден бас тартуға болады. Анонимділік кепіл етіледі, барлық деректер жалпы түрде жарияланады.

Зерттеушілер:

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1. Сіздің жынысыңыз:
C. ер
D. әйел

2. Сіздің жасыңыз: _____

3. Сіз осы ауылда қанша уақыт тұрдыңыз?
E. 5 жылға дейін
F. 5-10 жыл
G. 11-20 жыл
H. 20 жылдан астам

4. Сіздің үйіңізде неше адам тұрады? _____
Олардың ішінде:
5 жасқа дейінгі балалар _____
5-12 жас аралығындағы балалар _____
жасөспірімдер (13-18 жас аралығы) _____
ересектер (18 жастан жоғары) _____
зейнеткерлер _____

5. Сіз ішу қажеттілігі үшін негізінен қандай су көзін қолданасыз?
H. Үй ішіндегі су құбыры
I. Көшедегі су бөлітен колонка
J. Ұңғыма
K. Құдық
L. Тасып әкелінетін су
M. Ашық су көзі
N. Басқа *(көрсетіңіз)* _____

6. Егер Сізде су құбыры бола тұра оны қолданбайтын болсаңыз, бұның себебі неде *(егер су құбырын пайдалансаңыз, №7 сұраққа көшіңіз)*?

F. Оның сапасы жайлы күмән
G. Арзанырақ немесе тегін су көздерінің болуы
H. Кесте бойынша сумен қамтамасыздандыру салдарынан су мөлшерінің жетіспеуі
I. Әдет бойынша басқа су көздерін пайдалану
J. Басқа *(көрсетіңіз)* _____

7. Сіздің үйіңізде орта есепен қанша су жұмсалады?
➢ _____ m³ / 30 күн *(су құбырын пайдаланушылар үшін)*
➢ _____ резервуар сыйымдылығы / пайдалану күндері *(басқа су көздерін пайдаланушылар үшін)*

8. Сізге су көздерінен үйіңізге ауыз суды өздігінен жеткізу үшін шамамен қанша уақыт қажет? _____ **минут**

9. Сіз суға ақша төлейсіз бе?
C. Иа
D. Жоқ *(№11 сұраққа көшіңіз)*

10. Егер иә болса, Сіз айына қанша теңге төлейсіз? _____

11. Егер Сіздің өз ұңғымаңыз/құдығыңыз болса, оған қанша теңге жұмсадыңыз? ____

12. Егер Сізде өз ұңғымаңыз/құдығыңыз болса, оны неше жыл қолданып келесіз? ___

13. Сіз бөтелкедегі суды сатып аласыз ба?
D. Иа
E. Жоқ *(№17 сұраққа көшіңіз)*

14. Егер иа болса, одна Сіз бөтелкедегі суды не үшін қолданасыз?
C. Ішуге
D. Ас даярлауға
F. Басқа *(көрсетіңіз)* _____

15. Бөтелкедегі суды Сіз қаншалықты жиі сатып алатыныңызды көрсетіңіз: _____

16. Орташа алғанда Сіз күніне қанша литр бөтелкедегі су пайдаланасыз? _____

17. Сіз ауыз суды тазалайсыз ба?
C. Иа
D. Жоқ *(№21 сұраққа көшіңіз)*

18. Егер иә болса, Сіз суды тазарту үшін не қолданасыз?
E. Зауытта жасалған сүзгіш
F. Дәке
G. Суды қайнату
H. Басқа *(көрсетіңіз)* _____

19. Егер Сіз зауытта жасалған сүзгішті пайдалансаңыз, Сіз оны қаншалықты жиі ауыстырасыз? _____

20. Егер Сіз зауытта жасалаған сүзгішті пайдалансаңыз, Сіз оны ауыстыру үшін қанша тенге жұмсайсыз? _____

21. Су сапасының келесі органолептикалық көрсеткіштерін бағалаңыз *(сәйкес бағандағы индикатордың алдына «+» белгісін қойыңыз)*:

| Көрсеткіштер	*НАШАР*	*ОРТАША*	*ЖАҚСЫ*
ТҮСІ			
ИІСІ			
ДӘМІ			
БҰЛДЫРЛЫҒЫ			

22. Қолданылатын ауыз су көзінің сенімділігін қалай бағалайсыз?
D. Сенімді
E. Әрдайым емес
F. Сенімді емес

23. 1-ден 10-ға дейінгі шкала бойынша Сіз ауыз судың сапасын қанша баллға бағалар едіңіз *(керекті санды дөңгелектеңіз, 1 балл – нашар және 10 балл – жақсы сапа)*:

24. 1-ден 10-ға дейінгі шкала бойынша Сіз ауыз судың бағасын қанша баллға бағалар едіңіз *(керекті санды дөңгелектеңіз, 1 балл – қолайлы және 10 балл – қымбат)*:
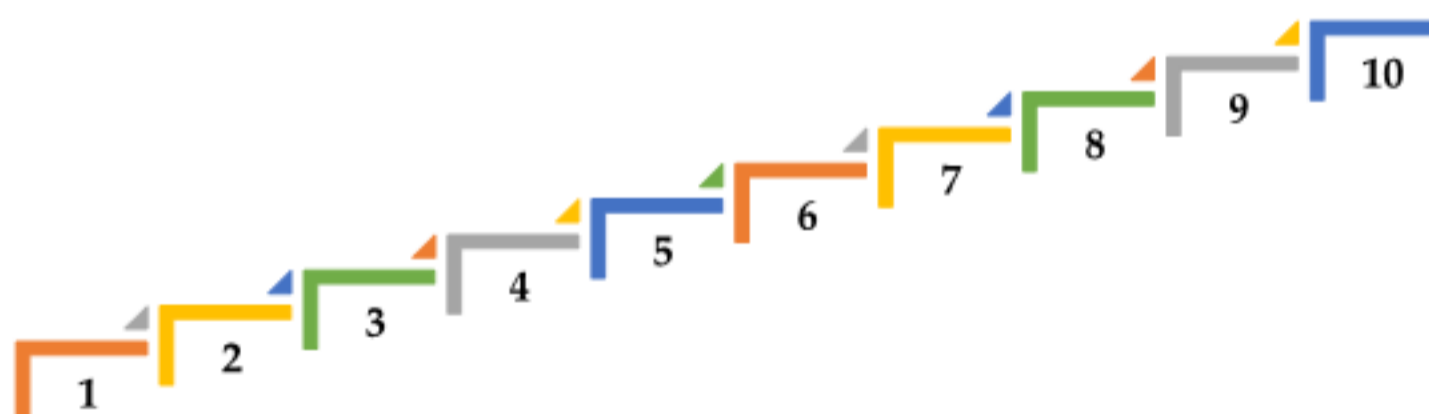
БҰЛ СҰРАУНАМАНЫ ТОЛТЫРУҒА УАҚЫТ БӨЛГЕНІҢІЗ ҮШІН АЛҒЫСЫМЫЗДЫ БІЛДІРЕМІЗ

**Анкета по оценке удовлетворенности сельского населения качеством и
количеством питьевого водоснабжения**

Уважаемый респондент,

Целью анкеты является оценить какие источники используются сельским населением и их удовлетворенность качеством и количеством питьевого водоснабжения. Ваше мнение позволит нам выявить проблемы связанными с водоснабжением сельских регионов, оценить качество питьевого водоснабжения и способствовать его улучшению.

Просим Вас ответить на все вопросы, *обведя нужный вариант или вписав ответ в отведенное для этого место.* Участие является добровольным, и вы можете отказаться от предоставления любой информации в любое время без причины. Анонимность гарантируется, все данные будут опубликованы в общем виде.

Исследователь:

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1. Ваш пол:
E. мужской
F. женский

2. Ваш возраст: _____

3. Как долго Вы проживаете в этом поселке?
I. До 5 лет
J. 5-10 лет
K. 11-20 лет
L. Больше 20 лет

4. Сколько людей проживают в Вашем доме? _____
Сколько из них:
детей в возрасте до 5 лет _____
детей в возрасте 5-12 лет _____
подростков (13-18 лет) _____
взрослых (старше 18 лет) _____
пенсионеров _____

5. Каким источникам, в основном, Вы пользуетесь для питьевых нужд?
O. Водопроводный кран внутри дома
P. Водоразборная колонка на улице
Q. Скважина
R. Колодец
S. Привозная вода
T. Открытый источник
U. Другое *(укажите)* _____
6. Если у Вас есть доступ к водопроводной воде, но Вы им не пользуетесь, то что служит причиной этому *(если пользуетесь водопроводной водой переходите к вопросу №7)*?

K. Сомнения относительно его качества
L. Наличие более дешевых или бесплатных источников воды
M. Нехватка ее количества из-за подачи воды по графику
N. Использование других источников по привычке
O. Другое *(укажите)* _____

7. Сколько воды, в среднем, потребляют в Вашем доме?
➢ _____ m³ / 30 дней *(для пользователей водопроводной воды)*
➢ _____ емкость резервуара / дни использования *(для пользователей других источников)*

8. Сколько времени, в среднем, требуется Вам для самостоятельной доставки питьевой воды из источников в Ваш дом? _____ **минут**

9. Вы платите за воду?
E. Да
F. Нет *(переходите к вопросу №11)*

10. Если да, сколько тенге Вы платите за месяц? _____

11. Если у Вас своя скважина/колодец, во сколько тенге Вам она обошлась? _____

12. Если у Вас своя скважина/колодец, сколько лет Вы уже им пользуетесь? _____

13. Вы покупаете бутилированную воду?
G. Да
H. Нет *(переходите к вопросу №17)*

14. Если да, то для чего Вы используете бутилированную воду?
E. Для питья
F. Для приготовления пищи
I. Другое *(укажите)* _____

15. Укажите, как часто Вы покупаете бутилированную воду: _____

16. Сколько литров бутилированной воды, в среднем, Вы используете за сутки? _____

17. Очищаете ли Вы питьевую воду?
E. Да
F. Нет *(переходите к вопросу №21)*

18. Если да, что Вы используете для очистки воды?
I. Заводской фильтр
J. Марлю
K. Кипячение воды
L. Другое *(укажите)* _____

19. Если Вы используете заводской фильтр, как часто Вы его меняете? _____

20. Если Вы используете заводской фильтр, сколько тенге Вы тратите на его замену? _____
21. Оцените следующие органолептические показатели качества воды *(пожалуйста, поставьте знак «+» напротив показателя в соответствующем столбце):*

Показатели	ПЛОХОЙ	СРЕДНИЙ	ХОРОШИЙ
ЦВЕТ			
ЗАПАХ			
ВКУС			
МУТНОСТЬ			

22. Как Вы оцениваете надежность используемого источника питьевой воды?
G. Надежный
H. Не всегда
I. Не надежный

23. На сколько баллов по шкале от 1 до 10 Вы бы оценили качества питьевой воды *(обведите нужную цифру, где 1 балл – низкое и 10 баллов – хорошее качество)*:

24. На сколько баллов по шкале от 1 до 10 Вы бы оценили *цену* питьевой воды *(обведите нужную цифру, где 1 балл – приемлемо и 10 баллов – дорого)*:

**БОЛЬШОЕ СПАСИБО ЗА ТО,
ЧТО УДЕЛИЛИ ВРЕМЯ ДЛЯ ЗАПОЛНЕНИЯ ЭТОЙ АНКЕТЫ**