Università Politecnica Delle Marche

Environmental Engineering

Circular Processes and Chemical Environmental Plants

WWTP Design in the 13th district of Kabul City, Afghanistan

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Chapter 1

1.1. Environmental legislation in Afghanistan

The Environmental Law of Afghanistan was approved and signed by the National Assembly of the Islamic Republic of Afghanistan in 2007, consisting of 9 chapters and 78 articles. I will write here the articles that it has to be mentioning.

1.1.1. Prohibition of Discharges
Article 27:

1- No person has the right to discharge pollutants into the environment or cause environmental pollution, or allow the environment (land, water, air) to become polluted to the extent that it negatively affects the environment or human health, unless they hold a waste control permit as per the provisions of Article 28 of this law and act in accordance with it.
2- Granting a permit under the provisions of Article 28 of this law does not relieve the applicant of the responsibility to obtain the necessary permits for carrying out activities or implementing the project in compliance with the provisions of this law or other laws.

3- A person who discharges pollutants is obligated to take and implement necessary measures to ensure better and effective environmental protection.

1.1.2. Pollution Control Permits
Article 28:

- The National Environmental Protection Agency evaluates requests for pollution control permits and takes the following actions:

1. Issues the permit with or without conditions, provided it is assured that the discharge of pollutants does not have significant adverse effects on the environment or such effects have been sufficiently reduced.
2. Refuses to issue the permit and provides the reasons in writing to the applicant.

- The National Environmental Protection Agency is obligated to make its decision regarding the issuance or rejection of the permit within 30 days from the date of the application, as per the provisions of paragraph (1) of this article.

- The National Environmental Protection Agency may modify or revoke the pollution control permit or impose additional conditions if there are valid reasons.

- The validity period of a pollution control permit cannot exceed five years.

1.1.3. Reporting and Limiting Discharges
Article 29:

1- A person who pollutes the environment, causes pollution, or allows pollutants to be released in violation of environmental rules and regulations to the extent that it has harmful effects, is required to immediately inform the National Environmental Protection Agency and take all practical measures to control its impact on the environment, prevent further release, or reduce it, at their own expense. They must also provide a solution to the pollution in a way that satisfies the National Environmental Protection Agency.

2- A person who becomes aware of the discharge or disposal of pollutants as mentioned in paragraph (1) of this article is obligated to immediately inform the National Environmental Protection Agency.

1.1.4. Public Prohibition and Duty of Maintenance

Article 30:

1- No person is allowed to collect, transport, categorize, dispose of, or manage waste in a manner that causes significant adverse effects on the environment.

2- A person who produces, imports, transports, transits, stores, or otherwise deals with waste is obligated to take necessary measures to prevent its significant harmful effects on the environment.

3- The owner or occupant of a building where harmful waste is produced is required to separate it from other waste and, in accordance with the rules and regulations of the National Environmental Protection Agency and the conditions stated in the permit, store it in a separate container or location.

(4) No person is allowed to dispose of waste in a manner that causes environmental pollution or turns it into pollution.

1.1.5. Permit for the Management of Hazardous Waste

Article 32:

a- The landowner or occupant of a location where hazardous waste is stored, disposed of, or used must submit a request to the National Environmental Protection Agency for a permit. The request should contain the following details:

1. The chemical composition and characteristics, and the volume of the produced waste.
2. The industrial, commercial, or operational process that causes the generation of waste.
3. The method proposed by the applicant for the storage, disposal, management, and preparation of hazardous waste procedures.
4. The precautionary measures taken to prevent the harmful effects of hazardous waste on the environment.

b- After evaluating the requests in paragraph (1) of this article, the National Environmental Protection Agency will take the following actions:

1. Issue the permit with or without conditions, provided that the proposed method for storing, disposing, or managing the hazardous waste does not cause harmful effects.
2. Refuse to issue the permit and provide the reasons in writing to the applicant.

c- The National Environmental Protection Agency must make a decision on issuing or rejecting the permit within 30 days from the date of submission of the request.

d- d- If there are valid reasons, the National Environmental Protection Agency may amend, suspend, or revoke the hazardous waste management permit or impose additional conditions on it.

e- The validity period of the hazardous waste management permit cannot exceed five years, provided that the permit holder notifies the National Environmental Protection Agency about any changes in the quantity or quality of the waste during the validity period. In such cases, the National Environmental Protection Agency may amend the permit to ensure that the storage, disposal, and management of the waste do not cause harmful effects.

1.2. Water Regulation Law in Afghanistan 2020

The Water Regulation Law consists of 48 articles and was signed by the former President of Afghanistan in 2020. Here, I will translate and write some of the essential articles.

Article 5:

1. Access to clean and safe drinking water is the right of the people.
2. The provision of access to clean and safe drinking water shall be ensured in accordance with the provisions of this law and other legislative documents.

Article 6:
Comprehensive management of water resources for the purpose of protection, sustainable use, and environmental conservation, considering hydrological boundaries and watershed methods, shall be carried out in accordance with the provisions of this law.

Article 7:

1. The use of water resources and their allocation are prioritized based on their importance for humans and animals.
2. The use of water resources and their allocation for other purposes is regulated according to their economic and regional feasibility.

Article 8:

1. The Ministry of Water and Energy, for the purpose of creating reserves, transferring operational matters, and maintaining and overseeing systems and other water-related services, shall charge users both directly and indirectly.
2. The Ministry of Water and Energy is obligated to determine the price for the use of water from the source and the service fees every three years based on a separate regulation.

Article 23

1. The Ministry of Water and Energy is obligated to design, construct, and rebuild water infrastructure and facilities for environmental protection.
2. The mechanism for the use of water resources for environmental protection shall be regulated by the Ministry of Water and Energy in cooperation with the National Environmental Protection Agency, according to a separate regulation.

Article 21

1. The Ministry of Water and Energy is obligated to design, construct, and rebuild irrigation infrastructure, systems, and networks.
2. The mechanism for water use in irrigation shall be regulated by the Ministry of Water and Energy in cooperation with the technical departments of the Ministry of Agriculture and Livestock, according to a separate regulation.

1.2.1. **Article 20**

1. The Ministry of Water and Energy is obligated to design, construct, and rebuild infrastructure, systems, and water distribution networks for drinking purposes.
2. The mechanism for the distribution of drinking water shall be regulated by the Ministry of Water and Energy in cooperation with the technical departments of the Ministry of Urban Development and Land, the Ministry of Rural Rehabilitation and Development, and the Urban Water Supply and Sewerage Company of Afghanistan, according to the law.
3. The Ministry of Water and Energy is obligated to supply and distribute water for public and private pastures for livestock in cooperation with the Ministry of Agriculture and Livestock.

1.3. wastewater discharge law.

1.3.1. Reuse of Water

Article 28.

The reuse of wastewater for non-drinking purposes shall be regulated by the Ministry of Water and Energy according to a separate regulation.

1.3.2. Sewage Disposal

Article 29.

Sewage disposal matters shall be regulated by the Ministry of Water and Energy in cooperation with the relevant technical departments according to a separate regulation.

1.3.3. Obligations of Wastewater Treatment Plant Officials

Article 30

1- Wastewater treatment companies are required to obtain an environmental permit from the National Environmental Protection Agency and act according to the conditions specified in it.

2- Officials of wastewater treatment plants must issue two certificates, with serial numbers and the discharge date, in the name of the driver and the wastewater producer's authority for tanker visits for discharge and treatment.

3- Wastewater treatment companies must sign contracts with wastewater producers and send a copy of the contract to the National Environmental Protection Agency for environmental monitoring and inspection.

1.3.4. Obligations of Sewage Tanker Owners

Article 31

1- Owners of sewage tankers are required to register with one of the authorized sewage service companies, obtain a sewage transfer card, and present it during environmental inspections. If there are no authorized sewage service companies available, sewage tanker owners must register their tankers with the National Environmental Protection Agency and obtain a sewage transfer card.

2- Transporting sewage without an environmental card is prohibited.

3- Disposing of untreated sewage in seas, waterways, and agricultural areas is prohibited.

1.3.5. Control and Monitoring Committee

Article 32.

1. To control and supervise the discharge of sewage into city sewage networks, the collection, transportation, and disposal of waste materials, a Control and Monitoring Committee will be established at the central level upon the proposal of the Head of the National Environmental Protection Agency and approval of the President.
2. A Control and Monitoring Committee will be established at the provincial level upon the proposal of the provincial Environmental Protection Agency head and the approval of the provincial governor.
3. The operational procedures for the committees mentioned in paragraphs (1) and (2) of this article will be set out in separate regulations prepared by the National Environmental Protection Agency and approved by the central Control and Monitoring Committee.

1.3.6. Violation and Compensation for Damages

Article 33.

- Individuals and entities that commit violations of any of the provisions in this regulation shall, depending on the circumstances and considering the area of pollution discharge into water resources, be required to compensate for the damage caused in accordance with the law.

1.3.7. Report Submission

Article 34 - The responsible parties for industrial and commercial establishments are required to submit a written report on the sewage treatment process every six months to the National Environmental Protection Agency.

1.3.7. Inspection of Water Sources and Water Quality

Article 35

a) The National Environmental Protection Agency shall appoint professional inspectors as environmental inspectors to implement the provisions of this regulation.

b) The inspectors mentioned in paragraph (1) of this article have the following duties and powers:

1. To monitor, assess, and ensure timely control of any changes in water quality according to environmental standards.
2. To identify and determine the areas of pollution discharge, in collaboration with relevant authorities.
3. To take preventive actions to prevent pollution of water resources, in collaboration with relevant authorities.

4. To review and monitor the implementation of conditions mentioned in environmental permits.
5. To review and monitor projects that may affect water resources.
6. To control and monitor the discharge of sewage and its treatment process.
7. To establish a system for collecting data to ensure continuous monitoring of water quality across the country.

    c- Ministries, government and non-government agencies, and owners of industrial and commercial establishments utilizing water resources are obligated to provide the necessary facilities to environmental inspectors to facilitate continuous monitoring and control.

1.3.8. **Regulations and Procedures**

Article 36

The National Environmental Protection Agency, in collaboration with relevant water sector authorities, may issue regulations and procedures to ensure better implementation of the provisions of this regulation.

1.4. National Water Quality Monitoring Policy: Order No. 1403

The General Director of the National Environmental Protection Agency Water pollution, overcrowding in cities, failure to maintain environmental hygiene, digging of substandard wastewater absorption wells, and improper disposal of wastewater are major environmental issues. To implement the provisions of Chapter Five of the Water Law and the Environmental Law, the National Water Quality Monitoring Policy, prepared by the Directorate of Legislation and Policy and reviewed by the responsible committee, is now in effect after consultations with relevant ministries and departments and approval from the concerned authority. The National Water Quality Monitoring Policy covers many points. However, I will summarize and list the key points here.

1.4.1. **Vision, Goal, and Objectives of the Policy**

Vision: This policy aims to protect and monitor the quality of water resources (both surface and groundwater) to provide clean and pollution-free water for various purposes throughout the country.

Goal: The National Water Quality Monitoring Policy is designed to set water quality standards for different uses, monitor water quality, identify sources of pollution, and take preventive measures to protect water according to the Water and Environmental Laws and both national and international standards.

Objectives:

- Identify water pollution sources and elements across the country.
- Establish and strengthen the monitoring system for drinking water quality.

- Monitor water resources' quality and prevent pollution nationwide.
- Establish a monitoring system for agricultural water quality and industrial wastewater discharge.
- Control drinking water quality standards in the country.
- Raise public awareness on environmental hygiene and the sustainable use of water.
- Ensure proper management and monitoring of urban water zones and city sewerage systems.
- Create a database to collect accurate statistics on the quality of both underground and surface drinking water, initially in major cities and then in other cities.

1.4.2. Pollution Sources

Water pollution occurs when physical, chemical, or biological changes in the water environment harm human, animal, plant, or other living organisms. Freshwater can become polluted due to human activities or natural disasters. Key sources of water pollution include:

- Digging of substandard wastewater absorption wells.
- Mining activities.
- Use of radioactive materials.
- Discharge of wastewater into water bodies.
- Construction of unregulated settlements.
- Discharge of solid, urban, clinic, hazardous, and electronic waste into surface water.
- Car washing and carpet cleaning activities.
- Operations of pump stations.
- Slaughterhouses.
- Household washing.
- Manufacturing and industrial activities.
- Vehicle repair workshops.
- Use of chemical fertilizers in agriculture.
- Use of unauthorized pesticides and agricultural wastewater.

1.4.3. Groundwater

Ground water accounts for two-thirds of Afghanistan's freshwater. Groundwater in major Afghan cities has decreased due to prolonged droughts, population growth, and overuse. Studies from 1982 to 2006 show a decline of up to 10 meters in groundwater levels, which causes access issues for citizens. Major causes of groundwater depletion include the loss of irrigated lands, destruction of wetlands, and increased impervious surfaces. Groundwater in cities like Kabul is also threatened by improper well digging, wastewater contamination, and urban sewage systems.

Table 1. **Chemical parameters most likely to be found in the ground water in Afghanistan.**

Parameter	***Risk level* mg/L**	***Risk level* +50% mg/L**	***Tolerable daily intake /Acceptable daily intake* mg/kg per day (85 kg/65kg) mg per day**	***LOAEL* mg/kg per day (85kg/65kg) mg per day**	***Total mg intake with 10 L intake per day***		***Total volume of liters per day, at risk level, in order to reach LOAEL/ADI***
					Water w/risk level content	***Water w/risk level +50% content***	
Antimony (Sb)	0,005	0,0075	0,006 (0,51/0,39)	0,35 (29,8/22,8)	0,05	0,075	65 kg: 1380/78 85 kg: 1800/102
Arsen (As)	0,01	0,015	0,002 (0,17/0,13)	0,014 (1,2/0,9)	0,1	0,15	65 kg: 90/13 85 kg: 120/17
Lead (Pb)	0,01	0,015	0,0035 (0,30/0,23)	0,2 (17/13)	0,1	0,15	65 kg: 1300/23 85 kg: 1700/30
Boron (B)	1,0	1,50	**0,16** **(13,60/10,40)**	Not set. But 72 mg gives adverse effect	10	15	65 kg: 72/10,4 85 kg: 72/13,6
Cyanide (CN)	0,01	0,015	0,012 (1,02/0,78)	1,2 (102/78)	0,1	0,15	65 kg: 7800/78 85 kg: 10200/102
Iron (Fe)	0,2	0,30	Men: 9 mg/day Women: 15mg/day	100mg/day	2	3	65 kg: 500/75 85 kg: 500/45
Cadmium (Cd)	0,005	0,0075	**0,001** **(0,085/ 0,065)**	**0,001 (some ref. to 0,0002)** **(0,085/0,065)**	0,05	0,075	65 kg: 13/13 85 kg: 17/17
Copper (Cu)	0,1	0,15	**0,9mg/day**	5,3 mg per day	1	1,50	65 kg: 53/9 85 kg: 53/9
Manganese (Mn)	0,05	0,075	0,06 (5,1/3,9)	15 mg per day	0,5	0,75	65 kg: 300/78 85 kg: 300/102
Magnesium (Mg)	125 (EU)	187,5	250 mg per day	360 mg per day	1250	1875	65 kg: 3/- 85 kg: 3/-

Parameter	Risk level mg/L	Risk level +50% mg/L	Tolerable daily intake /Acceptable daily intake mg/kg per day (85 kg/65kg) mg per day	LOAEL mg/kg per day (85kg/65kg) mg per day	Total mg intake with 10 L intake per day		Total volume of liters per day, at risk level, in order to reach LOAEL/ADI
					Water w/risk level content	Water w/risk level +50% content	
Nitrate (NO_3 - N)	10	15	0-3,7 (314,5/240,5)	*1,8-3,2* *(153/117)*	100	150	65 kg: 11,7/24 85 kg: 15,3/31,5
Nitrite (NO_2 - N)	0,05	0,075	0,07 (5,95/4,55)	0,37 (31,5/24)	0,5	0,75	65 kg: 480/91 85 kg: 630/119
Selenium	0,01	0,015	Men: 0,05mg/day Women: 0,04mg/day	0,91 mg per day	0,1	0,15	65 kg: 91/4 85 kg: 91/5
Sodium (Na)	200	300	2400mg per day	Not set	2000	3000	65 kg: ?/12 85 kg:?/12

Table1. chemical parameters mostly like to be found in the groundwater in Afghanistan

1.4.4. Current Water Situation in Cities

One major environmental issue is the pollution of groundwater. Currently, 91.5% of people in cities and 56.6% in rural areas lack access to safe drinking water. Urban population growth, poor hygiene practices, and improper well digging have contributed to the pollution of city water. Additionally, the increasing demand for water in domestic, agricultural, and industrial uses is expected to further reduce access to clean water, especially in cities. Recent studies by the Hydrology Directorate of the Ministry of Energy and Water show that some areas of Kabul meet World Health Organization standards, while others do not.

1.4.5. National Water Quality Standards.

National water quality standards define the characteristics of water quality for safe use. These standards aim to improve water quality and prevent pollution, safeguard public health, ensure safe drinking water, protect aquatic life, support agriculture and industry, and ensure the sustainable use of water resources.

1.4.6. Policy Recommendations:

- Implement standards to prevent the discharge of pollutants into water sources.
- Conduct technical evaluations of pollution sources based on these standards.
- Manage water quality through wastewater discharge permits in accordance with the standards.
- Continuously evaluate and update pollution discharge standards for water sources.

- Create guidelines for monitoring and controlling water-polluting activities according to standards.
- Issue warnings if drinking water becomes excessively polluted beyond acceptable limits as per the standards.

Table 2: Primary water pollutants and elements

Numbers	Sources	Class-One pollutants
1	Agricultural activities	Ammonium, Nitrates, Pesticides, Human and animal sewage
2	Domestic wastewater	Nitrates, Human and animal sewage
3	Elimination of filth and mud	Nitrates, lead, zinc
4	Solid waste disposal sites	Ammonium, Nitrates, salinity, Some halogenated hydrocarbons, heavy metals
5	Dry cleaning facilities	Halogenated hydrocarbons
6	Oil product pump stations, vehicle workshops, and old vehicle storage areas.	Mineral oil, benzene, other aromatic hydrocarbons, some halogenated hydrocarbons
7	Leather tanning	Chromium, phenols
8	Mining industry	Acidity, various heavy metals
9	Slaughterhouses	Parasites and microbes
10	Painting and plastering	Lead, copper, zinc

Table 3. Class-Two Water Pollutants

Numbers	Class-Two Water Pollutants
1	Agricultural chemicals
2	Asbestos
3	Brick, bitumen, or concrete cutting wastewater
4	Carpet or upholstery cleaning waste
5	Chemicals designed for human or animal therapeutic use
6	Cleaning agents
7	Condensate from compressors
8	Construction and demolition waste (whether or not inert)
9	Engine coolant
10	Food or beverage waste
11	Fuel dispensing area wash water
12	Hard waste (for example, vehicles, tires, batteries, metal parts, piping, electronic equipment, municipal solid waste)
13	Hazardous waste
14	Human waste
15	High pressure water blasting waste
16	Liquid waste
17	Medical waste
18	Motor vehicle servicing or repairs waste
19	Oil, grease or lubricants
20	Pool backwash water
21	Craps and dead Organic waste (for example, foods animals that are putrid or likely to become putrid)

22	Radioactive waste
23	Sawdust
24	Street cleaning waste
25	Down water from cleaning vehicles, plant or wash equipment
26	Down water from commercial or industrial wash premises or wharves
27	Air conditioning or cooling system wastewater
28	Animal faces
29	Green waste

Table 4: List of Drinking Water Quality Specifications Related to Inorganic Chemical Substances

Parameter/ Characteristics	Standards for Afghanistan (mg/L)	WHO Guidelines 2011 (mg/L)	Standard Limits for Most Asian Countries (mg/L)	Remarks
Aluminium (Al)	0.2	NGVS	0.2	
Antimony (Sb)	0.02	0.02	0.02	
Barium (Ba)	0.7	0.7	0.7	
Boron (B)	2.4	2.4	2.4	
Cadmium (Cd)	0.003	0.003	0.003	
Chloride (Cl)	250	NGVS	250	If water is absent, the limit can be increased up to 1000 mg/L.
Chromium (Cr)	0.05	0.05	0.05	
Copper (Cu)	2	2	2	
Iron (Fe)	0.3	NGVS	0.3	
Potassium (K)	10	NGVS	10	
Sodium (Na)	200	NGVS	200	
Sulphate (SO_4^{2-})	250	NGVS	250	If water is absent, the limit can be increased up to 400 mg/L.
Magnesium (Mg)	30	NGVS	30	If water is absent, the limit can be increased up to 100 mg/L.
Calcium (Ca)	75	NGVS	75	If water is absent, the limit can be increased up to 200 mg/L.

Table 5: List of Drinking Water Quality Specifications Related to Organic and Inorganic Toxic Substances

Parameter/Characteristics	Standards for Afghanistan (mg/L)	WHO Guidelines 2011 (mg/L)	Standard Limits for Most Asian Countries (mg/L)
Cyanide (CN)	0.05	0.05	0.05
Arsenic (As)	0.05	0.01	0.01- 0.05
Fluoride (F)	1.5	1.5	1.5
Lead (Pb)	0.01	0.01	0.01
Manganese (Mn)	0.3	0.3	0.3
Mercury (Hg)	0.006	0.006	0.006
Nickel (Ni)	0.07	0.07	0.07
Nitrate (NO_3^-)	50	50	50
Nitrite (NO_2^-)	3	3	3
Selenium (Se)	0.04	0.04	0.04
Nitrite in the form of nitrogen	11	11	11

Table 6: Physical Characteristics of Drinking Water Quality

Parameter/ Characteristics	Standards for Afghanistan	WHO Guidelines 2011	Standard Limits for Most Asian Countries	Remarks
Colour	<15TCU	NGVS	<15TCU	
Taste	Unacceptable	Unacceptable	Unacceptable	
Odor	Unacceptable	Unacceptable	Unacceptable	
Turbidity or darkness	5 NTU	NGVS	5 NTU	
Total dissolved solid (TDS) (mg/L)	1000 mg/L	NGVS	1000 mg/L	If water is absent, the limit can be increased up to 2000 mg/L.
Total hardness ($CaCO_3$) (mg/L)	500 mg/L	NGVS	500 mg/L	If water is absent, the limit can be increased up to 600 mg/L.
pH	6.5-8.5	NGVS	6.5-8.5	

1.5. Water Law of Afghanistan by World Health Organization (WHO)

1.5.1. Wastewater and Sewage

Article Seven (Fees for Water Services)

Allows water service providers to charge fees for services including wastewater treatment, transmission, irrigation system and sewage systems.

Article Eight (Responsibilities of Government Institutions)

- Sub-article (6): Providing clean water for drinking and daily use in cities is a shared responsibility led by the Ministry of Urban Development. This includes building **water treatment plants**, pipelines, sewer systems, and **wastewater treatment** facilities that meet national standards. To make it all work, the ministry collaborates with several other agencies like the Ministries of Energy and Water, Mines, Public Health, Agriculture, and the National Environmental Protection Agency ensuring that the water supply and sanitation services are safe, reliable, and sustainable.
- Sub-article (7): The Ministry of Rural Rehabilitation and Development is responsible for sewage treatment systems in villages.

Article Twenty-One (Application for Activity Permit and Usage License)

Requires permits/licenses for:

- Disposal of wastewater into water resources (Sub-article 2).
- Disposal of drainage water into water resources (Sub-article 3).

Article Twenty-Two (Installation of Measuring Devices)

- Mandates measurement of **wastewater discharge** into watercourses.

Article Twenty-Four (Water Quality Standards)

- Sub-article (3): The standard for **industrial wastewater discharge** that is recommended in line with accepted standards by the Ministry of Urban Development in close collaboration with Ministry of Mines, Ministry of Public Health, Ministry of Agriculture, Irrigation and Livestock and National Environmental Protection Agency shall be strictly observed.

Article Thirty (Water Resources Pollution Prevention)

- Real and legal persons cannot contaminate water resources by using or discharging garbage, wastewater, industrial waste, chemicals and toxics beyond the limit.

Article Thirty-One (Control and Monitoring of Water Quality)

- Requires industrial facilities to submit monthly reports on wastewater treatment to authorities.

1.5.2. Sanitation / Wastewater treatment Plant

Article Six (Public Use of Water Resources)

- Water resources may be used according to the provisions of this law with due consideration for the praiseworthy customs and traditions of the people to meet the needs for drinking water, livelihood, agriculture, industry, public services, energy production, transportation, navigation, fisheries and the environment. Priority for use of water resources shall be given to drinking water and livelihood.

Article Eight (Responsibilities of Government Institutions for the construction or WWTP)

- Sub-article (6): The construction of water treatment plants, water conveyance facilities, sewerage systems and sewage treatment plants in accordance with accepted standards in urban settings, is the responsibility of the Ministry of Urban Development Ministry of Urban Development with cooperation from Ministry of Energy and Water, Ministry of Mines, Ministry of Public Health, Ministry of Agriculture, Irrigation and Livestock, and National Environmental Protection Agency.

1.5.3. Water Quality Standards

Article Twenty-Four (Water Quality Standards)

- Sub-article (1): The Ministry of Public Health sets drinking water quality standards.
- Sub-article (2): The Ministry of Agriculture sets water quality standards for agriculture.
- Sub-article (3): Standards for industrial wastewater discharge are established by the Ministry of Urban Development.

Article Twenty-Nine (Establishing Water Resources Quality Standards)

- The National Environmental Protection Agency, in cooperation with the Ministry of Public Health, sets quality standards for water sources and pollution tolerance limits.

Article Thirty-One (Control and Monitoring of Water Quality)

- Ensures compliance with water quality regulations.

1.6. Standards for Treated Wastewater Effluent in Afghanistan

According to United Nation Environmental Protection (UNEP), Afghanistan lacks its own national wastewater effluent discharge standards and relies in some cases on international guidelines, and only one city (Kabul) and just 2% of Kabul population collects wastewater and delivers it to a wastewater treatment plant, this service is provided to two areas of the city (Districts 9 and 16) that are home to approximately 100 000 residents. The treatment plant processes about 12 000 m3 of wastewater daily, discharging its effluent into the Kabul River.

For this reason, after much research, I concluded that Pakistan could be a suitable option due to its many similarities in climate and neighbourhood, so that I could use their standards for treated wastewater effluent in my project.

"NATIONAL ENVIRONMENTAL QUALITY STANDARDS FOR MUNICIPAL AND LIQUID INDUSTRIAL EFFLUENTS (mg/I, UNLESS OTHERWISE DEFINED)

S. No.	Parameter	Existing Standards	Revised Standards Into Inland Waters	Into Sewage Treatment (5)	Into Sea ( )
1	2	3	4	5	6
1.	Temperature or Temperature Increase *	40^0C	≤3°C	≤3°C	≤3°C
2.	pH value (H^+) .	6-10	6-9	6-9	6-9
3.	Biochemical Oxygen Demand $(BOD)_5$ at 20^0C (1)	80	80	250	80**
4.	Chemical Oxygen Demand (COD) (1)	150	150	400	400
5.	Total Suspended Solids (TSS)	150	200	400	200
6.	Total Dissolved Solids (TDS)	3500	3500	3500	3500
7.	Oil and Grease	10	10	10	10
8.	Phenolic compounds (as phenol)	0.1	0.1	0.3	0.3
9.	Chloride (as Cl^-)	1000	1000	1000	SC***
10.	Fluoride (as F^-)	20	10	10	10
11.	Cyanide (as CN^-) total ..	2	1.0	1.0	1.0
12.	An-ionic detergents (as MBAS) (2)	20	20	20	20
13.	Sulphate (SO_4^{2-})	600	600	1000	SC***
14.	Sulphide (S^{2-})	1.0	1.0	1.0	1.0
15.	Ammonia (NH_3)	40	40	40	40
16.	Pesticides (3)	0.15	0.15	0.15	0.15

table 7. Limits for municipal and industrial effluent of Pakistan

Parameter	Unit	Pakistan	Iran
BOD_5	mg/l	80	50, 100 for irrigation
COD	mg/l	150	100, 200 for irrigation
TSS	mg/l	150	60, 100 for irrigation
pH	–	6.0–9.0	5.5–9.0
Temperature	°C	40	
Oil and Grease	mg/l	10	10
NO4-N	mg/l	–	50
NH_4	mg/l	–	5/2
NH_3–N	mg/l	40	

Table 8. Treated effluent limits of two neighbouring countries of Afghanistan

Fate of Septic Tank Solids After Emptying in Afghanistan

According to the UNEP, sludge from septic tanks is frequently collected by vacuum trucks or manually. However, the final disposal is often uncontrolled, with sludge dumped on open land, in drainage channels, or water bodies, posing significant environmental and public health risks, or directly to use in agriculture.

Chapter 2.

2.1. Study Area

2.1.1. General Information about Wastewater in Kabul City:

Kabul does not have a proper sewage system, and its wastewater disposal system is neither well-organized nor up to standard.

Years of mismanagement by authorities, successive governments' neglect, and the absence of a structured wastewater disposal framework have led to the uncontrolled discharge of sewage into roadside drains, the Kabul River, and residential areas without any treatment.

52 companies and 40 individual sewage tankers are officially operating in Kabul. However, officials from the National Environmental Protection Agency confirm that many other tankers operate illegally without permits.

Data provided by the ministry of water and energy in 2019 and 2021 reveals that 27.2% of Kabul's residents use septic tanks, while 70% rely on absorption wells, which contaminate groundwater. Furthermore, a 2021 report from the National Environmental Protection Agency states that 57% to 70% of deep and semi-deep well water in Kabul is polluted with human waste.

2.1.2. Groundwater Contamination Due to Sewage:

The lack of a proper sewage disposal and treatment system not only pollutes the urban environment by contaminating the city's air but also leads to groundwater contamination. When absorption wells are used for wastewater disposal, they directly pollute underground water sources. If this issue is not addressed, it could result in a major environmental and public health crisis for the people of Kabul.

According to data from Kabul Municipality, there are 80,000 houses (ranging from one to five stories) in planned areas, 200,000 houses (one to four stories) in unplanned areas, and 60,000 houses built on hillsides across the city. The National Environmental Protection Agency reports that less than 30% of these homes have septic tanks, while 70% rely on absorption wells.

Absorption wells are a major source of groundwater pollution, as contaminated water seeps into the ground while solid waste is collected by tankers. In contrast, septic tanks are a proper waste disposal system that prevents wastewater from seeping into the ground. However, absorption wells, being non-standard, allow polluted water to mix with groundwater.

A report published last year by the National Environmental Protection Agency revealed that out of 2,750 high-rise buildings surveyed across Kabul, daily water consumption was recorded at 4,375 cubic meters, with 530 cubic meters of wastewater being discharged.

The report also stated that 70% of Kabul's groundwater is contaminated with human waste.

This is particularly concerning, as a large number of Kabul residents rely on well water for drinking and daily use.

2.1.3. Sewage Disposal in Residential Areas of Kabul City

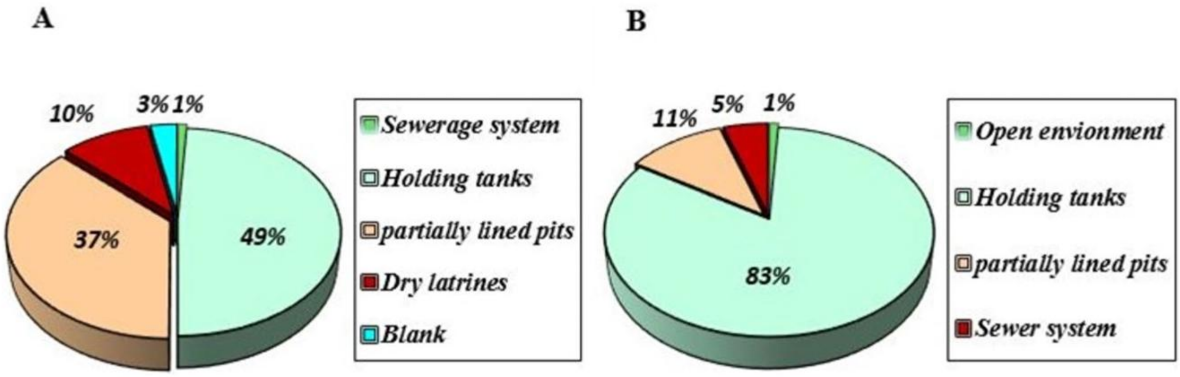
Two main categories of sewage disposal in Kabul city:

A. Sewage Disposal Methods in Residential Areas

1. 49% of households use holding tanks for blackwater storage.
2. 37% use partially lined pits, which allow some wastewater to seep into the ground.
3. 10% rely on dry latrines, which do not involve water for waste disposal.
4. Only 1.3% of the population is connected to a proper sewerage system.

B. Greywater Disposal (Water from Sinks, Showers, and Kitchens)

1. 83% of households discharge greywater directly into the environment.
2. 11% use holding tanks for greywater storage.
3. 5% use partially lined pits for greywater disposal.
4. Most homeowners do not treat their greywater before releasing it, leading to pollution.



2.1.4. Non-Functional Treatment Plant

The only centralized wastewater treatment plant in Kabul is the Makroyan Treatment Plant, but according to officials from the Makroyan Maintenance and Management Company, it does not effectively treat sewage to standard levels or some sources says it is completely deactivated.

For the past 15 years, some of its systems have developed technical issues, preventing the plant from properly processing wastewater.

2.2. Covered Area by the Wastewater treatment Plant

In this project three different residential communities (Rigration, Shahrak-e- Erfani, and Shahrak-e- Ettifaq) in the 13th district of Kabul considered. The areas covered by this treatment plant are located in the western part of Kabul. To the north, these areas are bordered by the Kabul River, to the south by Shaeed Mazari Road, to the east by Company Road, and to the west by the hills and totally with 8.2 km^2.

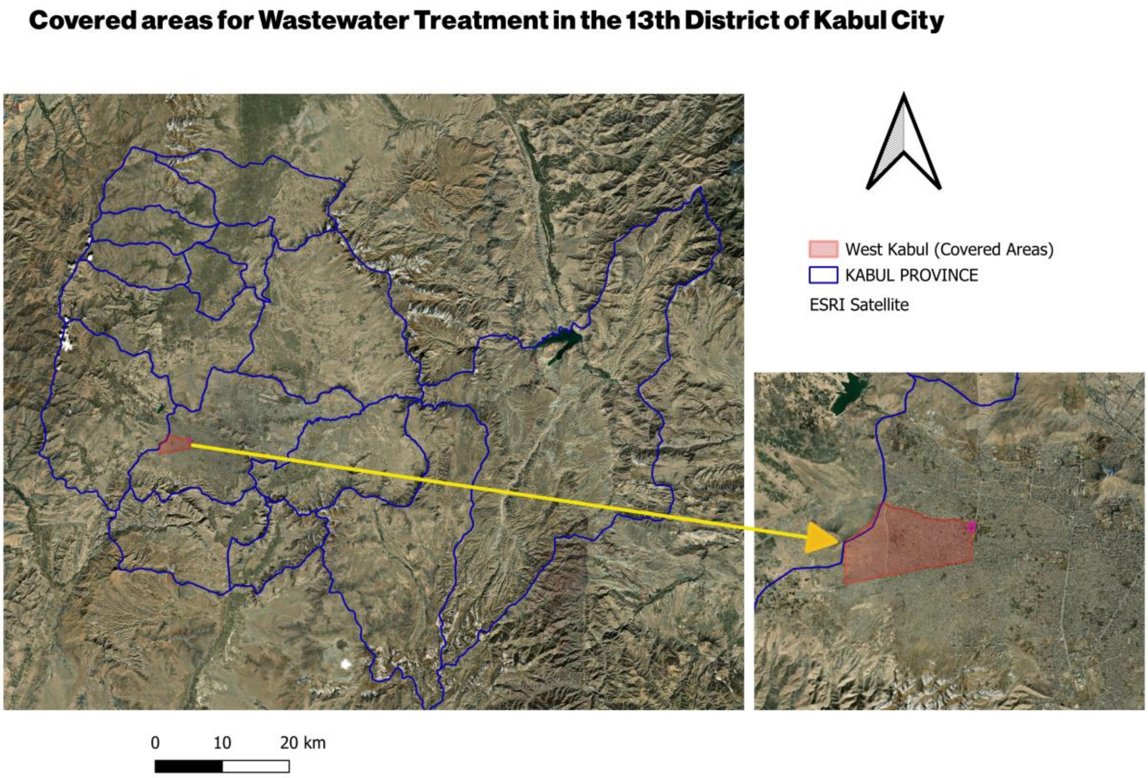


Figure 1. covered areas for WWT in the 13th district of Kabul city

2.3. Location of Wastewater treatment

The treatment plant has been placed in the eastern part of the covered area, at the lowest point in the covered area. There are three key reasons for choosing this location. First, its close proximity to the Kabul River is a significant advantage. The plant is bordered by the river to the north, making it an ideal spot for discharging treated water into the river, especially if it's not being used for agriculture or other purposes. Second, the area is located a bit further from residential neighbourhoods, which helps reduce the likelihood of any unpleasant Odors affecting nearby residents. Lastly, the low elevation of the site allows water to flow naturally toward the treatment plant through channels, eliminating the need for pumps and making the process more energy efficient.

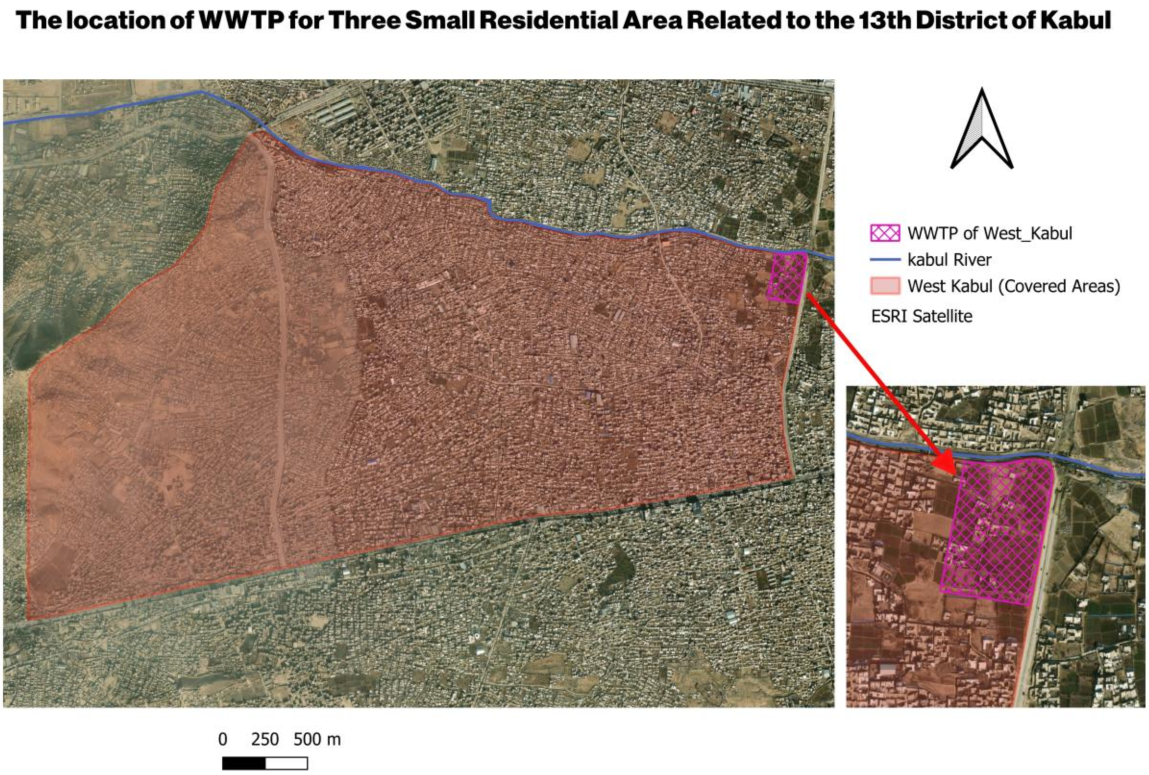


Figure 2. The location of WWTP

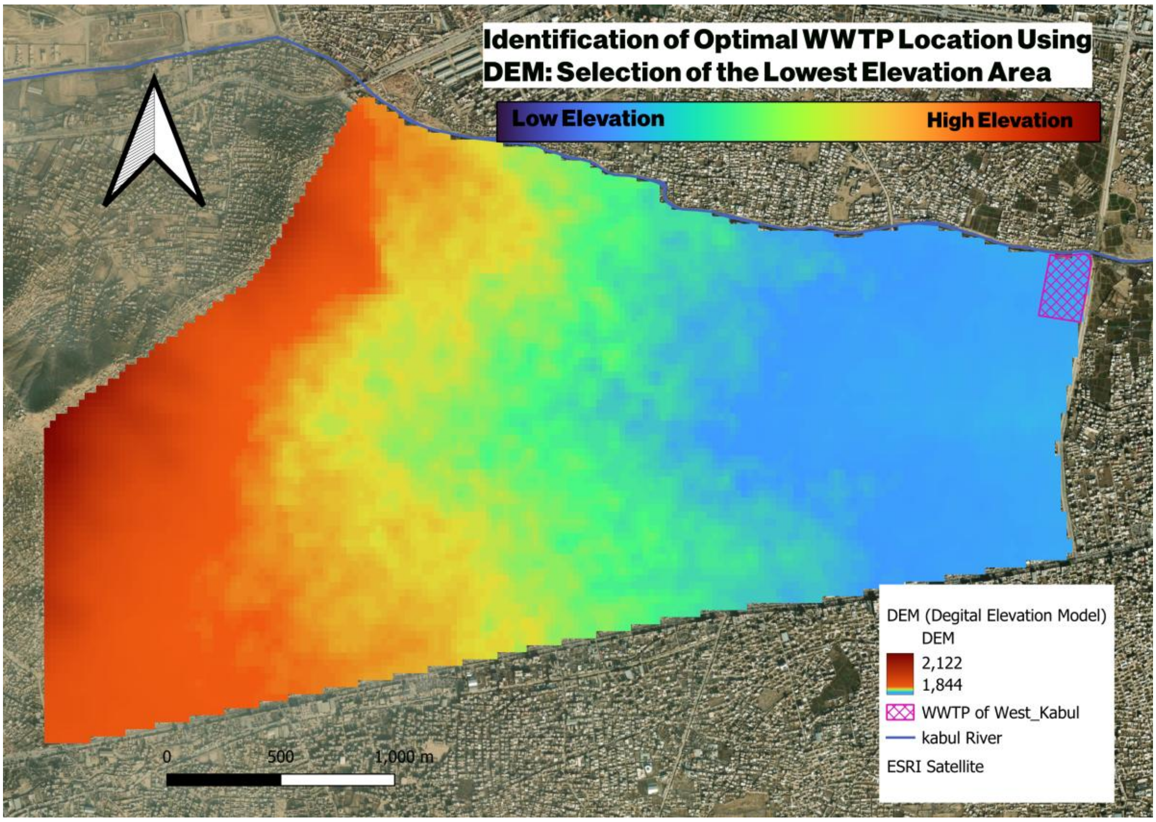


Figure 3. identification of WWTP using DEM

2.4. Population of Kabul

Since 2002, the Kabul city has experienced significant growth as Afghan people from neighbouring countries and other provinces have moved there in search of jobs and better social and economic opportunities, and Kabul became of the most populated capital in the world. This rapid influx has had a major impact on the environment and created challenges, especially due to the lack of sanitation and water supply systems. Currently, Kabul's population is approximately 5 to 5.5 million. According to the socio-economic framework. The population in intermediate years is shows in table for planning purpose.

"Table 1 shows increasing population of Kabul city (JICA, 2009).

Years	2008	2010	2015	2020	2025
Pop (000)	4007	4220	4751	5126	5500
Annual Increase (%)	0	2.6	2.4	1.5	1.4

Table 9. population of Kabul over years

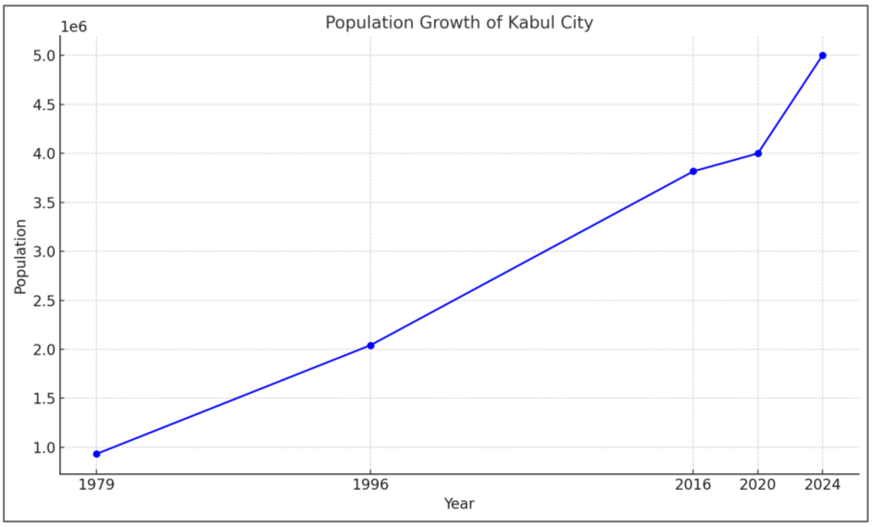


Figure 4. Shows the population growth in Kabul

2.5. Population of Covered Area of WWTP

Since there is no accurate population data available for Kabul, I can't determine the exact population of the areas covered by this wastewater treatment plant. However, based on estimated data got from different resources, the population of District 13 in Kabul is estimated to be between 500,000 and 600,000 people. Based on the area where I live, the population of these three residential area is estimated to be between 190,000 and 210,000 people. Therefore, I am considering an average of 200,000 people.

2.6. Population Trend of Covered Area Analysis by 2050

$P_t = P_0 \times (1+r)^n$: where r is the growth rate which is equal to 1.4% by 2025

$P_{2050} = 200{,}000*(1+0.014)^{25} = P_{2050} = 200000*(1.014)^{25} = P_{2050} = 200000* 1.416 =$

$P_{2050} = 283200$

Based on the population trend in 2050 the population of this area would be about 283,200 but based on the estimates and assessments due to immigration and urbanization, the population of the area will be even more.

Therefore, I estimate and predict that the area considered for the Wastewater Treatment Plant (WWTP) will see an increase of people, bringing the total population to 300,000 by the year 2050.

2.7. Climate

2.7.1. **Precipitation:** Afghanistan, a landlocked country located within the desert belt, experiences an arid to semi-arid climate with an average annual rainfall of **256mm**. Most of its precipitation falls as snow between November and April, with peaks in February and March.

Since 1960, the country's overall rainfall has been gradually declining, averaging a 0.5mm decrease per month or about 2% per decade. This drop is primarily due to a notable reduction in spring rainfall, which has decreased by 2.7mm per month (6.6% per decade). Meanwhile, there has been a slight increase in rainfall during the summer and autumn. Afghanistan is the most vulnerable to climate change and it was ranked 175th our of 182 countries in 2020.

So, a region with more or less 400 mm/year precipitation is year is arid. Between 2006 and 2020, Kabul City received an average annual precipitation of 312.71 mm, classifying it as an arid region. Over the entire study period, the total recorded precipitation, including both rain and snow, amounted to 4,690 mm.

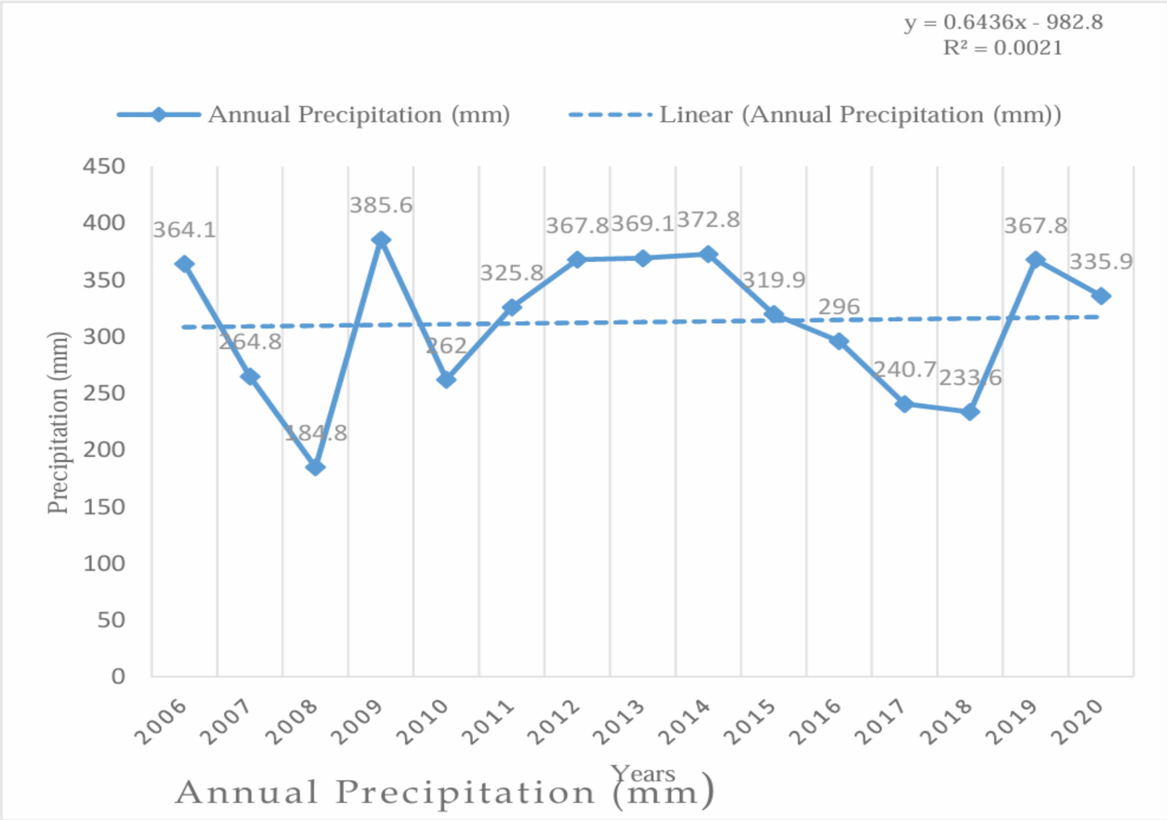


Figure 5. annual average precipitation in Kabul city over years

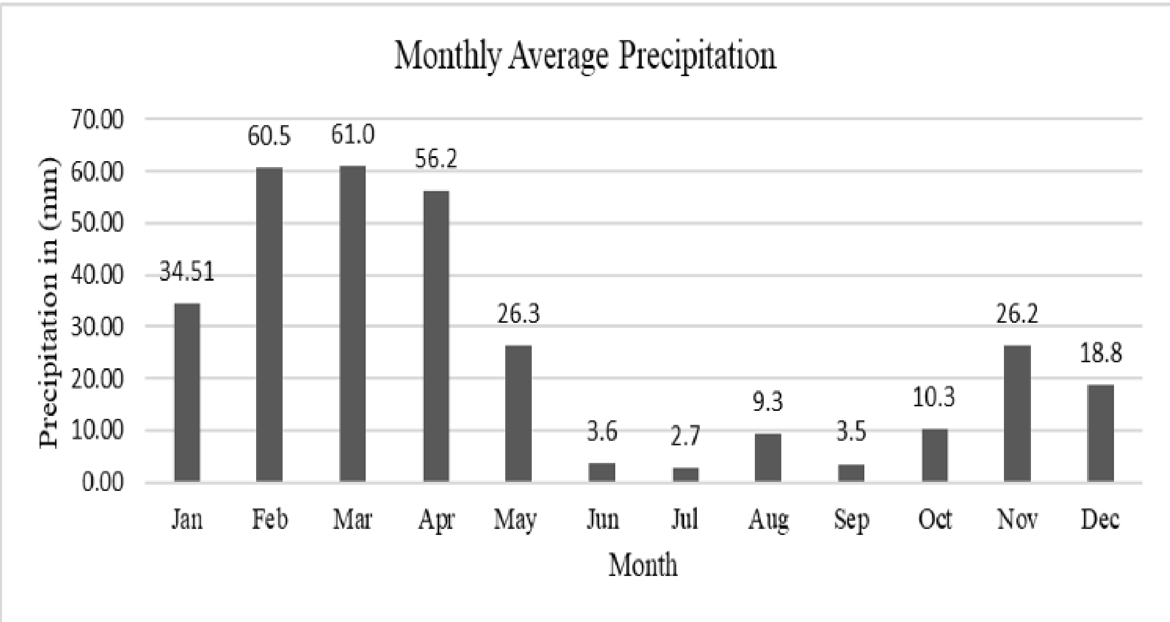


Figure 6. Monthly average precipitation from 2006-2020

The figure shows that the winter season, from December to March, has the highest average monthly precipitation, with February and March having the highest percentage amount of precipitation, at 19.32% (60.5mm) and 19.47% (61.0mm), respectively. From April to October, the precipitation decreases significantly, with June and July having the lowest percentage amount of precipitation, at 1.14% (3.6mm) and 0.86% (2.7mm), respectively.

2.7.2. Temperature of Kabul:

Afghanistan because of having the arid and simi-arid climate and yearly temperature average is about 12 degrees Celsius. The average daily temperature range between 15.2 Celsius. July is the warmest month with a mean temperature of 25 degrees Celsius, the coldest month is January, with average temperatures -2.3 degrees Celsius. In General Kabul has a hot summer and chilly or cold winter.

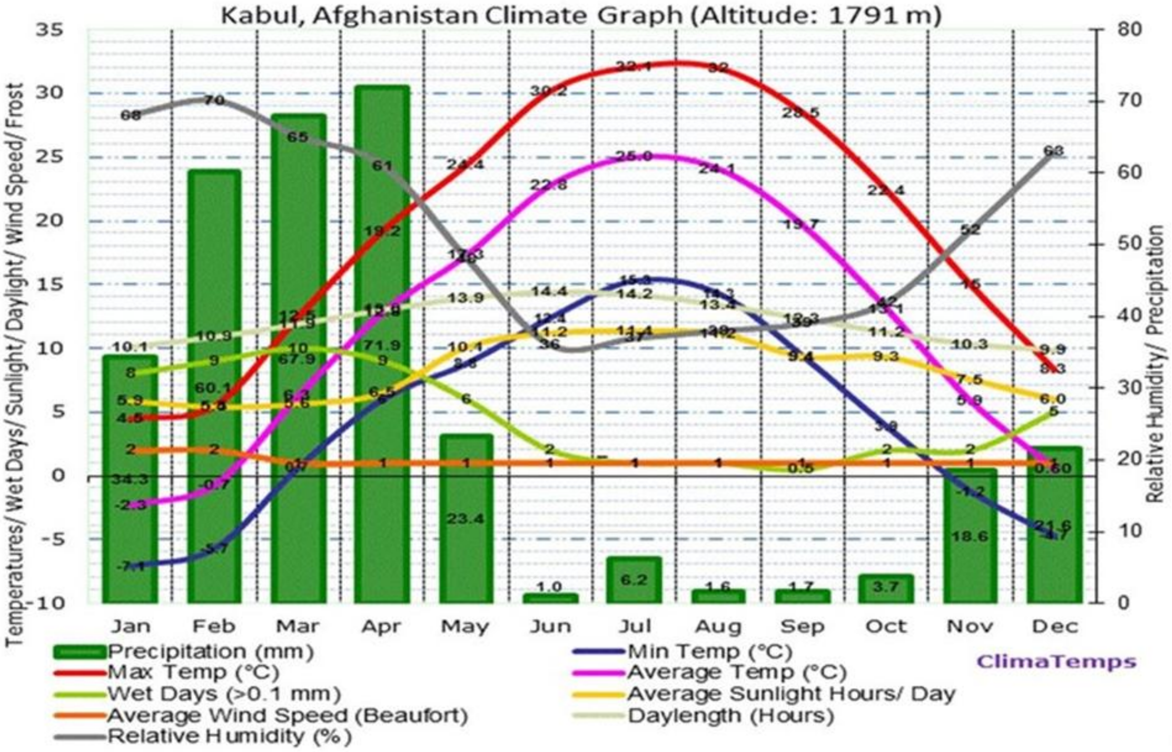


Figure 7. Kabu climate groph

2.8. Wastewater discharge

For this wastewater treatment plant, which provided for a specific area in the western part of Kabul, I've considered discharging the treated water into the river that flows the north of the WWTP. Based on its location, this river seems like the most suitable option for releasing the water after treatment. Additionally, I've also considered using the treated water for irrigating parks in Kabul or even for agricultural purposes, as another practical and sustainable solution.

2.8.1. Three Type of Pollutants

Generally, in wastewater, three different types of contaminants should be found.

1- **Conventional pollutants:** are the typical, well-known substances usually present in wastewater. These include things like suspended solids, organic material (often measured by biochemical oxygen demand or BOD), nutrients such as nitrogen and phosphorus, and harmful microorganisms like bacteria and viruses. These are the main contaminants considered when designing a wastewater treatment plant.

2- **Non-conventional contaminants:** On the other hand, non-conventional pollutants aren’t always present in wastewater, but they’re still recognized and their harmful effects are well-documented. This group includes heavy metals like lead, mercury, and cadmium, as well as certain organic chemicals such as pesticides, pharmaceuticals, and some industrial compounds. Unlike conventional pollutants, these aren’t usually considered in the standard design of a treatment plant.

3- **Emerging contaminants:** these are a relatively new group of pollutants that have started to raise concerns because of their potential impact on both the environment and human health. These substances often include things like pharmaceuticals, personal care products, endocrine disruptors, PFAS (per- and polyfluoroalkyl substances), and microplastics. Even though they usually appear in small amounts, conventional wastewater treatment plants aren't very effective at removing them. Dealing with these pollutants often requires more advanced treatment methods, such as adsorption or advanced oxidation processes.

Conventional	- Total suspended solids - Colloidal solids - BOD, COD, COT - Ammonia, nitrates, nitrites, total nitrogen - Phosphorus - Bacteria, oocysts of protozoa, viruses
Non-Conventional	- Refractory organics - Volatile organic compounds - Surfactants - Metals - Total dissolved solids
Emerging	- Prescribed drugs and prescription no. - Personal care and hygiene products - Antibiotics for human and animal use - Illicit drugs

For this project of WWTP just considered the conventional contaminants. The definition of some popular pollutants: **Chemical Oxygen Demand (COD):** is a measure used to assess water quality, particularly in wastewater. It tells us how much oxygen is required to oxidize the organic and oxidizable inorganic compounds present in the water.

Biochemical Oxygen Demand (BOD): Is a key measure of water quality. It shows how much oxygen is needed by microorganisms to break down organic matter in the water. This helps us understand how biodegradable the waste is and what kind of impact it might have on aquatic life. BOD is especially useful for assessing the level of organic pollution in places like rivers, lakes, and treated wastewater.

Total Suspended Solids (TSS): Refer to the tiny solid particles floating in wastewater, which can include things like silt, organic matter, and other debris.

Nutrients like nitrogen and phosphorus: Often found in wastewater from sources like human waste and fertilizers, are vital for plant growth. However, when too much of these nutrients end up in natural water bodies like rivers or lakes, they can cause serious environmental issues like eutrophication, where excessive algae growth harms water quality and aquatic life.

2.9. Flowrate

The average of flow rate on an basis represents of the flow values necessary for the design of the various sections of the plants. So for the average of dry weather is calculated based of the water supply per capita. In addition to the average daily flow rate on an annual basis, in fact, it is appropriate to define also other values of flow that characterize the flow of the incoming waste. Based on Japan International Cooperation Agency (JICA) the per capita water supply in Kabul city is as follow

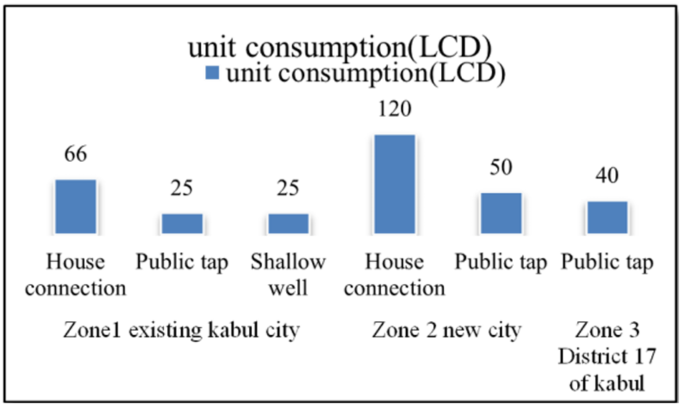


Figure 1 shows water supply in zones of Kabul city, Source: (JICA, 2009).

Figure 8. water supply in zones of Kabul city

According to this data, people in my project area use public taps, so I assume the per capita water use is **120** litters per day. However, there is also water from commercial and institutional use, industrial discharge, public facilities, and stormwater. So, I estimate the total water entering the wastewater treatment plant will be **200** litters per person per day.

- **Design Population (2050)**: 300,000 people
- **Water use per capita (wastewater contribution)**: 200 L/person/day
- **Average Flow (Q_avg)** = Population × Per capita water use

Qavg = 300,000 P.E * 200 L/P.E.d =60,000,000 L/day=60,000 m^3/day = 0.694 m^3/ second

Table 10. Design Flowrate for WWTP (2050, with 300,000 population)

Parameter	Value (m^3/day)	Value (m^3/s)
Q average	60,000	0.694
Q peak	120,000	1.388
Q minimum	30,000	0.347

Item	Description
Hourly (instantaneous) peak flow	Average of maximum flow rates on a time basis in observation period
Average daily flow rates in dry weather	Average of the daily flow rates observed in dry weather
Average daily flow rate on annual base	Average of the daily flow rates observed in a year
Average flowrate in wet weather	Average daily flow rates in rainy weather
Possible design flowrate	Average range of daylight hours

FLOWRATE	DESCRIPTION	PURPOSE FOR DESIGN AND OPERATION
Average daily flow	The average of the daily flows	development of flowrate ratios and for estimating pumping and chemical costs
Maximum day	the average of the peak flows sustained for a period of days in the record examined (the duration of the peak flows may vary)	sizing of equalization basin, chlorine contact tanks, sludge pumping system
Maximum month	the average of the maximum daily flows sustained for a period of 1 month in the record examined	record keeping and reporting; sizing of chemical storage facilities
Minimum hour	the average of the minimum flows sustained for the period of 1 hour in the record examined (usually based on 10 min increments)	sizing turndown of pumping facilities and determining low range of plant flowmeter
Minimum day	the average of the minimum flows sustained for the period of a day in the record examined (usually for the period from 2 am to 6 am)	sizing of influent channels to control solids deposition; sizing effluent recycle requirements for trickling filters
Minimum month	the average of the minimum daily flows sustained for the period of 1 month in the record examined	selection of minimum number of operating units required during low-flow periods; scheduling shutdown for maintenance

Table 11. water flowrate metrics

2.10. WW influent constituents

In Kabul city in general, there is no clear information about the quality of incoming wastewater, such as BOD, COD, suspended solids, and nutrients.

Because of this, I used standard values from the Metcalf and Eddy (2014) reference book for designing the treatment plant, and considered the volues of pakistan's wastewater. The table below shows the typical characteristics of domestic wastewater used for the design.

Parameter of WW Constituents	Estimated Value
Population	300,000
Design Flow (m^3/day)	60,000
BOD_5 (mg/L)	350
COD (mg/L)	650
TSS (mg/L)	400
SS (mg/L)	400
TKN (mg/L)	65
NH_4-N (mg/L)	50
TP (mg/L)	12
E. coli (MPN/100 mL)	$10^7 – 10^8$

Table 12. influent wastewater charachteristics in Kabul

Table 8–1

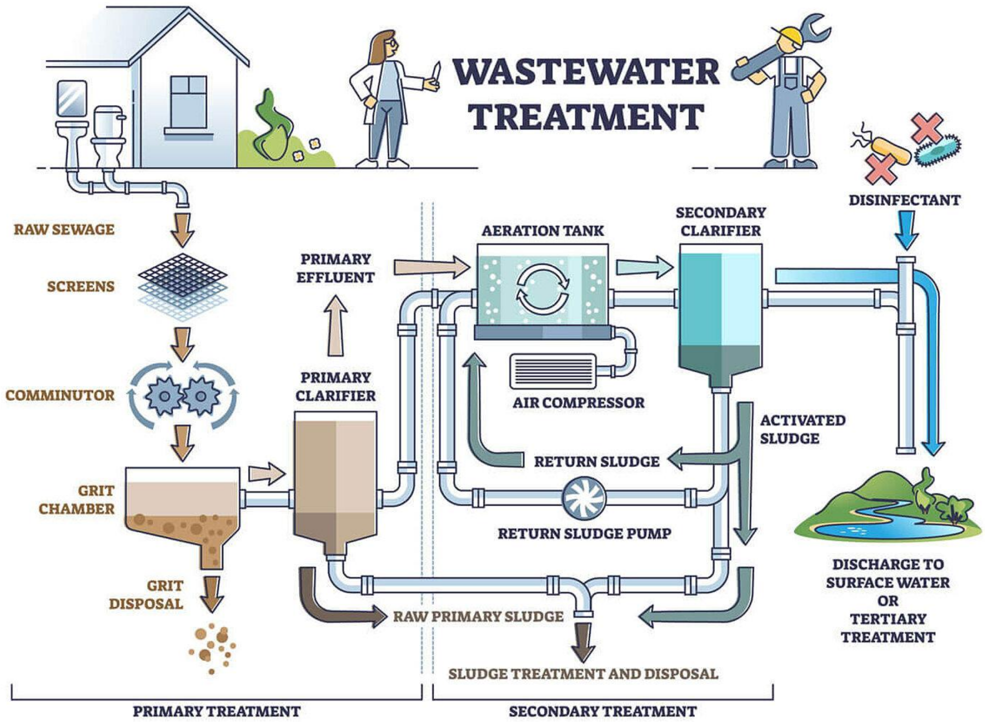
Example of typical domestic wastewater characterization parameters and typical values

Component	Concentration, mg/L[a]
COD	508
sCOD	177
BOD	200
TSS	195
VSS	150
TKN	35
NH_4-N	20
NO_3-N	0
Total phosphorus	5.6
Alkalinity	200 (as $CaCO_3$)

[a] Typical medium strength wastewater, from Table 3–18.

Table 13. example of typical domestic wastewater characterization parameters, got from Metcalf

Chapter 3.
Wastewater Treatment Plant Design



3.1. Screening

The purpose of screening is to remove solid or inert particles from wastewater. This helps prevent clogging and damage to machines that come later in the treatment process. Screening also helps reduce the amount of sediment and saves space in the next treatment steps.

There are different types of screening.

a) Classification based the space between the bars: Screens are used to catch solid objects that don't move on their own. These objects get stuck between the bars.

1. Coarse screens have big openings—about 20 to 60 mm wide.
2. Medium screens have openings between 6 and 20 mm.
3. Fine screens are smaller, between 1 and 6 mm.
4. Micro-screens are very small, with openings less than 1 mm.

b) Classification by how the screen is cleaned:
Screens can be cleaned in two ways:

1. Manually, by a person
2. Automatically, using machines or sensors

3.2. Coarse Screens

Coarse screen in WWTP is to protect the pumps, pipes and values to installed at the later stage of the process from clogging due to large objects.
Coarse screen are usually placed before the fine screens to stop large objects that could damage them. In industrial wastewater treatment, coarse screens are often not used because of the type of wastewater.
There are two main types of bar racks, depending on how they are cleaned:
1-Manual 2- mechanical. Mechanical coarse screen are easier to use and help reduce problems with operation and maintenance.
If we decide to install mechanical bar racks, it's a good idea to have **more than one unit**. This way, if one breaks down or there's a power failure, the system can still work. If that's not possible, you should at least include a manually cleaned bar rack as a backup to keep things running.
Design guidelines for mechanical coarse screen:

1. Minimum water speed before the rack: 0.4 m/s – to stop solids from building up.
2. Maximum water speed through the rack: 0.9 m/s – to stop waste from slipping through.
3. Maximum allowed head loss: 150 mm

Parameter	Unit	Value / Range
Approach Velocity (Minimum)	m/s	0.3 - 0.5
Approach Velocity (Maximum)	m/s	0.6 - 1.0
Maximum Velocity	m/s	0.9
Width	mm	5-15
Depth	mm	25 - 38
Clear Space Between Bars	mm	15 - 75
Slope from Vertical	degrees	0-30
Allowable Head Loss	mm	150 - 600
Screening production (mm spacing)	$L/1000m^3$	4-6

Table 14. parameters for manually coarse designed

3.3. Grit Removal

Grit in WW includes sand, gravel and heavy materials. These are heavier than organic waste and can settle to the bottom. Grit is removed early in treatment to protect pipes and equipment from damage and reduce cleaning needs. It is especially important for machines with delicate parts, like pumps or filters. The goal of grit removal is to take out grit during both normal and rainy conditions, then prepare it for landfill.
A grit removal system usually has three steps: separation, washing, and drying. One common type is the aerated grit chamber (AGC). In this system, air is blown into one side of the tank, making the water move in a spiral. This helps heavy grit fall to the bottom while lighter organic material stays in the water. The grit is then pumped out and dried. If the air is not controlled properly, the grit may stay in the water or organic matter may also be removed by mistake.

3.4. Pumping Station

A pumping station is a key part of a wastewater treatment plant, responsible for moving water from one stage to the next—especially when gravity alone isn't enough. After the initial cleaning steps, like grit removal, the water often needs to be lifted to a higher elevation to continue through the treatment process. The station uses powerful pumps to handle both regular daily flows and sudden increases during rainstorms. To ensure reliability, multiple pumps are typically installed, with some dedicated to normal flow, others to handle peak loads, and at least one kept as a backup. We must consider pumps for dry weather and also for the wet weather which the flow changes.

3.5. Equalization tank

An equalization tank in a wastewater treatment plant helps keep the water flow steady. The amount of water coming into the plant can change a lot because of rain, seasons, or factory activities. These tanks store extra water when the flow is too high and release it later when the flow is lower. This helps the treatment plant work better and avoid problems. The tank is aerated and mixed so that solids don't settle at the bottom and bad smells don't form. It's usually placed before or after the first cleaning steps to make maintenance easier.

There are many benefits to using this tank. It helps the plant treat the water more efficiently and saves money by making sure machines don't have to deal with big changes in water flow or quality. It also makes the plant safer by reducing the risk of overload or accidents. Another advantage is that it helps even out pollution levels and slows down sludge aging, which is good for producing biogas or recovering useful materials. The tank is used mostly during high-flow times, like in rainy months, and stays offline when not needed.

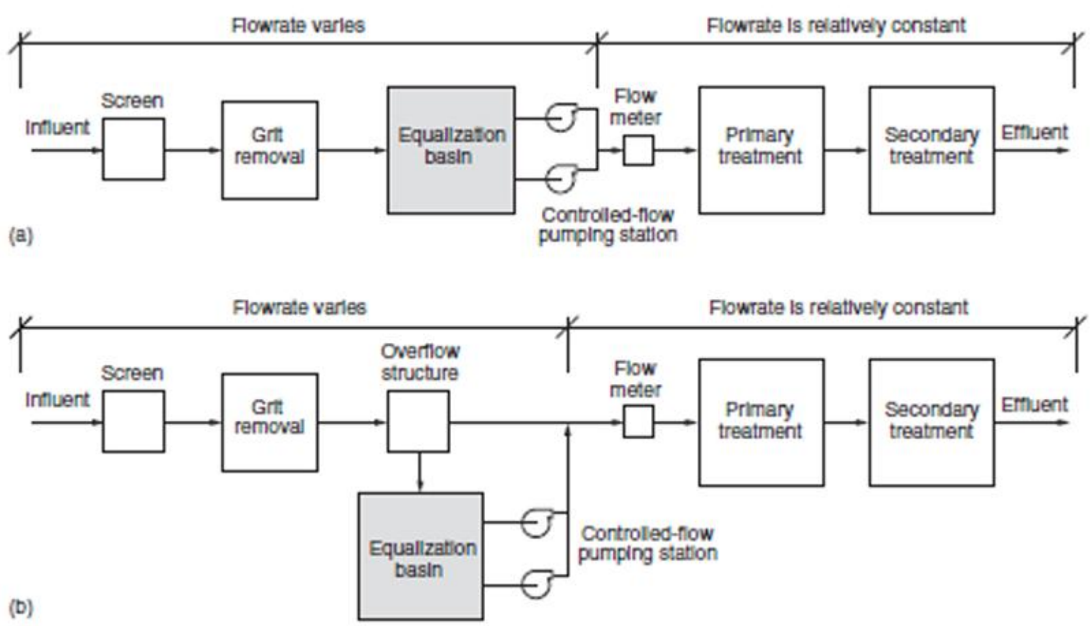


Figure 9. equalization tank position

3.6. Primary Clarifier

The main goals of sedimentation is to remove solids that can settle quickly and materials that float. this helps to lower the amount of suspended solids in water.

This process remove about 50–70% of the solids, 25–30% of BOD (Biochemical Oxygen Demand), and about 5% of N nitrogen and P phosphorus.

The **HRT** (Hydraulic Retention Time) or the water should stay in the sedimentation tank for at least 30 minutes. In most cases, the HRT is about 1.5 to 2.5 hours. The water level at the top should be deep enough so that the settled solids at the bottom are not disturbed. Since the tanks are open, wind can move the water and affect the process.

Tests like the SVI are used to help plan how tall each part of the clarifier should be.

From top to bottom in the tank, different settling zones can be seen:

a. At the top, there is **discrete settling**, where particles fall without touching each other, or particles are separating without interaction.
b. Below that, in the **flocculant settling** zone, the number of particles increases and they start to join into small flocs.
c. In the **settling zone**, the flocs become more concentrated and move down together.
d. At the bottom, in the **compression zone**, the solids become even more compact as water is pushed out from the space between them.

Table 5-19

Typical design information for primary sedimentation tanks[a]

	U.S. customary units			SI units		
Item	**Unit**	**Range**	**Typical**	**Unit**	**Range**	**Typical**
Primary sedimentation tanks followed by secondary treatment						
Detention time	h	1.5–2.5	2.0	h	1.5–2.5	2.0
Overflow rate						
Average flowrate	gal/ft^2·d	800–1200	1000	m^3/m^2·d	30–50	40
Peak hourly flowrate	gal/ft^2·d	2000–3000	2500	m^3/m^2·d	80–120	100
Weir loading rate	gal/ft·d	10,000–40,000	20,000	m^3/m·d	125–500	250
Primary settling with waste activated sludge return						
Detention time	h	1.5–2.5	2.0	h	1.5–2.5	2.0
Overflow rate						
Average flowrate	gal/ft^2·d	600–800	700	m^3/m^2·d	24–32	28
Peak hourly flowrate	gal/ft^2·d	1200–1700	1500	m^3/m^2·d	48–70	60
Weir loading rate	gal/ft·d	10,000–40,000	20,000	m^3/m·d	125–500	250

[a] Comparable data for secondary clarifiers are presented in Chap. 8.

Table 16. typical design information for primary sedimentation tank

Table 5-20

Typical dimensional data for rectangular and circular sedimentation tanks used for primary treatment of wastewater

Item	U.S. customary units			SI units		
	Unit	Range	Typical	Unit	Range	Typical
Rectangular:						
Depth	ft	10–16	14	m	3–4.9	4.3
Length	ft	50–300	80–130	m	15–90	24–40
Width[a]	ft	10–80	16–32	m	3–24	4.9–9.8
Flight speed	ft/min	2–4	3	m/min	0.6–1.2	0.9
Circular:						
Depth	ft	10–16	14	m	3–4.9	4.3
Diameter	ft	10–200	40–150	m	3–60	12–45
Bottom slope	in./ft	3/4–2	1.0	mm/mm	1/16–1/6	1/12
Flight speed	rev/min	0.02–0.05	0.03	rev/min	0.02–0.05	0.03

Table 17. typical dimensional data for rectangular and circular sedimentation tank

3.7. Biological Treatment

Biological reactor is one of the most important parts of a wastewater treatment plant (WWTP). In this part of the plant, microorganisms help clean the water by breaking down harmful substances or contaminants before the water is released back into nature.

The main goal of biological treatment is to remove organic matter and nutrients (like nitrogen and phosphorus) to meet environmental rules. It also helps to remove small particles that do not settle easily.

Microorganisms such as bacteria, fungi, and protozoa are used in this process. They eat the pollution, turning it into gases and new cells.

There are three main types of biological treatment processes, based on the kind of oxygen the microorganisms use:

Aerobic: Microorganisms use dissolved oxygen for their metabolism.

Anaerobic: Microorganisms use oxygen contained in organic and inorganic substances.

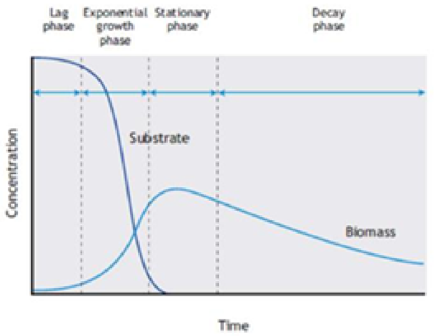
Anoxic: Microorganisms use oxygen contained in inorganic like nitrates, not from the air.

Different stages of bacterial growth are illustrated by what's known as the bacterial growth curve. This curve has four main phases: the lag phase, the exponential (or log) phase, the stationary phase, and finally, the death phase.

Stages of bacterial growth curve

"Lag" phase: represents the time for microorganisms to be acclimated to the new environment and they begin to divide. Practically it is characterized by zero growth. The duration of this phase depends on the type of substrate and biomass.

Logarithmic growth phase: cells divide at a rate determined by their generation time and by their ability to treat the substrate. The growth rate is independent of the concentration of substrate, which is still in excess of the needs of the biomass.



Stationary phase: in this phase the population remains stationary as the cells have exhausted the substrate or the nutrients required for growth and the growth of new cells is counterbalanced by the death of old ones.

Death phase: in this phase the death rate exceeds the rate of production of new cells. The death rate is usually a function of vital population and the environmental characteristics. The number of microorganisms is reduced due to the shortage of food and then the autooxidation of cellular protoplasm.

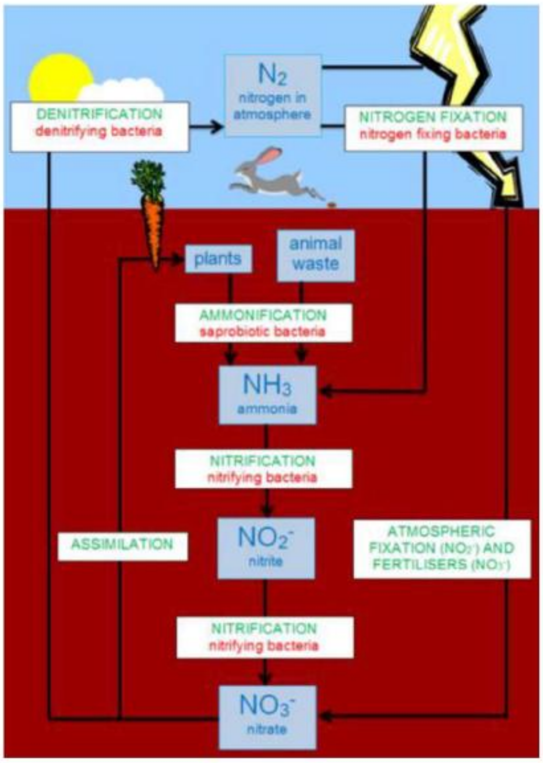
3.7.1. Overview of Nitrogen in Nature / WWTP

The nitrogen cycle is a natural process that already exist in the ecosystem. But with human activities, especially the development of the Haber-Bosch process, and human activities, this balance has been destroyed. As a result, removing nitrogen from wastewater has become a major environmental challenge.

Nitrogen Cycle

- Nitrogen fixation (convert to reactive forms, NH_4^+, organic, NO_3)
  - Biological (e.g. *Azotobacter to NH3*)
  - Combustion of fossil fuels
  - Other processes (i.e. lightning)
  - Industrial (high temperature and pressure, Haber–Bosch process)

  $N_2 + 3\,H_2 \rightarrow 2\,NH_3$
- Assimilation by plants
- Ammonification
- Nitrification
- Denitrification



When nitrogen from wastewater is released into nature, it can cause eutrophication, a process where water bodies become overloaded with nutrients. This leads to excessive algae growth, which eventually reduces oxygen levels in the water and harms aquatic life.

There are two main ways we remove nitrogen from wastewater:

1- Biological methods are typically used when nitrogen levels are below 5000 mg/L.

5. Physicochemical methods like air stripping, precipitation, and ion exchange are used when nitrogen levels are above 5000 mg/L and biological treatment alone isn't effective. The diagram below gives an overview of what happens to nitrogen in a typical wastewater treatment plant.

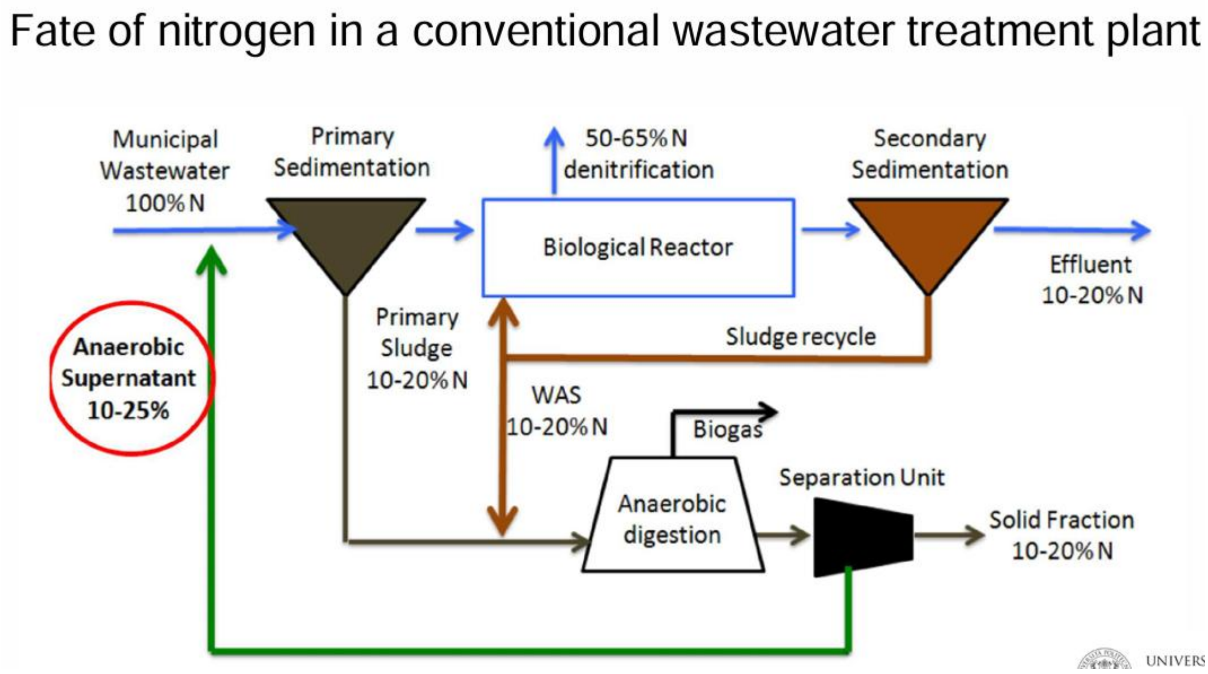


Figure 10. fate of nitrogen in WWTP

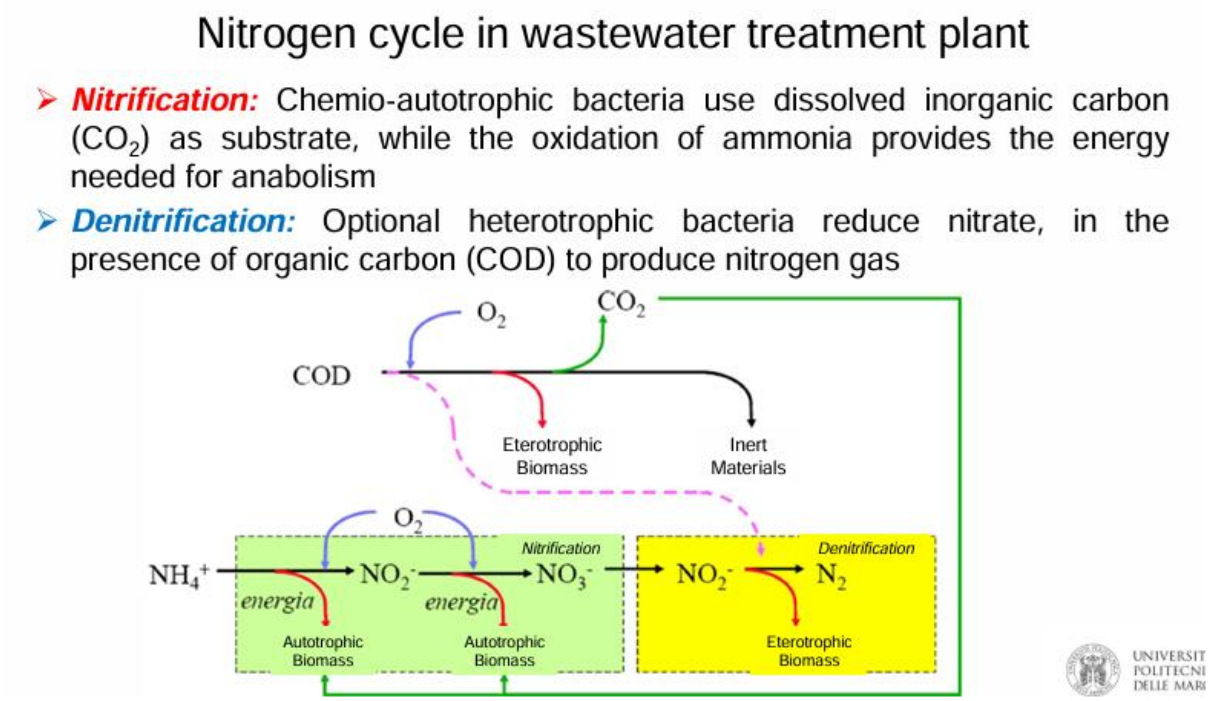
Biological nitrogen removal happens in two steps: nitrification and denitrification.

- **Nitrification:**

In this step, a special type of bacteria called chemo-autotrophs uses carbon dioxide (CO_2) as their food source. They get their energy by converting ammonia into nitrate, which help them grow and do their job in the treatment proces.

- **Denitrification:**

Here, another type of bacteria (called heterotrophs) takes over. They remove nitrate by turning it into nitrogen gas, which is safely released into the air. But to do this, they need organic matter (COD) as a source of energy.



3.7.2. Nitrification

During nitrification, oxygen is consumed at a rate of 4.57 mg O_2 per mg of nitrogen removed, and about 0.24 mg of biomass (COD) is produced per mg of nitrogen. Additionally, the process uses 7.14 mg of alkalinity ($CaCO_3$) for each mg of nitrogen converted.

Because both BOD removal and nitrification require oxygen, they can happen in the same aerobic tank. However, it's important to note that nitrifying bacteria grow more slowly than the bacteria that remove organic matter (heterotrophs), and they are also more sensitive to environmental stress, like heavy metals.

To make sure nitrifying bacteria survive and do their job, the sludge retention time (SRT) needs to be long.

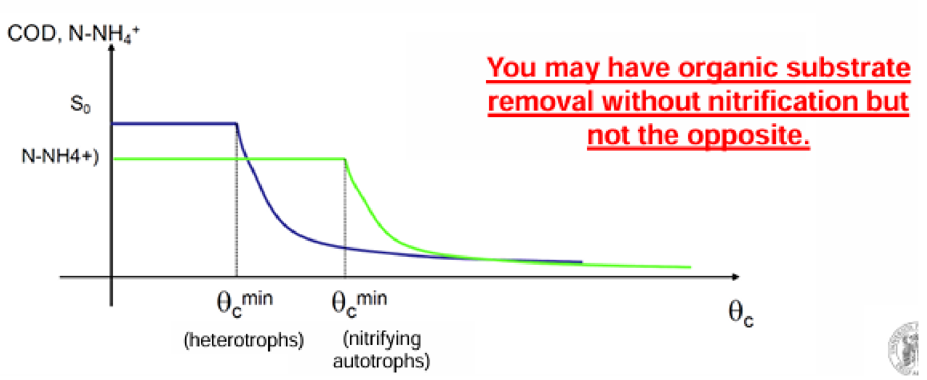


Figure 11 Minimum SRT for heterotrophs and nitrifying autotrophs

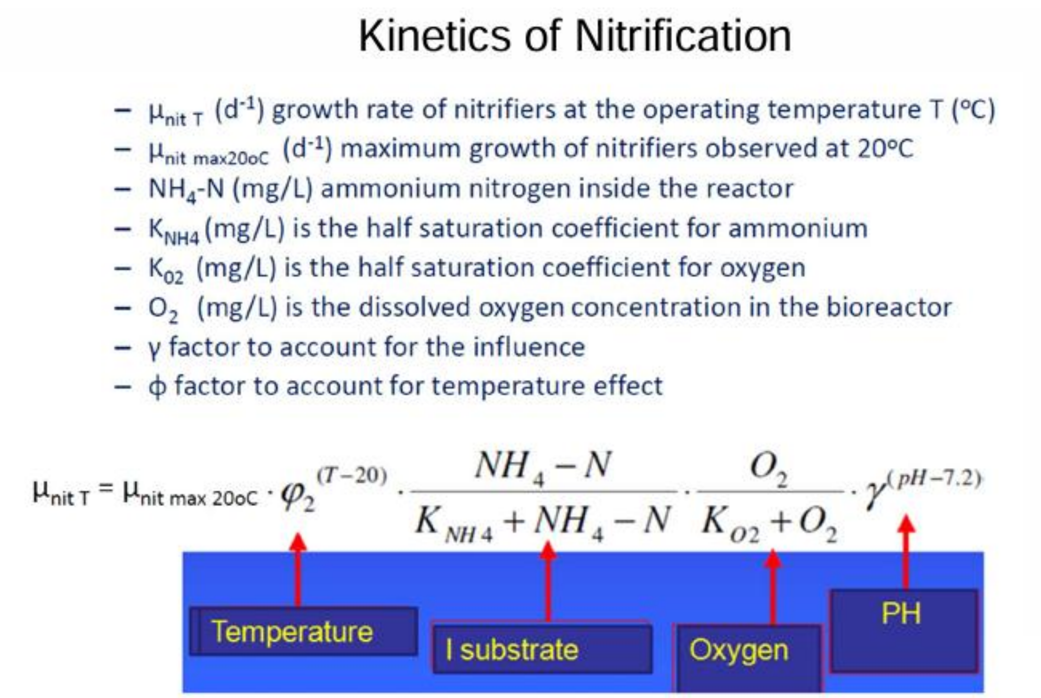
Comparison between heterotrophs and verifying autotrophs bacteria

This table is a summary of the main differences between heterotrophs and nitrifying bacteria. And the higher the ration between BOD/TKN, the lower the percentage of nitrifiers.

Parameter	Heterotrophic Bacteria	Nitrifying Bacteria	Unit
Dissolved Oxygen (DO)	> 0.5	> 1.5	mg/L
Temperature (T)	> 5	> 13	°C
pH Range	5.5 – 9	6.5 – 8.5	–
Sludge Retention Time (SRT)	1–2	> 4	days (d)

Table 18. heterotrophic and nitrifying bacteria

In nitrification kinetic, how fast nitrifying bacteria can grow depends on a few key things. Their growth speed is based on their maximum potential, but it's limited by how much oxygen (DO) and ammonia are available in the tank. Temperature and pH also affect this rate, so correction factors are used to adjust for those conditions.



Kinetic of nitrogen

Steps to Design a tank for BOD removal and Nitrification

Designing a tank system that removes both BOD and ammonia, the key factor is nitrification, which is slower than BOD removal. So, the nitrification kinetics process determines the size and behaviour of the aeration tank

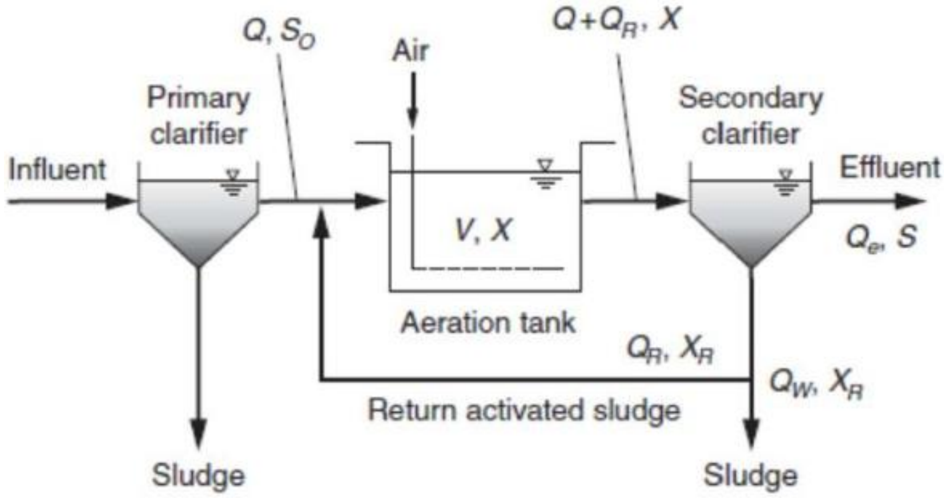


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Figure 12. Aeration tank for BOD and Nitrogen removal

The following steps is considered to design a reactor:

1. Collect data on the incoming wastewater characterization data.
2. Identify the target effluent levels for ammonium (NH_4-N), suspended solids (TSS), and BOD.
3. Choose a safety factor for nitrification SRT (usually between 1.3 and 2.0).

4. Set a minimum dissolved oxygen (DO) level for the aeration basin liquor. At least 2.0 mg/L is needed for effective nitrification.

5. Determine the nitrification maximum specific growth rate μ_{max} and determine k_{dn}, based on aeration basin temperature and DO concentration.

6. Determine the net specific growth rate and SRT at this growth rate, to meet the effluent NH4 N concentration. The growth rate of nitrifying bacteria is given by the maximum growth rate that multiplies the limiting factors of the concentration of ammonia and the DO concentration. Mu,max, KNH4 ad kdn must be corrected thanks to Arrhenius for the design temperature of

$$Mu = mu, max * \frac{NH4}{NH4 + KNH4} * \frac{DO}{DO + KDO} - kdn$$

12°C.

7. Calculate the design SRT by applying the safety factor from Step 6. Since SRT is inversely proportional to the net growth rate, it is calculated as:

$$SRT = \frac{1}{mu} * FS$$

8. Obtain the biomass production.

$$Px, bio = \frac{QY(So - S)}{1 + kd\,SRT} + \frac{fd(kd)QY(So - S)SRT}{1 + kd\,SRT} + \frac{QNOxYn}{1 + kdnSRT}$$

9. Perform a nitrogen balance to determine NOx, the concentration of NH4-N oxidized.

$$NOx = TKN - Ne - 0{,}12\frac{Px, bio}{Q}$$

10. Calculate the VSS mass and TSS mass for the aeration basin.

$$Px, vss = Px, bio + Q * (nbVSS)$$

$$Px, tss = \frac{Px, bio}{0{,}85} + nbVSS * Q + Q(TSS0 - VSS0)$$

11. Select a design MLSS concentration and determine the aeration basin volume and hydraulic residence time.

$$V = \frac{Px, tss * SRT}{Xtss} \quad HRT = \frac{V}{Q}$$

12. Determine the overall sludge production and observed yield.

$$Yobs, tss = \frac{Px,tss}{Q(S0-S)}$$

13. Calculate the oxygen demand

$$RO2 = Q(So - S) - 1{,}42Px, bio + 4.33QNOx$$

14. Design the aeration oxygen transfer system (in the following)

15. Determine if alkalinity addition is needed.

16. Design the secondary clarifier.

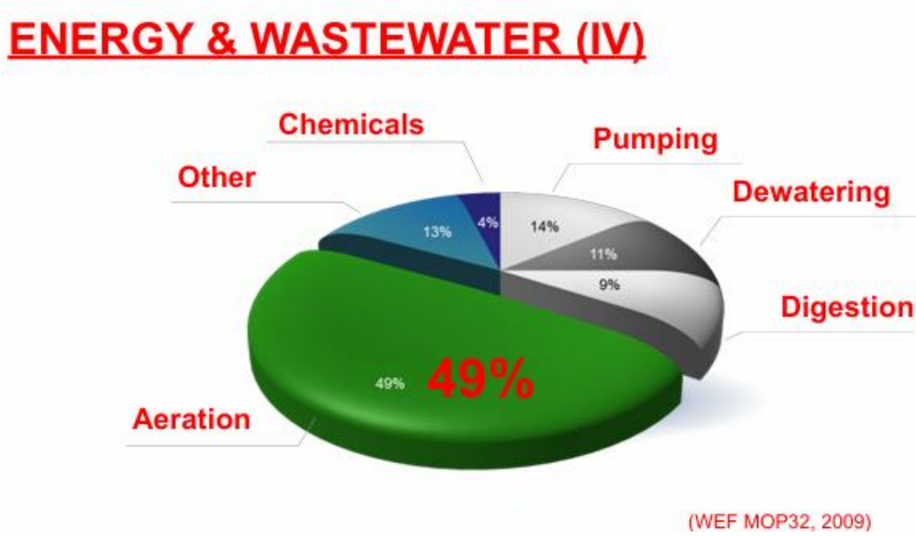
17. Summarize the final effluent quality.

18. Prepare a design summary table.

Aeration Design

Aeration tank is a part of the wastewater treatment process where air is added into water. This extra oxygen helps bacteria break down the waste in the water more quickly. As a result, harmful substances like BOD and suspended solids are reduced. This helps make the water safe to release into rivers or lakes, preventing problems like pollution, algae growth, and low oxygen levels in nature.

Generally, about 50% of the energy required in a WWTP is due to aeration systems.



The first aim of the aeration tank is to convert BOD to suspended solids (SS). In the aeration tank the mixed liquor is aerated. By aerating the mixed liquor, the aerobic processes will be stimulated, the growth rate of bacteria will be much faster. Required O2 was calculated for both BOD removal and nitrification, thanks to the following formula:

$$RO2 = Q(So - S) - 1{,}42Px, bio + 4.33QNOx$$

In the aeration tank the smaller the size of the bubbles, the higher is the oxygen transfer efficiency.

3.7.3. Denitrification

The denitrification is a heterotrophic process that uses organic carbon, here nitrate or nitrite act as electron acceptors, and the end product is inert nitrogen gas.

The conditions required for denitrification include:

4- Low or no dissolved oxygen in the mixed liquor (DO < 0.3 mg/L), anoxic conditions
5- Availability of nitrate or nitrite (as electron acceptors)
6- Presence of organic matter (as the electron donor)

Regarding kinetics, the growth rate of denitrifying bacteria equals the maximum growth rate, adjusted by an inhibiting factor (DO concentration) and limiting factors (nitrate and organic matter concentrations). The process is also affected by temperature, following the Arrhenius equation.

3.7.4. Anoxic Tank Design for Denitrification

1. Active biomass calculation

The design process for an anoxic tank used in denitrification begins with calculating the amount of active biomass in the reactor. This is done using the following formula:

$$X_b = \frac{\mathrm{SRT}}{\mathrm{HRT}} \cdot \frac{Y(S_o - S)}{1 + k_d \cdot \mathrm{SRT}}$$

Where:

- X_b is the biomass concentration,
- SRT is the solids retention time,
- HRT is the hydraulic retention time,
- Y is the biomass yield,
- S0 is the influent substrate concentration,
- S is the effluent substrate concentration,
- k_d is the decay coefficient.

2. Internal Recycle calculation

Next, the internal recycle flow is calculated to determine how much nitrate is returned from the aerobic tank to the anoxic zone. This is done using the equation:

$$IR = \frac{NOx}{Ne} - 1 - R$$

Where:

- NO_x is the amount of nitrate produced in the aerobic tank,
- Ne is the effluent NO3,
- R is the return sludge ratio (typically assumed to be 0.5).

3. Nitrate Fed to the Anoxic Reactor

Using this, the amount of nitrate fed into the anoxic reactor is calculated as:

$$NO_{3,\mathrm{feed}} = Q_{\mathrm{anoxic}} \cdot N_e$$

Where:

- Q_anoxic is the total flow entering the anoxic tank, calculated as:

Qanoxic=IR·Q+R·Q
Q is the influent flow rate

Once an initial guess for the HRT is made, it can be used to determine the required volume of the anoxic tank.

4. **Specific Denitrification Rate (SDNR)**

A key design parameter here is the **Specific Denitrification Rate (SDNR)**, which represents the amount of MLSS needed to identify total grams of NNO3 [kgNNO3 / kgMLSS / d].

Where KgNNO3 is the mass of nitrogen (N) in the form of Nitrate (NO3)

5. **Final Anoxic Volume Calculation**

Using the SDNR, the **volume of the anoxic tank** can be determined with the following relationship:

$$V_{den} = \frac{N_{den}}{SDNR \cdot X} \quad [m^3]$$

Where:

- **Nden** is the nitrogen load to be denitrified
- **X** is the concentration of solid.

SDNR is mainly influenced by: the temperature in the reactor, the quality of the organic carbon, F/M, the internal recycle, the temperature.

3.7.5. **Phosphorus Removal**

Controlling phosphorus in municipal and industrial wastewater is essential for protecting surface water from eutrophication. Phosphorus plays a major role in overgrowth of algae in lakes and rivers, which can lead to a variety of water quality problems. These include higher water treatment costs, decreased recreational and ecological value of water bodies, harm to livestock, and in some cases, toxic algae that pose a risk to drinking water supplies.

Phosphorus is most commonly removed through chemical precipitation. While effective, this method is expensive and significantly increases the volume of sludge—by around 40%. As a result, biological phosphorus removal (BPR) is becoming a popular alternative.

Municipal wastewater typically contains between 5 and 20 mg/L of total phosphorus. Of this, 1 to 5 mg/L is organic, while the remainder is inorganic. About half is present as orthophosphate, 40% as polyphosphate, and around 10% as organic phosphate. Since phosphorus is a key ingredient in synthetic detergents, individual household contributions are significant, averaging about 2.18 grams per person per day, though this can vary.

The most common phosphorus compounds found in wastewater are:

1. **Orthophosphates**, which can be readily taken up by microorganisms.
2. **Polyphosphates**, which are made up of multiple phosphorus atoms and other elements like oxygen and hydrogen. These slowly break down into orthophosphates through hydrolysis.

Secondary treatment in wastewater plants typically only removes about 1–2 mg/L of phosphorus. This means that large amounts often remain in the treated effluent, contributing to eutrophication in downstream waters. Regulations now require phosphorus levels in discharged water to be much lower, typically between 0.1 and 1 mg/L, and in some cases, as low as 0.05 mg/L.

3.7.6. **Chemical Phosphorus Removal**

Chemical phosphorus removal involves adding a reagent—like aluminum salts, iron salts, or lime—that reacts with orthophosphates to form a solid, which can then be separated from the water. There are three main approaches:

Pre precipitation: The chemical is added before biological treatment. This allows early solid-liquid separation but has limitations: it may not effectively target all forms of phosphorus, other compounds may also precipitate, and it can reduce the phosphorus needed for biological processes.

Co precipitation: The most commonly used method. The co precipitation process is particularly suitable for active sludge plants, where the chemicals are fed directly in the aeration tank or before it.

Post precipitation: After secondary clarifier, expects higher investment costs than previous choices (due to the installation of an additional sedimentation tank), it is used when high performance is desired. Its possible disadvantage is that no infrastructure available for solid-liquid separation and need for another clarifier is necessary to separate solids from liquid.

3.7.7. Biological phosphorus Removal

In the biological there are two different ways to remove phosphorus:

1- **For cell synthesis**: Phosphorus removal, related to the normal metabolic needs of heterotrophic microorganisms, depends on how much new biomass is produced. This biomass typically has the composition $C_5H_7NO_2P_{0.15}$, meaning it naturally contains some phosphorus. The amount of phosphorus that can be stored this way is about 1.5–2% of the dry weight of the biological sludge, and it depends on the availability of biodegradable organic carbon.

2- Luxury uptake:

It is the intracellular accumulation of polyphosphate, with values often much higher than what microorganisms need for normal metabolism—up to 10% of the sludge's dry weight. The microorganisms responsible for this are called PAOs (phosphorus-accumulating organisms) or DPAOs (denitrifying PAOs).

The first phase is the anaerobic phase, where PAOs(Phosphorus-Accumulating Organism) use VFA (Volatile Fatty Acids)to produce an organic carbon source called PHA(Polyhydroxyalkanoates), which is then stored inside the cell. To make PHA, the cell needs chemical energy (ATP- Adenosine Triphosphate). This energy comes from breaking down polyphosphate (polyp). When polyp is broken down, it leads to the release of orthophosphates into the surrounding liquid.

For designing the tank for phosphorus removal, it's important to take all of the following steps into account:

1- Determine the amount of rbCOD available for enhanced biological phosphorus removal:

a. rbCOD in the influent
b. rbCOD consumed by nitrate (used in denitrification)
c. rbCOD remaining (available) for phosphorus removal

The available rbCOD for P removal is calculated as:

rbCOD for P removal = rbCODin – rbCOD denitro

Where:

rbCOD denitro = NO3 to anaerobic×(rbCOD/NO3-N)

The NO_3 going to the anaerobic zone is determined from a mass balance:

NO3in×Qr+NO3RAS×Qr = (Q+Qr) × NO3 to anaerobic

2- Determine phosphorus removal by Enhanced Biological Phosphorus Removal (EBPR):

P removed = P used biologically+P for cell synthesis

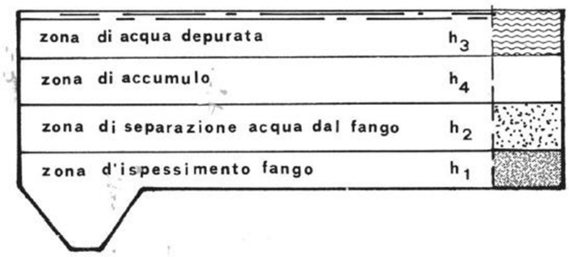
Steps:

a. Determine the VFA/rbCOD ratio in the influent.
b. Determine the rbCOD to P removal ratio.
c. Calculate P removal by EBPR.

P used biologically = rbCOD for P removal / rbCODfor / P removal ratio
3- Determine P removal by other heterotrophic bacteria for synthesis.
4- Calculate Effluent P.
5- Determine P content of waste sludge.

Secondary Clarifier:

The final stage of wastewater treatment involves separating solids from liquids, resulting in a clarified effluent and a concentrated solids stream. This is typically done through sedimentation in a unit called the secondary clarifier. This step is crucial for meeting treatment efficiency and discharge standards. Beyond clarification, this phase also thickens the sludge that will be recirculated or removed.



$$h_1(m) = \frac{SVI \cdot C_a}{1000} \qquad h_2(m) = 0{,}8 - 1 \qquad h_3(m) \geq 0{,}5$$

$$h_4(m) = \frac{SVI \cdot \Delta C_a \cdot V_{ossidazione}}{500 \cdot S}$$

C_a = conc. of aerated mixed liquor
ΔC_a = variation of aerated mixed liquor in wet weather conditions
S = sedimentation tank surface

The image above describes the 4 vertical zones inside a secondary clarifier in a wastewater treatment plant, according to

1- **Zona di acqua depurata (Clarified water zone) h3**

The top layer of the clarifier, containing the cleaned effluent that overflows and exits the tank. Acts as a buffer zone where treated water is collected before discharge.

The minimum height $h3 \geq 0.5$ m

2- **Zona di accumulo (Sludge accumulation zone) h4**

The zone just below the clarified water, where flocculated particles accumulate and begin to settle. Supports zone settling and compression as sludge concentration increases.

$$h_4(m) = \frac{SVI \cdot \Delta C_a \cdot V_{ossidazione}}{500 \cdot S}$$

3- **Zona di separazione acqua dal fango (Sludge-water separation zone)h_2**

The intermediate transition layer where the actual separation of water and sludge occurs. Allows particles to settle without being re-entrained into the effluent.

Height h_2 = 0.8–1.0 m.

4- Zone dispessimento where settled (sludge thickening Zone)

The bottom zone where settled sludge is compacted by gravity. Concentrates sludge to be either recirculated (BAS) or wasted (WAS).

$$h_1(m) = \frac{SVI \cdot C_a}{1000}$$

Design Criteria For Secondary Clarifier In WWT

1- Surface Overflow Rate (SOR)

SOR = Q / A

Where:

Q = Influent flowrate (m^3/day)

A = Clarifier surface area (m^2)

SOR Represents the upward velocity of liquid in the clarifier. Determines whether particles settle or exit with the effluent. Typical surface overflow rates range from 16 to 33 m/d.

2- Sludge Loading Rate (SLR)

$$\text{SLR} = \frac{(Q+Q_R).MLSS\ (1\ kg/10^3 g)}{A}$$

SLR = Solid loading rate, (kg MLSS/m2.h)

Q= influent flowrate (m3/h)

QR= return activated sludge flowrate (m3/h)

A= Surface area of clarifier (m2)

Measures the solids applied per unit area, affecting sludge thickening capacity at the tank bottom. Typically, 4–6 kg/m^2·h.

3- Sludge Volume Index (SVI)

$$\text{SVI, (mL/g)} = \frac{Volume\ of\ settled\ sludge\ \left(\frac{mL}{L}\right) * 1\frac{kg}{10^3 g}}{MLSS\ in\ mL/g}$$

Evaluates sludge settleability and clarifier performance.

- 40 –100 mL/g is a Good settling and thickening.
- >150 mL/g is a Poor settling (e.g., sludge bulking from filamentous bacteria).

Sludge Line

In wastewater treatment plants, materials like **screenings, grit, scum, solids, and biosolids** are removed from the water. The solids and biosolids left behind are usually in liquid or semi-liquid form, containing 0.25% to 12% solids by weight, depending on the treatment process used. The term biosolids refers to treated organic solids that can be safely reused, for example through stabilization or composting. The word sludge is used for untreated solids before they meet the standards for beneficial use. You'll often see terms like primary sludge or waste activated sludge to describe specific types.

Among all the materials removed during treatment, solids and biosolids make up the largest volume and also present the most complex challenges for engineers, especially in handling, reuse, and disposal.

These challenges arise because:

1- They contain most of the substances that make raw wastewater smell bad.
2- Even after biological treatment, biosolids still contain organic matter that can decompose and produce odors.
3- Despite their volume, they are made up mostly of water, not solid material.

The principal methods used for solids processing are listed below:

Pumping, preliminary operation, thickening, stabilization, dewatering, heat drying, incineration, application of biosolids to land, conveyance and storage.

Thickening, conditioning, dewatering and drying are used primarily to remove moisture from solids. Digestion, composting and incineration are used primarily to treat or stabilize the organic material in the solids.

In general, the main aim of the sludge line is to:

1. Stabilize the organic matter

2. Reduce the quantity of water for the disposal of sludge

Sludge Pumping Station

For the sludge pumping station, it's important to achieve high pressure while managing a relatively low flow rate. Pumps that can handle thick sludge with a high solid content sometimes up to 60-70% are ideal. This is crucial since sludge treatment often faces varying conditions, like seasonal changes and fluctuating flow rates throughout the day.

Thickener

In wastewater treatment plants, a thickener plays a vital role in separating solids from liquids. Its main purpose is to increase the solids content in the wastewater, which reduces the volume of liquid that needs further treatment and disposal. This step is essential for treating wastewater both effectively and economically.

Key functions include:

Separating the solid and liquid parts of wastewater using gravity. The solids settle at the bottom of the tank, allowing the clearer water to move on for further treatment.

Reducing the overall volume of wastewater by concentrating the solids. This makes transporting and disposing of the waste less expensive and improves the efficiency of subsequent treatment processes.

Typically, primary sludge contains about 3% total solids (TS), while waste activated sludge (WAS) has around 0.75% TS. Because of this, primary sludge usually doesn't need thickening, whereas secondary sludge from the secondary clarifier does.

Anaerobic Digestion

Anaerobic digestion is a process used to **stabilize organic matter** in wastewater treatment. It takes place in the absence of oxygen and involves several types of bacteria. A key benefit of this process is the production of methane, which can be captured and used as a renewable energy source for heating or biofuel.

Anaerobic digestion is operating in a range of pH from **6.5 to 7.5** usually. This depends a lot on the composition of the substrate and the inoculum. As far as it concerns the temperature, mesophilic digestion systems are more tolerant to changes in environmental conditions and more stable than thermophilic systems. The optimal temperature range for mesophilic bacteria is between **25 and 40°C.**

Anaerobic digestion design

1) The first step is to find the sludge mass, which can calculate by this equation.

$$sludge\ mass\ (\frac{kg}{d}) = Qin * Xtss * E\%$$

2) Then the sludge volume is calculated as:

$$sludge\ volume\ (\frac{m3}{d}) = \frac{sludge\ mass}{specific\ gravity\ of\ sludge * (1 - moisture\ content)}$$

Where the moisture content of the primary sludge is 95% usually and the specific gravity is 1.02.

3) bCOD loading calculation.

$$bCOD\ loading = Qin * Xcod * E\%$$

4) volume of the reactor should be calculated.

V =$HRT * Q$ ($sludge\ volume$). Where the HRT is between 15-20 days

5) volume of the methane.
   $VCH4 = 0.4 * Q * (So - S) - 1.42 Px,bio$
   0.35 is the conversion factor in the production of methane at 35 celsius

$$Px, bio = \frac{Y * Q * (So - S)}{1 + kdSRT}$$

$$S = bCOD\ load * (1 - solids\ conversion)$$

6) Calculation of the reduction of volatile solids.
7) Estimation of digester heating requirements
   - Concrete digestion dimensions
   - Heat transfer coefficient
   - Temperature: air, earth next to the wall, incoming sludge, earth bellow floor.
   - Specific heat of sludge
   - Computation of the heat requirement for the sludge
   - Compute the area of the wall, floor and roof
   - Compute the heat loos
   - Compute the required heat-exchanger capacity
     $capacity = q\ digester + qwalls + qfloor + qroof$

Sludge dewatering

After anaerobic digestion, the remaining sludge still contains a large amount of water, which makes it heavy and costly to handle. Sludge dewatering is the process used to remove as much of this water as possible, reducing both the volume and weight of the sludge. This step is important for making the sludge easier and more economical to transport, store, or dispose of.

Biofilter

In wastewater treatment plants, especially those near residential areas, controlling odors is a major priority. While good operational practices can reduce smells, additional odor treatment is often necessary. Among the various methods available like chemical scrubbing or thermal oxidation biofiltration stands out as one of the most effective and cost-efficient solutions.

A biofilter works by using a bed of organic materials such as compost, bark, or soil to trap and biologically break down odorous compounds. Process air, after being cooled and humidified, is passed through this filter bed where naturally occurring bacteria consume the odor-causing substances and convert them into harmless byproducts like water vapor and carbon dioxide.

Annex 1- Design Calculation

Screening

Parameter	Unit	Value	Notes
Qave	m3/d	60000.00	Influent Data
Qmax	m3/d	120000.00	2* Qave
Qmax	m3/s	1.39	Conversion
Number of Tanks	-	2.00	Logical Assumption
Q	m3/s	0.69	For each Tank
Approach Velocity	m/s	0.75	From Table
Channel Area	m2	0.93	
Channel Width	m	1.00	Logical Assumption
Channel depth	m	0.93	
Bar Width	mm	15.00	From Table
Bar Spacing	mm	50.00	From Table
Nbars	-	15	
Nspaces	-	16	
Total opening area	m2	0.74	
Velocity through openings	m/s	1.88	
Angle assumption	Deg	0.87	From Table
Rack Height	m	1.47	Depth +0.25 m
Headloss hL	m	0.05000	<0.15 m from the table
Screenings removed	l/1000m3	4.00	From Table
Screenings removed	m3/d	240.00	
Freeboard	m	0.30	From metcalf & eddy

Grit Removal

Parameter	Unit	Value	Notes
Qave	m3/d	60000.00	Previous
Qmax	m3/d	120000.00	Previous
Qmax	m3/s	1.39	Previous
Number of Tanks	-	2.00	Logical Assumption
Q	m3/s	0.69	For each Tank
HRT	min	3.00	From Table
Total Volume V	m3	250.00	
Depth D	m	3.00	From Table
Width-depth Ratio	-	1.50	From Table
Width	m	4.50	
Length	m	18.52	
Length-Width Ratio	-	4.12	To reach Table values
Grit Collected	m3/1000m3	0.05	From Table
Grit Collected	m3/d	3.00	

Primary Sedimentation

Parameter	Unit	Value	Notes
Qave	m3/d	60000.00	Previous
Qmax	m3/d	120000.00	Previous
SOR	m3/m2.d	30.00	From Table
WLR	m3/m.d	250.00	From Table
Total Area A	m2	2000.00	
Total Diameter D	m	50.46	
Number Of Tanks	-	2.00	Selected to stay within limits
Single Tank diameter	m	35.68	
Tank Depth	m	3.00	From Table
Single Tank Volume	m3	2998.00	
Total Volume	m3	5997.00	
HRT at Average	h	2.40	
SOR Check at Peak	m3/m2.d	60.00	Compare with the Table limits
HRT at Peak	h	1.20	
BOD removal	%	35.00	From Graph
TSS Removal	%	58.00	From Graph

BOD + NH4 Removal

Inflow Characteristics	U.M.	
BOD	mg/L	350.00
BODs	mg/L	175.00
COD	mg/L	650.00
CODs	mg/L	286.00
RBCOD	mg/L	200.00
bCOD	mg/L	560.00
nbCOD	mg/L	90.00
nbsCODe	mg/L	6.00
nbpCOD	mg/L	84.00
TSS	mg/L	400.00
VSS	mg/L	342.86
iTSS	mg/L	57.14
VSSCOD (g	gCOD/gVSS	1.06
nbVSS	mg/L	79.12
TKN	mg/L	65.00
NH4-N	mg/L	50.00
TP	mg/L	12.00
Alkalinity (come CaCO3)	mg/L	200.00
Qin biologico(m3/d)	m3/d	60000.0
DESIGN DATA	u.m	
MLSS	mg/l	7601
OD	mgO2/l	2
T°process	°C	20
Kinetic coefficients		
Yh	gVSS / g bCOD/d	0.45
bh 20°	1/d	0.12
u MAX20°	gVSS/gVSS/d	6
Ks	mg/l	8
fd		0.15
umax AOB	1/d	0.9
bAOB		0.17
KNH4	mg/l	0.5
Yn	gVSS / g NOX	0.15
K 0,AOB	mg/l	0.5
bh T°	1/d	0.12
u max T°	gVSS/gVSS/d	6.00
μmax AOB, T°	1/d	0.900
bAOB,T°		0.170
u AOB	1/d	0.190
Average peak of nitrogen load		1.500
SRT teorico	d	5.3
SRT minimo	d	7.9
SRT di progetto	d	**15.0**
Px,bio,VSS di 1° tentativo	KgVSS/d	6987
S (COD)	mg/l	0.26
NOx ossidato	mgN/l	50.5
Px,bio,VSS	**KgVSS/d**	**6983**
Px,vss	KgVSS/d	11730
Px,Tss	KgTSS/d	16391
Kg MLSS in vasca	Kg	245866
Kg MLVSS in vasca	Kg	175953
MLVSS/MLSS		0.72
EFFLUENT BOD5		
BOD	**mg/l**	

BIOLOGICAL REACTOR AND OPERATIVE PARAMETERS DESIGN		
VOLUME	m3	32347
HRT	ore	12.94
MLVSS	mg/l	5440
F/M	Kg BOD/Kg MLVSS/d	0.119
Yobs,Tss	Kg TSS/ Kg BOD	0.781
Yobs,VSS	Kg VSS/ Kg BOD	0.559
BOD loading	Qso/V [kgBOD/m3d]	0.649
NLR loading	Qso/V [kgNH4/m3d]	0.093
AIR SUPPLY		
O2T	Kg O2/h	1571
SOTR	Kg O2/h	3468
Qair	Sm3/min	535
CONTROL OF ALKALINITY		
Alk to maintain pH 6,8-7	mgCaCO3/l	70
Alkalinity for the nitrification	mgCaCO3/l	361
alk=70mgL to guarantee ph=6.8-7	mgCaCO3/l	231
alk=70mgL to guaranteee ph=6.8-7	KgCaCO3/d	13846
NaHCO3 to be added	KgNaHCO3/d	23261
Qw	m3/d	1365.922

SECONDARY CLARIFIER DESIGN		
Xr	mg/l	12000
Recycle ratio		1.7
CIS Hydraulic areal load	m3/m2/d	13
Total Area	m2	4615
num lines		2
Area clarifier	m2	2307.7
diameter	m	54.2
Css to be verified(5-8Kg/m2/d)	KgMLSS/m2/h	11.2
AIR DIFFUSERS		
Water level	m	5
SOTE	%	35
Specific air for plate	Nm3/h/m2	5
Specific air for plate	Sm3/h/m2	5.25
area plate	m2	6117
Diffuser CSTR 1	%	33.3
Diffuser CSTR 2	%	33.3
Diffuser CSTR 3	%	33.3
Diffuser CSTR 1	m2	2037
Diffuser CSTR 2	m2	2037
Diffuser CSTR 3	m2	2037
Density CSTR 1 - verify	m2 diff/m2	300%
Density CSTR 2 - verify	m2 diff/m2	300%
Density CSTR 3 - verify	m2 diff/m2	300%

REACTOR GEOMETRY		
Area	m2	6469
Width	m	
Lenght	m	
Height	m	5
POWER SUPPLY		
SAE	kgO2/kWh	6
Power supply	kW	578.1

BOD + Denitrification

Inflow Characteristics	U.M.	
BOD	mg/L	350.00
sBOD	mg/L	175.00
COD	mg/L	650.00
sCOD	mg/L	286.00
RBCOD	mg/L	200.00
bCOD	mg/L	560.00
nbCOD	mg/L	90.00
nbsCODe	mg/L	6.00
nbpCOD	mg/L	84.00
NOx	mgN/L	50.53
Alkalinity (as $CaCO_3$)	mg/L	200.00

DESIGN DATA		
Qin biologico	m3/d	60,000.00
MLSS	mg/l	7,601.00
MLVSS	mg/l	5,439.63
OD	mgO2/l	2.00
T°process	°C	20.00
SRT aerobic	d	15.00
REACTOR VOLUME	m3	32,346.52
HRT	h	12.94
RECICLE RATIO		1.73
oxygen required OTR	kgO2/h	1,571.05
concentration of effluent N-NO3	mgN/l	6.00

Kinetic coefficients		
Yh	gVSS / g bCOD/d	0.45
$b_{h\ 20°}$	1/d	0.12
$u_{max20°}$	gVSS/gVSS/d	6.00
$b_{h\ t°}$	1/d	0.12
$u_{max\ T°}$	gVSS/gVSS/d	6.00
Ks	mg/l	8.00
fd		0.15
$U_{max\ AOB}$	1/d	0.90
b_{AOB}		0.17
K_{NH4}	mg/l	0.50
Yn	gVSS / g NOX	0.15
$K_{0,AOB}$	mg/l	0.50
$U_{max\ AOB,\ T°}$		0.90
$b_{AOB,T°}$		0.17
u_{AOB}	1/d	0.19

Biomass	mg/l	2,504.13
Qma/Qmn		5.69
Qin anoxic tank	m3/d	445,266.30
NOx influent	g/d	2,671,597.79

ANOXIC VOLUME		
% of anoxic/anoxic+oxic	%	30.00
HRT anoxic	h	3.88
HRT defined	h	4.27
HRT	d	0.18
VOLUME ANOX	**m3**	**10,674.35**
mixers for anoxic volume		
Mixing energy	kW/10^3m3	8.00
total power	kW	85.39
number of mixers	n.	3.00
single mixer power	kW	28.46
BIOLOGICAL REACTOR AND OPERATIVE PARAMETERS DESIGN		
F/M_b	gBOD/g/d	0.79
b_0		0.26
b1		0.16
$SDNR_b$	gN-NO3/gbiomass/d	0.22
SDNR(t°)	gN-NO3/gbiomass/d	0.22
SDNR adj	gN-NO3/gbiomass/d	0.21
$SDNR_{over}$	gN-NO3/gMLVSS/d	0.10
SDNRover	mgN-NO3/gMLVSS/h	4.07
NO3 reduced (with HRT =2,5)	gN-NO3/d	5,669,919.38
Check "denitrified" vs "to denitrify"		2,998,321.60

AIR SUPPLY		
Combined oxygen (RECOVERY)	Kg/d	7,640.77
	Kg/h	318.37
Required oxygen	Kg/h	1,252.68
Qair	Sm3/min	99.42

CONTROL OF ALKALINITY		
Alk to maintain pH 6,8-7	mgCaCO3/l	70.00
Alk used in nitrificat.	mgCaCO3/l	360.76
Alk produced in denitrific	mgCaCO3/l	158.96
Alk to be added	mgCaCO3/l	71.80
alk=70mgL to guaranteee ph=6.8-7	KgCaCO3/d	865.82
Saving of alk to be added	KgCaCO3/d	13,613.61

ANOXIC REACTOR		
Height	m	5.00
Anoxic area	m2	213.00
Width	m	80.10
Length	m	11.00

Phosphorus- Removal

INPUT		
Pin	mg/L	12.00
Pin	kg/d	942.00
COD	mg/L	650.00
rbCOD	mg/L	200.00
bCOD	mg/L	560.00
N-NH4	mg/L	50.00
N-NO3 Anaer	mg/L	4
acetate	mg/L	37.50
R		1.7
IR aerob		5.7
IR anox or R		1.7
Q anae	m3/d	30000
Q anae with recycle	m3/d	81837
rbCOD/NO3-N	grbCOD/gNO3-N	5.2
Y synthesis	gP/gVSS	0.02
PAO removal		
rbCODin	kg rbCOD/d	6000
NO3-Nin	kg NO3-N/d	207.35
rbCOD used by NO3-N	kg rbCOD/d	1078.21
rbCOD available	kg rbCOD/d	4922
VFA/rbCOD		0.19
rbCOD/P removal		15.1
rbCOD available	mg/L	164
P removal	mg/L	10.86
P removal	kg/d	325.946686
Synthesis removal		
Px,bio	kg VSS/d	6983
P removal by synthesis	gP/d	139659
P removal by synthesis	kgP/d	139.66

Total removal		
total P removal	kgP/d	465.61
P to the anoxic	kgP/d	360000.00
P effluent	kgP/d	360336.74
P effluent	mg/L	0.70
Px,TSS	kg TSS/d	16391.06
P in sludge	%	3%
Sizing		
HRT	h	0.5
V	m3	625
h	m	5
A	m2	125
total rbCOD consumpti	mg/l	200
ANAEROBIC SELECTOR		
Sludge load zone 1	gCOD/gMLSS d	5.051966846
Sludge load zone 2	gCOD/gMLSS d	5.051966846
Sludge load zone 3	gCOD/gMLSS d	2.525983423
real totale HRT	min	60
Total volume anaerobic	m3	625
one line	m3	
Volume zone 1	m3	156
Volume zona 2	m3	156
Volume zona 3	m3	313
thickening capacity of th	MLSSric/MLSSreac	1.6
MLSS anoxic selector	mg/L	7,601.00
Verify zone 1	gCOD/gMLSS d	5.1
Verify zone 2	gCOD/gMLSS d	5.1
Verify zone 3	gCOD/gMLSS d	2.5

DN After P Removal

Inflow Characteristics from anaer	U.M.	
BOD	mg/L	150.00
[redacted]		
COD	mg/L	450.00
rbCOD	mg/L	0.00
bCOD	mg/L	360.00
nbCOD	mg/L	90.00
nbsCODe	mg/L	6.00
nbpCOD	mg/L	84.00
NOx	mgN/L	50.53
Alkalinity (as CaCO3)	mg/L	200.00
DESIGN DATA		
Qin biologico from anaer	m3/d	30000
Qin biologico from influent	m3/d	30000

NEW INFLUENT		
Inflow Characteristics	U.M.	
BOD	mg/L	250
[redacted]		
COD	mg/L	550
RBCOD	mg/L	100
%rbCOD/COD	%	18%
bCOD	mg/L	460
nbCOD	mg/L	90
nbsCODe	mg/L	6
nbpCOD	mg/L	84
NOx	mgN/L	51
Alkalinity (as CaCO3)	mg/L	200

DESIGN DATA		
MLSS	mg/l	6000
MLVSS	mg/l	4514
OD	mgO2/l	2
T°process	°C	20
SRT aerobic	d	15
REACTOR VOLUME	m3	81069
HRT	h	21
RECICLE RATIO		1
oxygen required OTR	kgO2/h	2683
concentration of effluent N-NO3	mgN/l	6

Kinetic coefficients		
Yh	gVSS / g bCOD/d	0.45
$b_{h\ 20°}$	1/d	0.12
$u_{max20°}$	gVSS/gVSS/d	6
$b_{h\ t°}$	1/d	0.12
$u_{max\ T°}$	gVSS/gVSS/d	6.0
Ks	mg/l	8
fd		0.15
$u_{max\ AOB}$	1/d	0.9
b_{AOB}		0.17
K_{NH4}	mg/l	0.5
Yn	gVSS / g NOX	0.15
$K_{0,AOB}$	mg/l	0.5
$u_{max\ AOB,\ T°}$		0.90
$b_{AOB,T°}$		0.17
u_{AOB}	1/d	0.19

Biomass	mg/l	821
Qma/Qmn		6.42
Qin NOx anoxic tank	m3/d	445266
NOx influent	g/d	2671598

ANOXIC VOLUME		
% of anoxic/anoxic+oxic	%	30.00
HRT anoxic	h	6.21
HRT defined	h	6.83
HRT	d	0.285
VOLUME ANOX	**m3**	**17077**
mixers for anoxic volume		
Mixing energy	kW/10^3m3	8
total power	kW	137
number of mixers	n.	3
single mixer power	kW	46
BIOLOGICAL REACTOR AND OPERATIVE PARAMETERS DESIGN		
F/M_b	gBOD/g/d	1.07
b_0		0.26
b1		0.16
$SDNR_b$	gN-NO3/gbiomass/d	0.257
$SDNR_{12°}$	gN-NO3/gbiomass/d	0.26
SDNR adj	gN-NO3/gbiomass/d	0.243
$SDNR_{over}$	gN-NO3/gMLVSS/d	0.01
SDNRover	mgN-NO3/gMLVSS/h	0.28
NO3 reduced (with HRT =2,5)	gN-NO3/d	3404221
Check "denitrified" vs "to denitrify"		732624

AIR SUPPLY		
Combined oxygen (RECOVERY)	Kg/d	7641
	Kg/h	318.4
Required oxygen	Kg/h	2365
Qair	Sm3/min	417
no3 effluent		
CONTROL OF ALKALINITY		
Alk to maintain pH 6,8-7	mgCaCO3/l	70
Alk used in nitrificat.	mgCaCO3/l	360.8
Alk produced in denitrific	mgCaCO3/l	159.0
Alk to be added	mgCaCO3/l	71.8
alk=70mgL to guaranteee ph=6.8-7	KgCaCO3/d	4308.0
Saving of alk to be added	KgCaCO3/d	18952.6
ANOXIC REACTOR		
Height	m	5
Anoxic area	m2	3415
Width	m	30
Lenght	m	114

Anaerobic Digestion

WASTEWATER CHARACTERISTICS	U.M	VALUE
Q	m^3/d	60000
bCOD_inf	mg/L	861.54
SS_inf	mg/L	615.38
bCOD_1	mg/L	560.00
SS_1	mg/L	400.00
PARAMETRI DI PROGETTO		
Parameter	**U.M.**	**Value**
% Moisture	%	95.00%
Density	kg/L	1.02
E, solid conversion	-	0.7
T	°C	35
SRT	d	15
$\%CH_4$	%	65.00%
Costanti Cinetiche		
Parameter	**Unit**	**Value**
Y_anaerobic	gVSS/g bCOD	0.08
b_h	1/d	0.03
Sludge Production		
Parameter	**Unit**	**Value**
Sludge Mass	kg TSS/d	12923.077
Sludge Volume	m^3/d	253.3936652
TSS Concentration	mg/L	51000
AD Volume	m^3	3800.904977
Anaerobic Digestion		
Parameter	**Unit**	**Value**
bCOD Load	Kg bBOD/d	18092.308
Volumetric Load	Kg bBOD/m^3/d	4.76
S_0	gbBOD/m^3	301.5
S	gbBOD/m^3	90.5
Volumetric Load (VSS)	Kg VSS/m^3/d	3.35
Biogas Production		
Parameter	**Unit**	**Value**
Px	Kg VSS/d	698.7374005
Qch4 (35°C)	m^3/d	4668.96331
Qbiogas (35°C)	m^3/d	7183.020477

VSS Reduction		
Parameter	**U.M.**	**Value**
VSS untreated	%	86%
VSS digested sludge	%	50%
Volatile solids after DA	kgVSS/kgVSSi	0.142857143
Weight of digested sludge	kgTSS_slu/kgTSSi	0.285714286
TSS reduction	%	71%
VSS, red (mass balance)	%	83%
VSS, red (Van Kleeck eq)	%	83%
DIGESTER DIMENSIONS		
Parameter	**U.M.**	**Value**
V	m^3	3800.904977
D	m	10
Side depth	m	4
Mid depth	m	6.5
V'	m^3	477.7838827
Awalls	m^2	125.6637061
Afloor	m^2	87.81018414
Aroof	m^2	78.53981634
Msludge (wt basis)	kg/d	258461.5385
PARAMETRI DI PROGETTO (Heat Transfer)		
Parameter	**U.M.**	**Value**
Heat transfer walls	$W/m^2°C$	0.68
Heat transfer floor	$W/m^2°C$	2.85
Heat transfer roof	$W/m^2°C$	1.5
Tair	°C	5
Tearth	°C	7
Tdeep earth	°C	10
Tsludge	°C	20
Heat Requirements		
Parameter	**U.M.**	**Value**
Sludge	MJ/d	21710.76923
Walls	MJ/d	206.7238338
Floor	MJ/d	540.5594936
Roof	MJ/d	305.3628059
Total	MJ/d	**22763.41536**
	Kwh/d	**6323.170934**

Recovery from Biogas		
Parameter	**U.M.**	**Value**
Qch4 (25°C)	m^3/d	4517.373592
Kmols	kmol/d	184.8655096
Eproduced	Kcal/d	39376353.54
MJ/d	MJ/d	165380.6849
Electricity	MJ/d	57883.23971

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