

CURRENT STATE OF COMMUNAL SEWAGE TREATMENT IN THE REPUBLIC OF KAZAKHSTAN

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ABSTRACT

Protection of water environment from pollution is one of the major tasks in the contemporary world. Nowadays, in the Republic of Kazakhstan ecological situation concerning sewage treatment remains deficient. Raw sewage is often discharged directly onto filtration beds or landfills. Many existing wastewater treatment facilities in cities are in unsatisfactory technical conditions. In many villages and small settlement units the problem of treatment and disposal of sewage sludge from treatment facilities also requires urgent solutions. In this article, the current state of communal sewage treatment in the Republic of Kazakhstan is shown. The technical and technological characteristics of sewage disposal systems, including the cities of Almaty and Astana, are presented. This article is especially aimed at identification of environmental problems related with sewage treatment in the Republic of Kazakhstan.

Keywords: sewage treatment, sewage characteristics, decentralized systems, sustainability.

INTRODUCTION

The Republic of Kazakhstan is located between two continents – northwest of Asia and southeast of Europe. The state territory is 2724.9 thousand km², making it the 9th largest country of the world. Kazakhstan is stretched between the delta of the Volga river in the west and Altai Mountains in the east, Western-Siberian lowland in the north and Tian-Shan mountains in the south. The extent of state frontiers makes nearly 13.4 thousand km, including: with Russian Federation – 7591 km, Republic of Uzbekistan – 2354 km, Kirghiz Republic – 1241 km, China – 1782 km, Turkmenistan – 426 km.

According to statistical data, the population of Kazakhstan grows every year, reaching 17417.7 thousand persons at the beginning of 2015 (population density – 6.4 persons/km²). In the Republic there are 87 cities (among them 2 cities: Almaty and Astana are of republican im-

portance), 30 villages and 6724 rural settlements which are administratively divided into 14 regions and 176 administrative districts [Committee on Statistics 2015].

544 sewage treatment facilities operate on the territory of the republic. The total extent of sewerage network has more than 14.5 thousand km of sewers, among them the main collectors make 4757.7 km and distribution network – 9773.6 km [Zhumartov 2010]. The centralized system of wastewater disposal is dominating on urban territories of the Republic of Kazakhstan, collecting 62% of total sewage production in the country, from which 84% belongs to large cities and 10% to villages. From the existing 87 municipal sewage treatment facilities one third is in unsatisfactory technical conditions. In 39 cities and villages treatment facilities are absent – untreated wastewater is discharged directly on ground filtration fields, or landfills. Another real danger is constituted by the sewage storing reservoirs located in

surroundings of large settlements and industrial centers. In the Republic of Kazakhstan there are 540 sewage reservoirs, many of which are filled to a limiting level, creating threat for natural water resources and urban areas [Baekenova 2011]. Data on the largest sewage reservoirs of Kazakhstan are presented in Table 1.

From the Table 1 it can be observed that reservoirs in Kyzylorda, Kostanai, Petropavlovsk are filled to a designed level, which means that there is no extra volume available for accepting additional discharges. It should also be mentioned that almost all storages are in poor technical conditions due to lack of systematic geotechnical and hydro-chemical control. In the case of reservoir Sorbulak (storage for the city of Almaty – pos.1 in Table 1) in 1995 the by-pass channel was constructed to avoid overflowing the storage. This channel discharges cleaned sewage from Almaty treatment facilities to the Ili river in case of overflows [Zhumartov, Osanov 1998].

In general, deficient ecological situation connected with inefficient operation of sewage treatment facilities remains in the Republic of Kazakhstan. In many cases it is caused by long-term exploitation without reconstruction of treatment facilities, other plants often lack technological objects required for a full mechanical and biological treatment. That situation contributes to the deterioration of environment due to discharges of inadequately treated wastewater. Recently, it became obvious that antropogenous eutrophication affected a significant part of surface and ground water resources in Kazakhstan. The results of environmental monitoring showed that for a few last years the concentration of nitrate nitrogen (N-NO₃) in several rivers and lakes was exceed-

ing the maximum approved limit by a factor of 1.1 – 3.7 and ammonia nitrogen (N-NH₃) – by 1.1 – 14.2 [Baekenova 2011]. In this regard, the “Ak Bulak” program on providing population with qualitative drinking water and wastewater disposal services for 2011–2020 was accepted by Kazakh Government [Ministry of Economic Development and Trade 2011].

COMMUNAL SEWAGE DISPOSAL SYSTEMS IN SELECTED AREAS OF KAZAKHSTAN

Characteristics of wastewater and treatment methods in small cities and villages of Almaty region

During the last decade the Department of Engineering Systems and Environment Protection of Kazakh National Technical University in Almaty conducted regular monitoring of sewage composition as well as technical conditions of treatment facilities in more than 30 settlements of the Republic of Kazakhstan with population ranging from 2000 to 150 000 inhabitants, including the cities of Almaty and Astana. Table 2 presents the data collected from 15 small cities in Almaty region. It is worth noting that only 3 of the monitored cities had their own treatment facilities consisting of mechanical preliminary treatment and biological treatment in natural conditions using filtration beds before discharging to receiving waters.

Physicochemical characteristics of raw wastewater from small settlements in Almaty region, presented in Table 3, shows relatively low concentrations of both mineral and organic con-

Table 1. Technical parameters of the largest sewage reservoirs in Kazakhstan

Location	Capacity [mln m ³]		Fill level [m, above sea level]	
	designed	actual	designed	actual
Almaty	1000	860	622.0	620.5
Astana	63	44	347.2	346.2
Aktobe	40.4	8	–	–
Atyrau	16	8	–	–
Arkalyk	68.7	38.5	–	–
Kyzylorda	5	4.8	–	–
Kokshetau	15	60	240	239.4
Kostanai	97	101	184.8	184.2
Petropavlovsk	35	35	102	102
Oral	43.5	24.3	51.0	49.8
Shymkent	25.8	11.4	–	–

Table 2. Characteristics of sewage disposal systems in the Almaty region

City	Population [10 ³ ppl]	Unit length of main sewers [km/10 ³ ppl]	Designed capacity of treatment facilities [10 ³ m ³ /d]	Method of sewage treatment
Kapchagai	41.8	33.2	25.4	Mechanical + filtration beds
Talgar	42.2	25.5	2.0	Discharge to sewage disposal system of Almaty city
Yesik	25.9	23	4.2	Mechanical + filtration beds
Bakanas	7.0	2.7	0.1	Filtration fields
Uzynagash	22.2	1.0	1.0	Mechanical + filtration beds
Energeticheski	17.5	26.2	–	Discharge to sewage disposal system of Almaty city
Burundai	21.1	1.0	1.0	Discharge to sewage disposal system of Almaty city
Kaskelen	30.7	48.4	0.1	Discharge to sewage disposal system of Almaty city
Kugaly	4.9	0.8	0.2	Filtration fields
Chunzhaly	18.5	7.0	1.6	Mechanical + filtration beds
Chilik	24.4	13.3	5.2	Mechanical + biological treatment
Ushtobe	22.3	1.0	1.0	Discharge to treatment facilities of meat-processing factory
Kirovskii	12.6	0.4	0.2	Discharge to treatment facilities of sugar factory
Karabulak	17.9	0.8	0.6	Discharge to treatment facilities of sugar factory
Zharkent	34.5	22.0	7.0	Mechanical + filtration beds

Table 3. Characteristics of raw wastewater from selected cities in Almaty region

Indicator	Shelek	Zharkent	Talgar	Bakanas
Suspended solids (mg/dm ³)	58–102	60–90	80–90	70–80
BOD ₅ (mgO ₂ /dm ³)	60–80	70–90	70–90	50–70
COD (mgO ₂ /dm ³)	70–100	80–100	80–100	60–80
pH	7.1–7.2	7–7.1	7–7.2	7–7.5
Dry solids (mg/dm ³)	120	160	130–150	–
Ammonia nitrogen (mg/dm ³)	3.8–5	3.8–12	18–22	5–8
Nitrite nitrogen (mg/dm ³)	0.2–0.3	0.2–0.3	0.05–0.1	0.2–0.3
Nitrate nitrogen (mg/dm ³)	1.3–4	2.3–5	–	16–21
Chlorides (mg/dm ³)	35–40	1.5–20	30–32.5	1.5–2.0
Sulfates (mg/dm ³)	60–70	40–50	60–75	30–35
Phosphates (mg/dm ³)	2–3	2–4	5–7	2–4

taminants. Despite this fact, the discharge of inadequately treated sewage poses a serious threat for the environment – especially for ground waters, due to implementation of inefficient treatment methods, relying mostly on filtration beds.

Sewage disposal systems in the main cities of Kazakhstan

Almaty is the largest city of Kazakhstan known as “Southern Capital”. According to the current demographic reports, population at the beginning of 2014 reached 1 507 509 people [Committee on Statistics 2014]. The climate of Almaty is classified as continental, with additional influence of mountain and valley circulation, which is especially shown in the northern part of the city

located directly in a zone of transition from the mountains into the plain. Average air temperature is equal to 10 °C, with the coldest month (January) -4.7 °C and the warmest month (July) 23.8 °C.

The sewerage system of the Almaty city can be described as an incomplete separate system, consisting of storm sewers that collect rainfall waters and discharge them to small rivers and ditches, and municipal sewers network that collects industrial, commercial and household wastewater and transports it to Almaty Wastewater Treatment Plant (WWTP), popularly called “Stancia Aera-cii” (aeration station) with designed capacity of 640.0 m³/day.

Technological layout of the plant includes 3 stages: mechanical preliminary treatment, biological treatment using activated sludge bioreactors

and discharge with conditioning in natural environment. Thanks to natural terrain configuration it is possible to transport wastewater between subsequent treatment units mostly by gravity. Technological interconnections and by-passes enable operation in several different modes (Figure 1).

The first stage of Almaty WWTP consists of 9 fine screens, followed by 8 horizontal grit chambers and 12 primary settling tanks (radial). After mechanical treatment, it is possible to discharge partially cleared wastewater to the emergency storage with the volume of 1 500 000 m³ and then to filtration beds with the area of 856 ha, located 12 km north of the plant.

Secondary treatment facilities are divided into 2 technological lines, including 2 types of aerated bioreactors (No. 1 – experimental; No. 2 – standard) with activated sludge and 12 final clarifiers (40 m radius) in total. Technical characteristic of bioreactors is given in Table 4. After biological treatment clarified wastewater is discharged either to natural reservoir Sorbulak or to

the system of ditches and ponds called Right-bank Sorbulakski Channel (Pravobierezhnyj Sorbulak-skij Kanal – PSK), where the tertiary treatment is accomplished. From PSK channel it is possible to discharge water to the Ili river, after disinfection using chlorine.

The physicochemical characteristic of sewage at different stages of treatment at Almaty WWTP is presented in Table 5.

The second largest city in Kazakhstan and at the same time – the capital of the Republic is Astana, with the population of 814 435 people at the beginning of 2014 [Committee on Statistics 2014]. The climate of Astana is extremely continental: with hot and dry summer, and very cold, long winter. Average annual temperature is 3.1 °C. In the summer mean temperature is about 20 °C and in the winter -15 °C, but it is not rare that in summer maximum temperature exceeds 40 °C (due to hot air masses from Central Asia) while in winter it drops below -50 °C (due to Siberian frosts).

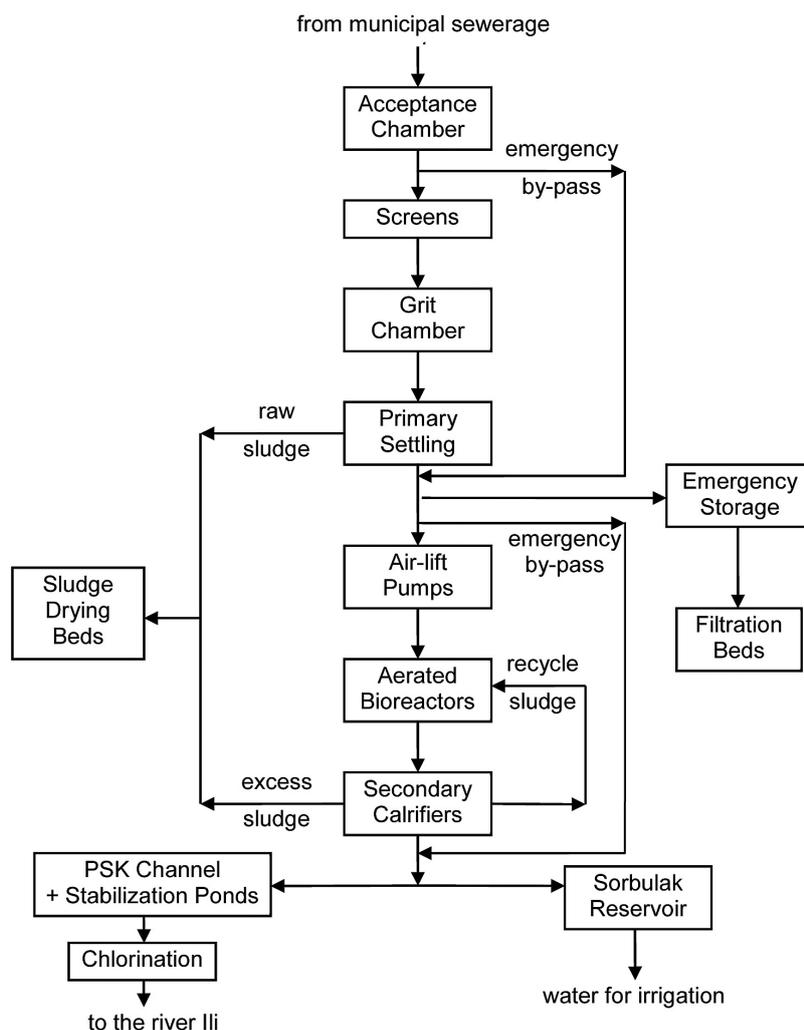


Figure 1. Technological diagram of Almaty WWTP [adapted from: Process ochistki 2015]

Table 4. Technical characteristics of the bioreactors at Almaty WWTP

Parameter	Block 1 – experimental	Block 2 – standard
Number of sections	2 (A + B)	4 (No. 1, 2, 3, 4)
Total volume	V = 126 280 m ³	V = 100 000 m ³
Dimensions (length x width)	110 x 164 m	144 x 144 m
Dimensions of one section	110 x 80 m	144 x 36 m
Operational depth	H = 7.0 m	H = 5.0 m
Number of compartments in one section	8	4
Design capacity of the block	320 000 m ³ /day	320 000 m ³ /day

Table 5. Characteristics of a chemical composition of sewage at Almaty WWTP

Indicator	Raw sewage (inflow)	After mechanical treatment	After biological treatment (discharge)	Overall removal efficiency (%)
Temperature (°C)	22.3	22.7	23.2	–
pH	7.6	7.7	7.8	–
Suspended solids (mg/dm ³)	336.9	101.6	10.3	96.9
Dry mass (mg/dm ³)	655.3	494.0	435.8	33.5
Ammonia nitrogen (mg/dm ³)	32.7	24.3	4.3	86.9
Nitrites (mg/dm ³)	0.05	0.06	0.33	–
Nitrates (mg/dm ³)	0.13	0.19	8.17	–
BOD ₅ (mg O ₂ /dm ³)	409.1	84.6	10.1	97.5
BOD ₂₀ (mg O ₂ /dm ³)	575.7	93.9	14.4	97.5
COD (mg O ₂ /dm ³)	872.8	187.1	21.6	97.5
Detergents (mg/dm ³)	0.8	0.5	0.08	90.0
Phosphates (mg/dm ³)	8.9	7.2	3.1	65.2
Oil products (mg/dm ³)	2.66	0.98	0.004	99.5
Chlorides (mg/dm ³)	77.9	71.1	62.5	19.8
Sulfates (mg/dm ³)	71.5	67.6	62.5	12.6
Copper (mg/dm ³)	0.018	0.008	0.0006	96.7
Lead (mg/dm ³)	0.003	0.002	0.001	66.7

Wastewater collected by municipal sewerage system of Astana is delivered by 2 pressure collectors of diameter 1500 and 2000 mm from main pumping station to wastewater treatment plant, which has an overall capacity of 136.000 m³/day. The first technological stage of the plant is mechanical treatment which consists of fine screens, followed by 5 grit chambers and 6 radial primary settling tanks. The secondary biological treatment is accomplished in aerated bioreactors with activated sludge. Biological part of Almaty WWTP has 4 bioreactors, with dimensions (length × width × depth) 117×32×3,8 m. Each reactor is divided into 4 compartments (width of 8 m) and has 25% of its volume intended for regeneration of recycled activated sludge. The mixture of treated sewage and activated sludge goes to final clarifiers (10 units with a radius of 28 m each), where clear wastewater is separated

from the sludge. The treated wastewater is then transported by pressure collectors from terminal pumping station to natural storage reservoir Taldy-Kol'. The characteristics of the treated wastewater in the Almaty WWTP is presented in Table 6.

PERSPECTIVES FOR THE FUTURE

“Ak Bulak” national program on developing water supply systems in the Republic of Kazakhstan assumed that in 2020 – 100% of the population in the cities (compared to 73% in 2010) and 80% of the population in rural areas (41,2% in 2010) will be supplied with high quality water from centralized water supply systems [Ministry of Economic Development and Trade 2011]. Implementation of this goal means inevitable

Table 6. Chemical composition of sewage at different stages of Astana WWTP

Indicators	Raw sewage (inflow)		After mechanical treatment		After biological treatment (discharge)	
	min	max	min	max	min	max
pH	7.2	7.9	7.2	7.6	7.2	7.6
Temperature (°C)	9	22	18	22	18	23
BOD ₅ (mg O ₂ /dm ³)	105	270	70	105	3.0	15.0
COD (mg O ₂ /dm ³)	250	630	160	190	16.4	4.8
Suspended solids (mg/dm ³)	150	320	80	150	5.5	16.4
Phosphorus (mg/dm ³)	1.2	3.76	0.9	2.8	0.8	2.6
Dense rest (mg/dm ³)	1028	1472	525	686	325	436
Ammonia nitrogen (mg/dm ³)	15.0	37.0	10.8	27.0	5.4	7.8
Nitrates (mg/dm ³)	0.075	1.35	0.09	1.5	5.6	12.4
Nitrites (mg/dm ³)	0.03	0.17	0.03	0.19	0.1	0.8
Nickel (mg/dm ³)	0.11	0.24	0.05	0.2	0.001	0.003
Zinc (mg/dm ³)	0.05	0.55	0.01	0.4	0.001	0.01
Iron (mg/dm ³)	1.6	2.8	0.5	1.5	0.01	0.05
Oil products (mg/dm ³)	1.0	4.0	1.0	2.5	0.1	0.4
Detergents (mg/dm ³)	1.2	3.8	1.0	2.9	0.5	1.2
Sulfates (mg/dm ³)	211.0	328.0	180.0	250.0	60.0	150.0

growth in water consumption, and at the same time – increasing production of wastewater. Taking into account the implementation of outdated technologies and poor technical conditions of the existing wastewater treatment facilities, it is necessary to undertake necessary steps to reconstruct and modify those objects or to build new treatment plants in justified cases. Special attention should be paid to the technologies with high efficiency of removing biogenic compounds.

One of possible and feasible solutions is modification of the existing activated sludge bioreactors by adding bio-film attachment surfaces (using different packing media), thus creating an integrated fixed-film activated sludge (IFAS) systems, which show a high potential for intensification of treatment process, especially in terms of removing nitrogen compounds [Randall and Seen 1996, Wang and Peng 2009]. In 2003, Scientific and Research Institute “WaterGeo” in Moscow (NII “VODGEO”) prepared a technical report on “Technological recommendations on retrofitting Almaty WWTP”, where the implementation of natural zeolite as a packing media was proposed for the reconstruction of the existing bioreactors. Re-designed bioreactor includes also anaerobic and anoxic zones that enhance biological phosphorus and nitrogen removal [Osmanov and El-zhasov 2010]. A schematic model of the proposed bioreactor is presented in Figure 2.

For a newly designed sewage disposal systems, both centralized and decentralized solutions may be considered, although decentralized systems are in general preferred for rural areas, while centralized ones – for urban settlements [Libralato et al. 2012, Gikas and Tchobanoglou 2009, Massoud et al. 2009]. Decentralized systems are gaining more and more attention, especially in developing countries, as they fit better to new expectations related with the concept of sustainable development. Technological solutions that can be used in decentralized systems can be divided as shown in Figure 3.

As described by Singhirunnusorn and Stenstrom [2009] appropriate solution of wastewater treatment system at a certain site should be selected taking into account various factors and variables presented in Figure 4.

Many authors emphasize that the most important factor in decision making process regarding water and wastewater management systems should be sustainability. It is worth noting that the term “sustainable technology” is very similar to “appropriate technology”, which can be defined as a technology that is compatible with natural economic, technical and social environment and offers a possibility of further development. Assessing sustainability of wastewater treatment system can be supported by different techniques and tools, among them: exergy (ef-

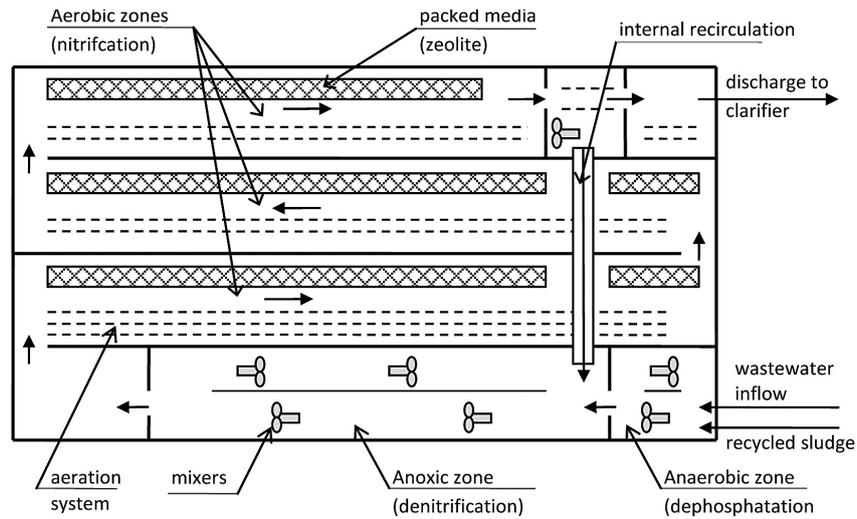


Figure 2. Proposal of IFAS system for Astana WWTP [adapted from Ospanov, Elzhasov 2010]

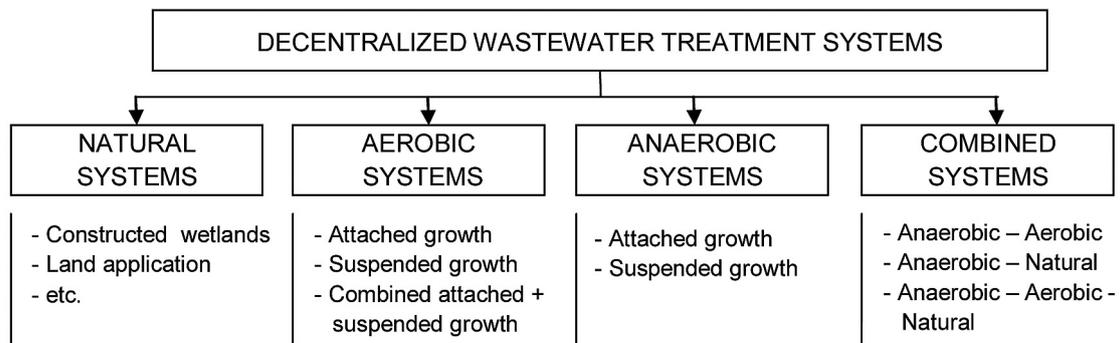


Figure 3. Classification of decentralized wastewater treatment methods [adapted from: Massoud et al. 2009]

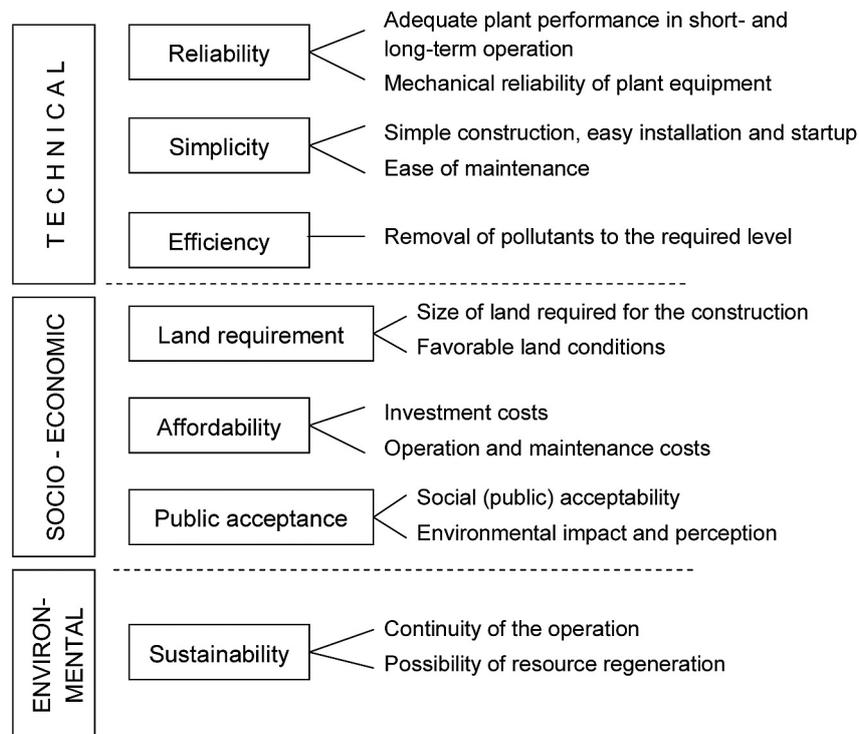


Figure 4. Conceptual variables determining selection of wastewater treatment technology [adapted from Singhirunnusorn and Stenstrom 2009]

iciency) analysis. economic analysis, life-cycle assessment (LCA) and general system analysis are frequently used [Balkema et al. 2002]. All the above mentioned methods result in the estimation of specific indicators that make it possible to choose an optimum (i.e. most appropriate or sustainable) solution.

CONCLUSIONS

The general data obtained from monitoring small settlements in Kazakhstan show that wastewater from villages and small cities has relatively low content of mineral and organic pollutants, and very low salinity. At the same time most of those settlements are equipped with basic treatment facilities only (mechanical and natural treatment), which are old and often in poor technical conditions. Their construction and technological efficiency reflects the standards that were obligatory in the 1960–80's. These facts prove that ground and underground waters contamination that is observed recently in Kazakhstan has an anthropogenous origin and, in general, all settlements of the Republic of Kazakhstan contribute to deterioration of quality of underground waters. The most widespread and dangerous is pollution from nitrogen compounds.

The analysis of sewage disposal systems in main cities of Kazakhstan – Almaty and Astana shows good conditions of wastewater treatment facilities and their high efficiency in removal of organic and mineral compounds, represented by BOD and suspended solids respectively. For Almaty WWTP average efficiency of BOD₅ removal is 97,5% and for suspended solids – 96,9%, which results in high quality effluent with BOD₅ concentration much lower than required 15 mg/dm³. On the other hand, the efficiency of biogenic compounds removal still remains unsatisfactory, reaching only 30 – 40%. To cope with this problem, the possibility of intensification of nitrogen and phosphorus removal using zeolite as bio-film carrier in activated sludge tank is being examined.

Undergoing rapid growth in centralized water supply of both urban and rural areas of Kazakhstan will also require a development of new sewage disposal systems or rebuilding the existing ones. In this regard, decentralized systems should be considered in particular, due to their better fit to sustainability concept and proved applicability in developing countries.

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