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Sewage Treatment Plants: Occupational Safety Risks and Health Hazards

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Highlights:
- Sewage Treatment Plants
- Occupational Safety Risks and Health Hazard
- Risk Analysis

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- Occupational Health and Safety
- Risk Assesment
- Sewage Treatment Plant
- Hazard
- Risk

ABSTRACT:

Increasing population and urbanization cause water consumption and wastewater generation to increase. Developing water resources without proper treatment causes water levels to drop and water ecosystems to be damaged. Therefore, the operation and management of wastewater treatment plants is essential to prevent water leaks or significantly reduce pollution. As in every workplace, necessary occupational health and safety measures can be taken in wastewater treatment plants. During the operation, maintenance and repair of these plants, risk assessments should be carried out within the scope of occupational health and safety in order to eliminate or minimize the risks of occupational accidents and occupational diseases.

There are hazards that need to be taken into consideration at every stage of wastewater treatment plants. In this study, in order to examine the occupational health and safety activities at the Durugöl Wastewater Treatment Plant in Ordu province, the plant area was examined in detail using interview and observation methods and interviews were conducted with plant managers and personnel. As a result of the risk analysis of the plant, regulatory and preventive measures were suggested for the sections with the highest risk scores. Thus, as a result of the study;

1- The prevalence of occupational health and safety hazards among plant employees was evaluated,

2- The factors affecting the prevalence of occupational health and safety hazards were determined,

3- Suggestions were presented to the upper management on the development of guidelines to protect the safety of employees and prevent diseases.

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INTRODUCTION

Sewage treatment plants are a crucial component of the infrastructure in modern cities. Sewage treatment is a process designed to remove pollutants and improve the quality of sewage so that it can be safely returned to the water cycle. Depending on the characteristics of the sewage considered in the design, various processes are used to reduce the concentration of pollutants in the water. These treatment processes are carried out in sewage treatment plants, where they are implemented.

The processes used in wastewater treatment plants pose significant occupational health and safety risks to workers. Sewage treatment plants are considered high-risk workplaces, as employees often work at elevated heights and are exposed to hazardous working environments. According to the Communiqué on the List of Hazard Classes Regarding Occupational Health and Safety, published in the Official Gazette in 2013 (No. 28602), workplaces involved in sewage (such as the removal and treatment of sewage waste, operation of sewage systems, maintenance of sewage treatment plants, emptying and cleaning of septic tanks and pools, mobile toilet services, etc.) are classified as very dangerous. There is a risk of injury and death for sewage treatment plant employees due to exposure to operational hazards such as falls, being caught in equipment, electrical shocks, fires, explosions, and oxygen deficiency. Additionally, sewage treatment plants (WWTPs) consist of semi-enclosed ponds and tanks that house electrical equipment, such as pumps, screens, sludge skimmers, dryers, and conveyors, which are used during various stages of sewage treatment. Maintenance and repairs are frequently necessary to keep machinery and equipment operating efficiently. This often requires workers to dismantle machinery, enter tanks, and/or move heavy objects to remove sludge and rust. Workers in this sector are exposed to both hazardous and non-hazardous chemicals, as well as biological substances found in sewage and chemicals used during treatment. For these reasons, working in sewage treatment is considered dangerous, as it can often lead to fatalities, especially in confined spaces. Sewage treatment plant workers are also at risk of respiratory diseases (Cyprowski et al., 2015) and gastrointestinal problems (Jeggli et al., 2004). A variety of airborne bacteria have been detected in WWTPs (Bruni et al., 2020), which are considered a potential health risk for workers.

The causes of accidents or near misses in workplaces are primarily due to incomplete or incorrect risk analysis, employees failing to comply with existing safety protocols, and managers not paying sufficient attention to risk management. Risk management depends on the effectiveness of managers in reducing risks by implementing the established risk assessments, providing necessary safety training to employees, and fostering safety awareness.

The process of identifying, analyzing, assessing, and managing risks is a step-by-step procedure. In the Risk Assessment Regulation (Ministry of Labour and Social Security, 2012) established under Occupational health and safety law no. 6331 (Ministry of Labour and Social Security, 2012), the steps defining this process are listed as follows:

1. Identification of existing and potential hazards in the workplace, determining who will be exposed to the hazards and how, and assigning risk ratings based on probability and severity.
2. Control measures – controlling hazards and related risks by implementing appropriate measures.
3. Review of the risk assessment and control process.

Risk assessment is a proactive process aimed at eliminating or minimizing the risk of injury and illness to employees, as well as preventing damage to the workplace, equipment, and the environment (Uslu and Uslu, 2022). Identifying existing and potential hazards in the workplace is crucial for eliminating or controlling them. Risk rating is a method used to identify which hazards are most likely to lead to the most severe outcomes, and thus, which hazards should be addressed first. The short-term or long-term disruption of the functionality of a WWTP can have significant implications for both the population and the environment. Therefore, as with other human activities, it is essential to assess and manage the risks associated with the operation of WWTPs and the safety of facility employees.

Hazards Faced by Workers in Sewage Treatment Plants

Threats to the safety of workers in sewage treatment plants come from various sources and vary throughout the treatment process. The hazards faced by sewage treatment plant operators include chemical, physical, microbial, ergonomic, and psychosocial risks. Chemical and biological hazards arise from the processes used in sewage treatment, are inherent in sewage itself, or may result from industrial or illegal discharges of hazardous chemicals.

Chemical hazards

Various chemicals are used in coagulation, flocculation, disinfection, and sludge treatment processes. The choice of chemical is determined by the types and quantities of contaminants in the raw sewage. In general, chemicals used in coagulation and flocculation processes can cause skin irritation and chemical eye injuries due to direct contact. This is particularly true for solutions with a pH (acidity) lower than 3 or greater than 9. Disinfection of sewage is typically achieved using liquid or gaseous chlorine. Splashing chlorine into the eyes as a result of liquid chlorine use can also cause eye injuries. Ozone and ultraviolet light are also used to disinfect sewage. Chemical hazards in sewage treatment plants arise from the decomposition of organic matter, which produces hydrogen sulfide and methane, as well as from toxic waste disposed of in sewer lines. The primary route of exposure to these substances is inhalation, as sewage treatment processes are often conducted in numerous open tanks, which increase the concentration of toxic substances in the air (ILO, 2009).

Hydrogen sulfide is present in almost all sewage treatment plants. Also known as sewage gas, hydrogen sulfide has a distinctive, unpleasant odor often described as that of rotten eggs. However, the human nose quickly becomes accustomed to the smell. People exposed to hydrogen sulfide often lose their ability to perceive the odor (i.e., olfactory fatigue). Although its strong odor is easily identifiable, olfactory fatigue can occur at both high and persistently low concentrations. Therefore, the smell is not a reliable indicator of the presence of hydrogen sulfide. Furthermore, even if hydrogen sulfide is detected by olfaction, it is insufficient to evaluate the concentration in the surrounding air. Hydrogen sulfide prevents oxygen from being absorbed by tissue (Kara et. Al, 2018).

Methane is another gas produced as a result of the decomposition of organic matter. Methane, a simple asphyxiant, can explode if exposed to a spark or ignition source. The discharge of solvents, fuels, and other substances into sewage systems creates a hazardous environment for treatment plant workers due to the increased toxicity of the surroundings. When work is conducted indoors, employees must be equipped with respirators, as the oxygen levels in the environment will decrease and toxic gases will be released. Ventilation alone may not ensure that the concentration of toxic chemicals stays below the permissible limit (Dinçer and Erol, 2024).

The use of gaseous chlorine to decontaminate sewage at treatment plants is another serious chemical hazard. Even at low concentrations (ppm), gaseous chlorine is highly irritating to the alveoli in the lungs. Inhalation of high concentrations of chlorine causes inflammation of the alveoli and can lead to respiratory failure. When large quantities of chlorine (1 ton or more) are used in a sewage treatment plant, the danger extends not only to the plant workers but also to the surrounding community. Furthermore, facilities that use large amounts of chlorine are typically located in large cities with high population densities (Zaki et al., 2023).

Biological hazards

Biological processes break down the organic components of sewage. These processes can be aerobic (carried out in the presence of atmospheric or dissolved oxygen) or anaerobic (without free oxygen). Fats, carbohydrates (such as sugars and starches), proteins, and urine/fecal waste are broken down by animal and plant organisms that consume these substances. These organisms produce gases that are flammable, toxic, or can displace oxygen. These gases can accumulate to dangerous levels (Uslu & Uslu, 2021; Albatanony & El-Shafie, 2011; Lee et.al, 2007).

The source of danger to sewage treatment plant workers comes from microorganisms found in human and animal waste. The use of ventilation during the purification process can aerosolize these microorganisms, mixing them into the air. Additionally, workers who clean solid waste from the inlet channel are often exposed to microorganisms present in the material that splashes onto their skin and comes into contact with mucous membranes. The three main categories of microorganisms are fungi, bacteria, and viruses, which can cause both acute and chronic diseases. Acute symptoms, such as respiratory distress, abdominal pain, and diarrhea, have been reported in sewage treatment plant workers. Chronic diseases, such as asthma and allergic alveolitis, have been linked to microbial exposure during the treatment of domestic sewage in scientific studies (Khuder et al., 1998).

Sewage turbulence, intense flow rates, and aeration during the biological treatment of sewage are thought to promote the formation of bioaerosols and their release into the atmosphere of the sewage treatment plant (Crook et al., 1988). Exposure to various infections can occur through the following routes:

1. Hand-mouth contact during eating, drinking, or smoking, wiping the face with contaminated hands or gloves, and sweat on the face entering the mouth (most common);
2. The transmission of some organisms into the body through cuts, scratches, or penetrating injuries (e.g., from discarded hypodermic needles); and
3. Inhalation of dust, aerosols, or fog.

Respiratory symptoms are caused by exposure to endotoxins and airborne bacteria through bioaerosols (Zuskin et al., 1990).

An increased risk of stomach cancer among sewage workers has been described in several studies. In the past decade, *Helicobacter pylori* bacteria have emerged as a major risk factor for gastric cancer and are now recognized as a class 1 carcinogen by the International Agency for Research on Cancer (Friis et al., 1996). Apart from these commonly studied infections, several other infections, such as intestinal parasitic infections, gastroenteritis, and Pontiac fever, have also been identified among sewage workers. Brautbar and Navizadeh (1999) provided a case report suggesting that sewer workers may be at an increased risk of contracting hepatitis C.

In studies conducted to examine the respiratory functions of sewage treatment plant workers, it was determined that respiratory symptoms are common among this group of workers (Thorn et al., 2002). Other studies (Ambekar et al., 2004) identified leptospirosis, hepatitis, and *Helicobacter pylori* infection as common among the group of workers they examined. Rodents are often abundant in underground sewers and are carriers of *Leptospira sp.*. The urine of rodents and other animals in that area is likely to reach the sewers. Since *Leptospira* sp. is excreted in the urine of infected animals, it has been determined that sewage treatment plant workers are at potential risk of leptospirosis (Tirink & Özkoç, 2021; Tiwari,2008).

Ergonomic hazards

Musculoskeletal disorders caused by lifting heavy loads or improper use of equipment—such as the transportation of sacks of chemicals used in sewage treatment plants and inappropriate body postures during equipment maintenance/repair—are known as ergonomic risks. To completely eliminate ergonomic risk factors, it is necessary to modify the tools, equipment, work design, or work area. This is referred to as "using engineering controls." It is important to redesign workspaces in a way that eliminates reaching, bending, or other inappropriate postures. Mechanical cranes should be provided for the purpose of transporting and lifting materials (Thatcher et al., 2022).

Physical hazards

Physical hazards include confined spaces, accidental energization of machinery, noise from pumps, trips, and falls. Encountering physical hazards can have sudden, irreversible, serious, or even fatal consequences. Equipment such as mixing devices, sludge skimmers, pumps, and mechanical machinery used in various processes at sewage treatment plants can cause disabling injuries or fatalities if accidentally operated during maintenance or repair. One of the most common and serious hazards faced by sewage treatment plant workers is confined spaces—areas with limited entry and exit, not designed for permanent human habitation, and lacking adequate ventilation. Confined spaces are considered dangerous because they are associated with a lack of oxygen, the presence of toxic chemicals, or a suffocating environment created by substances such as water (Huang et.al.,2021).

A decrease in oxygen levels occurs when oxygen is displaced by gases such as methane or hydrogen sulfide, due to the oxygen demand required for the decay of organic material in sewage, or from the retention of oxygen molecules during the rusting of certain structures in a confined space. To control hazardous ambient air caused by low oxygen levels (below 19.5%) and toxic chemical gases in confined spaces, ventilation should be achieved mechanically using flexible pipe channels (Brophy, 1991).

Raw sewage or sludge is transported by large machinery within the sewage treatment plant. In the event of a possible malfunction in these machines, the energy supply must be completely shut off. Only the person performing the repair should have the key to re-energize the machines and must ensure that no other employee can accidentally restore power to the system. Dismemberment, mutilation of body parts, or even death can occur due to an inadequate lockout/tagout program. Control of hazardous energy involves more than simply applying a lock and/or label to a power switch; all residual energy must be isolated or grounded (Republic of Turkey, Ministry of Industry and Trade, 2009, p. 10).

Sewage treatment plants contain large tanks and pools. Workers may need to work on these tanks or walk past pools with a drop height of 2.5-3 meters when the water is drained. In addition to adequate environmental protection (e.g., guardrails) and personal protection (e.g., seat belts), workers should receive proper safety training (Özkoç et al., 2023).

Some of the physical hazards that sewage workers may be exposed to are summarized as follows (Cluster B, 2010):

- Falling into ditches, sewer shafts, and dry wells
- Excessive noise from mechanical equipment, traffic, and process flows
- Exposure to UV radiation
- Exposure to adverse weather conditions
- Slips due to rough and slippery surfaces
- Being caught in or struck by moving machinery
- Drowning

• Cuts and abrasions caused by sharp objects in the sewer system/sewage

• Being caught in or struck by moving machinery (duplicate hazard, removed from the list)

The Ministry of Environment and Urbanization, General Directorate of Environmental Management (2014) lists the measures that can be taken in the wells and closed environments in the facility as follows:

1. The coarse debris from the sewage system is retained by a grate located at the bottom of the well. To ensure employee safety while cleaning this grate without entering the well, it is crucial to install a mechanism that can lift the grate for cleaning and lower it back into the well once the cleaning is completed.

2. The presence of ventilation systems and dangerous gases in enclosed spaces and wells within the facility should be assessed. It is recommended to use forced ventilation to ensure proper air circulation (OSHA, 2003).

3. Detailed gas measurements should be conducted in the facility, with specific points for measurement clearly defined. For this purpose, detectors should be available at the workplace. If the concentration of harmful gases exceeds permissible levels, entry into the area should be prohibited until the concentration decreases. The oxygen concentration in the environment should also be monitored. Additionally, maintenance and calibration of the measurement devices should be performed periodically (Ahmed et al., 2021).

4. In areas where dangerous gases (e.g., CH_4, H_2S, CO_2) are present, energy sources should be cut off. Non-explosion-proof (non-EX-proof) devices, such as flashlights and open-flame lamps, should not be used. Instead, safety lamps and/or explosion-proof miner lamps should be used (Republic of Turkey, Ministry of Industry and Trade, 2009, p. 10).

5. Employees should carry air-fed respirators when entering enclosed spaces.

6. Facility employees should be trained on the hazards they may encounter, their potential effects, and the occupational safety procedures and first aid protocols to follow during work. The behavior of trained employees should be continually monitored during operations. Furthermore, warning signs and safety labels should be placed in the work environment (Dejan et. al, 2018).

7. Emergency action plans should be prepared for the facility, and emergency response and rescue teams should be established. Employees should be informed about the composition of these teams. In case of an accident, the rescue operation should follow the established plan, and rescue drills (e.g., for poisoning) should be conducted periodically. Cooperation with relevant organizations should be ensured, and facility employees must be well-prepared (Albatanony & El-Shafie, 2011).

8. There is a risk of infectious diseases in areas with contaminated water, such as sewage systems, pumping stations, and treatment plants. Preventive health services, including vaccinations and training, are essential to prevent illnesses, particularly those caused by viruses like hepatitis. Maintaining hygiene conditions in the work environment is also critical (CDC, 2024).

9. In workplaces with hazardous gases, such as sewage systems, pumping stations, and treatment plants, it is recommended that at least two employees with first aid knowledge accompany any worker entering the hazardous area for maintenance or repair services (OSHA, 2003).

10. The stairs in pumping station shafts should be designed to allow for easy removal of injured employees in case of an accident.

11. Employees entering dangerous areas should be equipped with seat belts and ropes. In case of an emergency, they can be pulled up using a crane or pulley system (Ahmed et al., 2021).

MATERIALS AND METHODS

Inspections on Occupational Health and Safety at Ordu Province Sewage Treatment Plant

The Durugöl Sewage Treatment Plant in Ordu, which was selected as the study area, was evaluated in terms of occupational health and safety. The facility was constructed on a 23,000 m² area. The treatment plant consists of physical treatment, biological treatment, and sludge drying units. It has the capacity to treat all the sewage from the Altınordu district, including its villages. The facility is designed based on physical and biological treatment processes and operates in two stages.

At Tier 1 (2025): To serve a population of 213.000 (34000 m^3 flow)

At Tier 2 (2045): To serve a population of 287.000 (43000 m^3 flow)

Figure 1. Bird's eye view of Durugöl Sewage Treatment Plant

Within the scope of the study, on-site observations were conducted at the Ordu Province Metropolitan Municipality Sewage Treatment Plant, shown in Figure 1. According to the observations and information obtained, it was found that the facility employees receive preventive vaccinations against infectious diseases monitored by the workplace physician, that employees use personal protective equipment such as helmets, gloves, masks, safety shoes, and work clothes, and that hygiene certificates are provided following the training sessions.

For pedestrian and traffic safety, the working environment is equipped with lanes, barriers, lighting, traffic signs, and information signs. In addition to occupational health and safety training, teams are established within the framework of emergency action plans, and personnel receive training in first aid, fire protection, and evacuation (Figures 2 and 3). Employees are employed both as permanent staff and through contracted companies. The workplace physician divides employee health checks into two groups and conducts them annually (Figure 4). Following these examinations, high-risk groups are identified, and employees undergo necessary tests, vaccinations, and treatments. Inspections are conducted three days a week in the districts by the Occupational Safety Specialist and workplace physician. Before each drill, facility employees are informed through presentations and explanations, and then the drill is carried out annually by the Metropolitan Municipality Fire Brigade Department (Türkmen, 2019).

The OHS Board meets once a month at the facility to evaluate the overall occupational safety situation. Additionally, since the facility is classified as a very dangerous workplace, the "Risk Assessment" is periodically updated every two years. An A-class certified occupational safety specialist is officially employed full-time at the facility. As of January 1, 2019, a disciplinary penalty schedule for non-compliance with occupational safety rules has been implemented at the facility.

Figure 2. Use of personal protective equipment and basic OHS training (Türkmen, 2019)

Figure 3. Fire drill with plant employees (Türkmen, 2019)

Figure 4. Routine health checks for facility employees (Türkmen, 2019)

In case of technical issues related to equipment repair and maintenance, technical experts from the Mechanical and Electrical Branch Directorate are consulted. Workplace environment measurements, including lighting, ventilation, noise, vibration, temperature, humidity, dust, and toxic factors, are conducted once a year.

The hazards considered during the risk analysis at the facility are listed below:

1. Methane, hydrogen sulfide, carbon dioxide, and ammonia gases that occur in confined spaces at all stages of treatment, as well as chemicals used for flocculation of sludge in the sludge dewatering section, pose a risk if employees are exposed.

2. Bacteria, viruses, and microorganisms in sewage, waste mixed with sewage, and activated sludge are biological risk factors for employees in case of exposure.

3. Noise from pumping stations, turbo ventilators in the ventilation room, separators and dryers in the sludge dewatering and drying section, dust encountered in the sludge dewatering and drying section, and the effects of hot and cold weather conditions due to working outdoors in many parts of the facility have been identified as physical risks to which employees may be exposed.

In order to determine the risks at the facility in terms of occupational health and safety, the Fine-Kinney method was used to analyze both current and potential risks. This method provides more reliable results than matrix methods because it includes the probability of the hazardous event occurring, the frequency of exposure, and the potential consequences (severity). As demonstrated by Kinney and Wiruth (1976), it is recommended to calculate current and potential risk values using the tables below (Tables 1, 2, 3, and 4).

The probability of occurrence of the identified hazards is determined according to the probability table below. A value of 0.2 is considered practically impossible, while a value of 10 indicates a very high likelihood. Intermediate values are assigned to states between these two reference points. For example, an event described as "quite possible" is assigned a probability value of 6, and a rare but still possible event is assigned a value of 3 (Table 1).

Table 1. Probability values

Value	Likelihood
0,2	Practically impossible
0.5	Improbable
1	Only remotely possible
3	Occasional
6	Probable
10	Expected (Frequent)

The frequency value, which represents the frequency of exposure to the hazard over time, ranges from 0.5 (once a year or less frequently) to 10 (constantly or more than once per hour). Scoring is done by selecting one of the six categories provided within this range (Table 2).

Table 2. Frequency rating

Frequency	Value
0,5	Very rare (yearly)
1	Rare (a few per year)
2	Unusual (monthly)
3	Occasional (weekly)
6	Frequent (daily)
10	Continuous

If the hazard occurs, the estimated damage it will cause is expected to be severe. A score is assigned between 1, representing a minor incident, and 100, which corresponds to multiple fatalities and major environmental disasters. The severity table is provided below (Table 3).

Table 3. Severity rating

Value	Severity
1	Noticeable (minor first aid accident)
3	Important (disability)
7	Serious (serious injury)
15	Very serious (fatality)
40	Disaster (few fatalities)
100	Catastrophe (many fatalities)

The risk value is obtained by multiplying the Probability, Frequency, and Severity components. Actions are implemented based on the risk values obtained, as shown in Table 4 below.

Table 4. Risk assessment result

No	Value	Risk	Action
1	$R<20$	Acceptable Risk	Precaution is not a priority (Urgent measures may not be required)
2	$20 \leq R<70$	Possible Risk	It should be implemented under supervision (included in an action plan).
3	$70 \leq R<200$	Important Risk	It should be improved in the long term (within a year).
4	$200 \leq R<400$	High Risk	It should be improved in the short term (within a few months).
5	$R \geq 400$	Very High Risk	Consider discontinuing operation

RESULTS AND DISCUSSION

When deciding on control measures after risk calculation, the following hierarchy should be followed: elimination of the hazard, substitution, control and isolation, engineering controls, administrative controls, and finally, the use of personal protective equipment. In this study, using the Fine-Kinney method, the risk score (R) was calculated by multiplying three risk factors—Frequency (F), Probability (O), and Severity (S)—for the activities carried out at the examined facility. The results are presented in the table below (Table 5).

Table 5. Significant, high and unacceptable risks of the facility

No	Activity	Danger Source / Hazard	Detected Risk	Affected People	P	F	S	Risk Score	Risk Level
1	Coarse wastewater treatment grill	Failure to periodically check equipment	Injury; Death	Facility employees	3	1	40	120	SIGNIFICANT RISK
2	Pools	No protection around passageways	Fall, injury, death	Facility employees	3	1	40	120	SIGNIFICANT RISK
3	Pools	Bad odor	Headache, lung diseases due to airborne bacteria, fatigue, irritability	Facility employees	3	3	40	360	HIGH RISK
4	Facility Entrances	Lack of security	Unauthorized access to the facility	Employees, third parties	3	2	40	240	HIGH RISK
5	Entire facility	Bare-hand contact	Illness due to infection	Facility employees	6	3	15	270	HIGH RISK
6	Entire facility	Lack of precautions during maintenance	Injury; Death	Maintenance team	3	3	40	360	HIGH RISK
7	Confined spaces	Poisonous gases	Poisoning, Death	Facility employees	3	2	100	600	UNACCEPTABLE RISK
8	Entire facility	Messy/damaged electrical cables	Fall, electric shock, injury, death	Facility employees	3	3	40	360	HIGH RISK
9	Entire facility	Lack of OHS training	Injury or death due to unawareness of risks	Facility employees	3	2	100	600	UNACCEPTABLE RISK
10	Entire facility	No emergency assembly area	Chaos, injury during evacuation	Employees, visitors	3	3	15	135	SIGNIFICANT RISK
11	Entire facility	Lack of firefighting equipment	Burns, smoke inhalation, poisoning, death	Employees, visitors	3	2	100	600	UNACCEPTABLE RISK
12	Entire facility	Worn/old emergency signs	Chaos, injury, death due to delayed evacuation	Employees, visitors	3	2	100	600	UNACCEPTABLE RISK
13	Entire facility	Obstacles in front of emergency exits	Chaos, injury, death during emergencies	Employees, visitors	2	3	100	600	UNACCEPTABLE RISK
14	Treatment units	Contact with chemicals	Poisoning	Facility employees	6	6	15	540	UNACCEPTABLE RISK
15	Electrical panel areas	Unauthorized access to electrical panels	Electric shock, death	Facility employees	3	2	40	240	HIGH RISK
17	Workshop	Lack of safety in press machine	Crushing, injury, limb loss	Workshop employees	6	3	15	270	HIGH RISK
18	Workshop	Operating machines without guards	Eye injuries from flying debris	Workshop employees	6	3	15	270	HIGH RISK
19	Electrical systems	Lack of grounding	Electric shock, death	Facility employees	3	3	40	360	HIGH RISK
20	Confined spaces	Inadequate ventilation	Poisoning or lung diseases due to dust/gas exposure	Facility employees	3	3	40	360	HIGH RISK
21	Storage areas	Improper stacking on shelves	Injuries due to falling heavy materials	Storage workers	6	3	15	270	HIGH RISK

As a result of the risk analysis conducted at the wastewater treatment plant evaluated in this study, significant, high, and unacceptable risks that require immediate intervention are shown in the table above. The measures to be taken to eliminate or reduce these risks are listed in Table 6.

Table 6. The precautions to be taken in the facility according to the High-Rated Risk Factors Identified in Table 5 (respectively)

No	Risk Area / Activity	Control Measures / Recommendations	Responsible Unit	Timeframe for Implementation
1	Lifting and conveying equipment integrity risk in coarse screen section	Annual inspections and preventive maintenance shall be performed by certified and authorized personnel to ensure operational safety and compliance.	Maintenance & Engineering	Every 12 months
2	Fall hazards in pool vicinity	Standard warning and caution signage shall be installed; guardrails shall be implemented along pool perimeters and walking platforms; life-saving buoys shall be deployed at strategic locations for emergency use.	OHS	Within 1 month
3	Occupational exposure to noxious odors	Certified respiratory protective equipment (e.g., masks) compliant with occupational health standards shall be provided to personnel operating near pools.	OHS & Operations	Immediate
4	Unauthorized and uncontrolled facility access	Continuous security personnel presence at access points shall be maintained; strict access control protocols including personnel registration and verification systems shall be enforced; unauthorized entry shall be prohibited.	Security Department	Within 1 month
5	Biological contamination during maintenance activities	Use of protective gloves when handling contaminated materials shall be mandated; prohibition of food and beverage consumption within operational zones shall be enforced; routine disinfection protocols shall be implemented; regular hygiene and PPE training shall be conducted; systematic health monitoring and vaccination programs shall be executed.	OHS & Operations	Immediate and ongoing
6	Safety risks during maintenance interventions	System operations shall be ceased prior to maintenance; presence of trained supervisory personnel shall be ensured to monitor and enforce safety compliance during maintenance activities.	Maintenance & Engineering	Before each maintenance activity
7	Hazardous atmosphere in confined spaces	Pre-entry atmospheric monitoring for toxic and combustible gases shall be conducted; use of self-contained breathing apparatus (SCBA) shall be enforced; electrical equipment shall be de-energized before maintenance; ignition sources and non-Ex-rated electrical devices shall be prohibited in hazardous zones.	OHS & Electrical Maintenance	Prior to each entry
8	Electrical hazards due to wet environment	Electrical wiring shall be installed within certified protective conduits; damaged or exposed cabling shall be repaired or replaced; cable routing shall be organized to minimize trip hazards in work areas.	Electrical Maintenance	Within 3 weeks
9	Insufficient occupational safety training	Mandatory annual occupational health and safety training shall be implemented; work assignments shall be restricted to personnel with valid certification.	HR & OHS	Annually
10	Emergency evacuation and assembly protocols	Emergency assembly points in hazard-free zones shall be designated and demarcated; high-visibility signage shall be installed throughout the facility; emergency response teams and procedures shall be established and communicated; emergency plans and site layouts shall be maintained and periodically updated; functional backup illumination systems shall be ensured.	OHS & Facility Management	Within 2 months
11	Inadequate fire protection equipment	Facility shall be equipped by regulatory standards with appropriately rated portable fire extinguishers, considering hazard classification and spatial requirements.	OHS & Fire Safety	Within 1 month
12	Visibility and compliance of emergency exit signage	Faded or damaged emergency exit signage shall be replaced with reflective, regulation-compliant signs; monthly inspections shall be performed to verify condition and visibility.	OHS	Monthly
13	Emergency egress door design and obstruction	Emergency exit doors shall be ensured to swing outward directly to safe egress zones; clear access pathways shall be maintained; sliding, revolving, or lockable exit doors shall be prohibited.	Facility Management	Within 2 weeks
14	Chemical exposure and handling	Up-to-date Material Safety Data Sheets (MSDS) shall be maintained onsite; PPE usage based on chemical hazard assessments and MSDS recommendations shall be enforced.	Chemical Safety / OHS	Immediate

Table 6 continued

No	Risk Area / Activity	Control Measures / Recommendations	Responsible Unit	Timeframe for Implementation
15	Electrical panel access and shock hazards	Access to electrical panels shall be restricted to qualified personnel; panels shall be secured with locks; insulation mats shall be placed in front of panels to minimize shock risk.	Electrical Maintenance	Within 1 week
16	Slip, trip, and fall hazards during cleaning operations	Wet cleaning tasks shall be scheduled outside regular operational hours when feasible; clear warning signage shall be installed; damaged anti-slip tapes on stairways shall be inspected and replaced.	Cleaning Services & OHS	Within 2 weeks
17	Mechanical hazards in press machine operation	Press machines shall be equipped with dual-hand-controlled safety systems; routine inspections shall be conducted by qualified personnel; operating instructions and safety warnings shall be displayed; comprehensive operator training and PPE shall be provided.	Mechanical Maintenance	Within 1 month
18	Exposure risks during grinding and cutting operations	Appropriate eye and respiratory protective devices shall be supplied; adequate general and localized ventilation systems shall be ensured during these tasks.	OHS & Workshop Supervisor	Immediate
19	Electrical system failure and electrocution risks	Periodic inspections of electrical distribution, grounding, and lightning protection systems shall be performed by qualified technicians to ensure system integrity and personnel safety.	Electrical Maintenance	Every 6 months
20	Insufficient ventilation and hazardous gas accumulation in confined spaces	Ventilation systems compliant with safety standards shall be installed and maintained; atmospheric gas monitoring shall be performed prior to entry; respiratory protection equipment shall be utilized as necessary; personnel training shall be provided; continuous gas detection and emergency preparedness protocols shall be implemented.	OHS & Mechanical Maintenance	Within 2 weeks and ongoing
21	Improper storage of materials on shelves	Heavy materials should be placed on the lower shelves, while lighter items should be stored on the upper shelves and secured to prevent falling. Additionally, guardrails should be installed in front of the shelves to prevent materials from falling.	OHS & Warehouse Supervisor	Within 1 month

In line with the study, a literature review was conducted focusing on high-level (significant/unacceptable) risk factors.

Özkoç et al. (2023) employed a 5x5 Type Matrix (L-Type) method, utilizing probability and severity parameters, to assess risks faced by personnel in drinking water treatment plants. In their 2022 study, Özkoç et al. emphasized that treatment plants have inherently high-risk processes. They highlighted the need to prioritize collective safety measures, promote the consistent use of personal protective equipment, and, above all, develop a strong workplace safety culture. Similarly, Uslu and Uslu (2021) evaluated potential risks in oral and dental health centers by considering existing hazards.

Özkars (2010) identified several factors in wastewater treatment plants—such as chemical exposure, unsecured electrical transformer doors, inadequate safety measures on tools and equipment, and commencement of work without proper occupational safety training—that contribute to serious risks including skin disorders, poisoning, failure to recognize hazards, hand injuries, electric shocks, fires, accidents, injuries, and even fatalities.

In a study by Karakuzu (2018), the absence of fire safety measures, lack of occupational safety training, absence of grounding for electrical risks, missing residual current devices in electrical panels, and explosion risks from pressurized gas cylinders were highlighted as significant contributors to severe health and safety hazards including fire, electric shock, accidents, injuries, and death.

Furthermore, studies by Orhan (2016) and Güner (2018) categorized the risks of skin disorders and poisoning due to chemical exposure as high-risk concerns.

Özkars et al. (2013) reported that the absence of a designated emergency assembly area, inadequate warning and caution signs, and missing emergency direction signs—due to shortcomings in emergency procedures—increased the risk of confusion, injuries, and fatalities to a high level.

Coutin et al. (2007) demonstrated that fires in open electrical panels can quickly spread to all components, leading to a larger fire. Therefore, uncontrolled electrical panels pose a high fire risk.

According to Flayeh (2009), workers who start without safety training are unable to recognize workplace hazards, resulting in a high risk of fatal accidents.

The risk analysis results obtained from the study are consistent with the aforementioned studies.

CONCLUSION

In workplaces, employees are exposed to a wide range of hazards; therefore, conducting regular risk assessments, providing comprehensive training and awareness programs, prioritizing collective protective measures, supplying appropriate personal protective equipment (PPE), and continuously monitoring the working environment are fundamental factors in preventing occupational accidents and health issues. The most critical aspect of conducting a proper and reliable risk analysis of any activity is to base it on information derived from past experiences. The Fine-Kinney method used in this study, along with similar approaches that incorporate probabilities and aim to identify the most effective solution, are essentially built upon real-life events and accumulated knowledge.

This study, conducted in a wastewater treatment plant—a facility recognized as critical from an occupational health and safety (OHS) perspective—aims to systematically assess OHS-related risks and to define practical control measures to mitigate these risks. According to the results presented in the risk assessment tables, various types of hazard sources (physical, chemical, biological, and mechanical) have been identified in different sections of the facility. For each activity, the type of hazard, associated risk, affected personnel, and risk parameters such as probability (P), frequency (F), and severity (S), as well as the calculated risk score and corresponding risk level, have been defined. Additionally, for each identified risk, specific control measures, responsible departments, and implementation timeframes have been outlined in a separate table. For example, the failure to perform periodic inspections of the coarse wastewater treatment grills is classified as a “significant risk” due to its potential to cause serious injury or death. It is recommended that the maintenance and engineering teams conduct annual inspections to ensure operational safety.

The absence of guardrails around pools poses a fall hazard that could result in injury or fatality. This, too, is categorized as a significant risk, and the OHS department is expected to implement the necessary safety measures within one month.

Exposure to unpleasant odors—capable of causing headaches, respiratory issues, and neurological effects—is identified as a high-level risk, particularly for personnel working near biological treatment units. Immediate provision and mandatory use of certified respiratory PPE is advised.

Confined spaces are among the most critical risk areas within the facility. The accumulation of toxic and flammable gases can result in poisoning or fatality and is therefore classified as an “unacceptable risk.” Key safety measures include pre-entry atmospheric monitoring, the use of self-contained breathing apparatus (SCBA), de-energizing of electrical systems, and the prohibition of ignition sources. These measures must be implemented by the OHS and electrical maintenance teams prior to each entry.

Disorganized and damaged electrical cables increase the risk of tripping and electric shock. Protective conduits should be installed, and any damaged cables must be repaired or replaced promptly. The electrical maintenance department is responsible for completing these actions within three weeks.

Furthermore, topics such as the availability of fire protection equipment, unobstructed emergency exits, the designation of emergency assembly points, periodic OHS training, and up-to-date Material Safety Data Sheets (MSDS) for hazardous chemicals are emphasized as priority areas in both the risk and control measure tables. These interventions not only protect employee health but also directly enhance the overall operational safety of the facility.

The assessment reveals that risk levels across the facility range from significant to unacceptable. Reducing these risks requires not only technical interventions but also an effective organizational structure, continuous training, routine inspections, and maintenance activities. Clearly defined responsibilities and time-bound implementation of control measures are crucial to establishing a strong safety culture across the facility.

In conclusion, this study aims to establish a robust foundation for implementing a systematic and sustainable occupational health and safety (OHS) approach in wastewater treatment plants. In doing so, both employee health will be safeguarded, and the efficiency and environmental compliance of the facility will be enhanced.

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Conflict of Interest

The article authors declare that there is no conflict of interest between them

Author’s Contributions

1st Author (Prof. Dr. Hülya BÖKE ÖZKOÇ):

- Contributed to the creation of the conceptual framework of the article.
- Conducted the analysis of occupational safety risks in wastewater treatment plants and literature review.

2nd Author (Corresponding Author) (Asist. Prof. Ayşenur USLU):

- Undertook the general planning and management of the article.
- Led the evaluation of research findings and interpretation of results.
- Managed the peer-review process and supervised the implementation of revisions.

3rd Author (Sevda TÜRKMEN):

- Contributed to the analysis of data on health and safety hazards.
- Helped ensure the integrity of language and expression of the article.

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