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A Qualitative Approach to the Seismic Estimation of Wastewater Treatment Plants and Potential Impacts on the Hydrosphere

Ploutarchos N. Kerpelis [1,2,*], Dimitrios E. Alexakis [2] and Spyridon K. Golfinopoulos [1]

[1] Department of Financial and Management Engineering, School of Engineering, University of Aegean, 41 Kountourioti Str., GR-82132 Chios, Greece
[2] Laboratory of Geoenvironmental Science and Environmental Quality Assurance, Department of Civil Engineering, School of Engineering, University of West Attica, 250 Thivon & P. Ralli Str., GR-12241 Athens, Greece
* Correspondence: kerpelis@uniwa.gr

Abstract: Many quantitative and qualitative methods have been developed to estimate the seismic vulnerability of Wastewater Treatment Plants (WWTPs). The research approach using questionnaires is the most common qualitative process to quickly access estimation results. In the present study, the Experts' Judgment method was implemented. A representative questionnaire was distributed to a hundred and sixteen (116) operators of Greece's WWTPs according to proportional stratified sampling for seven months. The questionnaire was based on the main parameters that contribute to seismic vulnerability (structural, non-structural and operational matters). The examination of the results included the search for reliability and validity. Their collection also revealed that the average seismic vulnerability of the samples was found at a low level after a direct question, and was slightly increased after analyzing a group of questions. In the case of soil–water pollution during the post-seismic period, the answers showed low percentages for the contribution to the seismic vulnerability (at the partial mode), and divided answers existed at low and slightly increased percentages. Non-structural and operational vulnerability somewhat increased the percentages in the judgments. During the 24 h post-seismic period, the possibility of soil–water pollution was expected at low percentages and it remained constant. The results of this study could be compared to future surveys for qualitative approaches to disaster risks or could be used in addition to the results from quantitative methods.

Keywords: wastewater treatment plants; seismic vulnerability; soil–water pollution; experts' judgment; questionnaire; qualitative estimation

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1. Introduction

An earthquake is a multi-parametric, probabilistic disaster. Prevention of the next seismic event is impossible, however estimating the values and parameters of a structure can be achieved using qualitative and parallel analytical methods [1–4]. Such qualitative methods are reported in the research into critical infrastructure [5], lifelines and utility networks [6], bridges [7] and other structures, as seismic impacts can influence humans and the environment generally [8–10]. Indicatively implemented methods, such as Rapid Visual Screening of structures, use questionnaires [11,12]. Additionally, questionnaires that use the expert's judgement methodology for Wastewater Treatment Plants (WWTPs) were developed to measure structural, non-structural and operational vulnerabilities [13–15].

Worldwide, more than 80% of sewage produced by human activities is discharged into rivers and oceans without any treatment, thus posing the risk of dispersing infectious diseases. Additionally, 80% of diseases and 50% of child deaths are related to poor water quality [16]. Micropollutants, endocrine disruptors, pesticides, pharmaceuticals, hormones, toxins, and industry-related synthetic dyes are contaminants that may pose health risks [17]. Advanced technologies that remove wastewater pollutants using engineered nanoparticles have been developed [17,18]. Wastewater pollutants released in soil and water may affect the ecosystems and hydrosphere. The GIS platform and maps can assist in recording potentially toxic elements and represent cost-effective methods, as compared to other in situ estimating methods [19]. Removing pollutants, such as Ni and Cu, from aqueous media has been a challenging issue in many research projects [20].

The primary pieces of legislation in Europe and Greece includes Directives 91/271/EEC and 98/15/EC and concern urban wastewater treatment, while in relation to water matters, the Directives 2000/60/EEC established a framework for community action in the field of water policy and 2008/98/EC concerns waste management. Additional national legislation includes the Joint Ministerial Decision (JMD) 5673/400/1997 Government Gazette (GG) 192B/14-3-1997, GG4685/2020 and GG405B/3-4-2002. Additionally, Directive 2008/99/EC imposes environmental protection terms. The organization of the Special Secretariat for Water (SSW) of the Hellenic Ministry of Environment defines the existence of 256 WWTPs [21], which is controlled by 126 Municipal Sewage Companies in Greece [22]. Further, the Water Supply and Sewerage Company of Athens, called “EYDAP S.A.”, manages wastewater in the Attica region, which covers a significant percent (35%) of the country’s population.

Europe has recorded, through the European Environment Agency (EEA) and the platform of Openquake [23,24], settlements and WWTPs using the GIS platform [24], which are in compliance with European standards. Greek compliance with the legislation concerning WWTPs was recorded until 2016 [23]. Additionally, vulnerability studies for WWTPs in Greece are not included in the repository of the Global Earthquake Model-GEM, except for the social–economic impacts of the Athens earthquake in 1999 [25]. Nevertheless, no vulnerability map has been published yet. The EEA published interactive maps to show the degree of municipal wastewater treatment through Discomap services [26].

Seismic impacts have been recorded due to structural vulnerabilities, such as drainage system failures [27], which were caused by construction materials and the earthquake’s intensity. Non-structural vulnerabilities cause seismic impacts to systems such as fire-protection, electro-mechanical (for monitoring and early alarm) and mechanical equipment support, while insufficient maintenance can cause additional problems [28,29]. Operational vulnerabilities may cause the pollution of soil and water, the leakage of hazardous materials or odors [30], the degradation of the environment and impact public health and safety [31–34]. Contaminated soils [35–39] and disinfectants can worsen the effects on human health due to infectious diseases [40]. WWTPs can release liquid or aerial substances during the post-seismic period [41], which likely cause fires, as was the case during the Northridge earthquake in U.S.A. (1994) and the leakage of oil through the hydrographic network [42]. The environmental impact reduction [43,44] and the degradation of biodiversity and ecosystems in the polluted regions is one of the EU’s most important priorities (Natura 2000 network).

The categorization of analytical, empirical and experimental methods to estimate seismic vulnerability is a topic being discussed and the advantages/disadvantages have been recorded by researchers [1,45]. The methods to estimate a structure’s seismic vulnerability is divided into research concerning: (a) A specific WWTP and (b) the total number of WWTPs in a specific region.

The most common methods for specific WWTs include the Pushover analysis and the Incremental Dynamic Analysis using time series [1]. A typical case estimates using the empirical method to discover the expected level of damage as a function of seismic intensity (seismic hazard) and is quantifiable. The empirical methods used to estimate the seismic vulnerability of a structure are as follows: Damage Probability Matrices [45,46], Vulnerability Index Methods [3], the Italian method Gruppo Nazionale per la Difesa dai Terremoti of The National Group of Defense from Earthquakes, the macroseismic evaluation European Macroseismic Scale (EMS98) as RISK-UE [1]. Furthermore, the following methods were developed mainly to estimate the vulnerability of buildings, assuming that the magnitude of the expected losses is the same for the construction of the same category: (a) Empirical Indices of Vulnerability [6], (b) Experts' Judgment and (c) Rapid Visual Screening.

Other combined approaches include hybrid methods. These are based on a combination of insufficient statistical injury data from previous earthquakes, thus resulting in extensive and incomplete analyses of representative buildings in each category [47,48]. The final stage of the seismic estimation of structures is the development of vulnerability curves.

The primary purpose of this study is to develop, for the first time, a qualitative approach to estimate the seismic vulnerability of WWTPs using the empirical method from the Experts' Judgment for WWTPs in Greece. The study's significance is the supplementation of existing analytical vulnerability estimating methods for these infrastructures in a fast and inexpensive way. Pre-estimation is the first and much needed stage of vulnerability studies, as revealed by the seismicity of Greece and demonstrated by maps of seismic risk (where vulnerability is a part of it) [49,50], by seismic impacts [51] and by a structure's seismic rules [52]. In Greece, WWTPs treat municipal sewages according to the first European Directive 91/271/EC (1997), and the Directive was integrated into national legislation in the Official Government Gazette 192B/14-3-1997. In 2015, the country was condemned and fined by the European Court of Justice for its non-compliance with the WWTP of Thriasio—EL3000950197012: Case C119/02 and C328/16. These are relatively new structures (instituted in approximately the 1980′s) and have not been officially recognized as critical infrastructure yet (proven by the non-existence of education by the Center for Security Studies) [53]. The rapid seismic assessment of public buildings did not include these structures [54], and the European Program Syner-G analyzed a systemic approach for lifeline networks and infrastructure [55].

2. Potential Impacts on the Hydrosphere

The degradation of the environment can be attributed to many factors, including economic issues [56]. Water is one of the most significant resources necessary for human life [16,57], and many countries have established legislation and directives concerning water quality parameters [58]. The established legislation is essential to protect the environment and infrastructure from natural disasters [59].

WWTPs are indicators of the post-seismic assessment [60]. These are point sources of environmental facilities [61], and simultaneously, pipeline failures can cause localized sewage flooding [62]. In addition, the vulnerability of WWTPs that manage urban wastewater is greater than the vulnerability of WWTPs that manage industrial waste [27]. For example, the lakes in Lucerne and Geneva (Switzerland) tend to control the concentration of Pb, Cu, Zn, and Mn in surface water through the effective management of WWTP effluents [63].

Operational Vulnerability (OV), such as soil, water and air pollution due to the leakage of hazardous materials or odors [30], degrades the environment and public health and safety [34]. Volatile organic compounds are released after wastewater treatment [64]. Moreover, the World Health Organization has already recorded the pollutants that are released after an earthquake [65]. In China, treatment effluents differ according to the area (economic issues and population), treatment method, compliance with the environmental discharge standards, percentages of sludge treatment and the involvement of new technologies in the utilization of recycled wastewater [66]. The difference in efficiency among the 3508 WWTPs in the country is the result of the above factors.

As human health is threatened by infectious diseases [16,40], investigations into the environmental efficiency of these facilities have been carried out in European countries by searching for the effects of pollutants (such as nitrogen) [67]. Within the WWTPs and the surrounding areas, the result is the further increasing of the possibility of contaminated soils [35] and increasing the necessary cleaning of the facilities caused by the sewage with the use of disinfectants that have adverse consequences for human health [68]. Organic substances of raw or treated wastewater can cause eutrophication, and a relationship exists between algae and the sewage [69]. Additionally, pesticides from WWTP effluents are a significant stressor on ecosystem quality and condition, thus affecting the macroinvertebrate community [70].

Mitigating the impacts on the environment and biodiversity of the ecosystem is a vital priority of the European Union (which has established natural areas) [43,44]. The legal aspect of the pollution of water resources is also essential. Countries such as Canada have doubted the current treatment management status of wastewaters [71].

Researchers have recorded seismic impacts in WWTPs and the consequences to the hydrosphere in specific periods [27,62,72]. In regards to the Loma Prieta (U.S.A.) earthquake (1989), extreme fires after the quake were noticed, while raw sewage was discharged to the Monterey Bay and San Francisco Bay ports. The earthquake occurred in 1993 in the region of Iowa (U.S.A.) and severely damaged WWTP tanks, which consequently flooded the surrounding area [73].

In the Northridge earthquake (1994), more than 1,400 failures in the drinking water network in Los Angeles and other malfunctions for more than thirty (30) days were observed [6]. Fifty-eight (58) people were killed, 1500 people were injured, and approximately 125,000 residents were evacuated from the Los Angeles area [74]. The earthquake caused hazardous materials to be released and this occurred during the quake. In the post-seismic period, a storm caused a mixture of oil and sewage to spread contamination in river water 12 miles away [42].

In 1995, during the Kobe (Japan) earthquake, wastewater was accidentally discharged into Osaka Bay without any treatment. Additionally, the Kobe earthquake caused damage to three main pipes and 86 finished water reservoirs that supplied the city of Kobe, as well as soil liquefaction in the broader area of the city [75]. Severe damage to the water network was observed during the earthquakes in Izmit and Kokaeli (Turkey, 1999). About 45% of the pipeline networks were destroyed, while 55% showed leakage [74]. In 2003, during the Bam earthquake (Iran), significant differences were detected in the concentration of substances in groundwater before and after the earthquake [76]. In 2003, during, the Lefkada earthquake (Greece), considerable damage was recorded in the water supply network due to subsidence throughout the city. In 2004, during the earthquake and tsunami, the sewage tanks were flooded in the coastal areas surrounding the Indic Ocean [77].

In 2009, during the L'Aquila earthquake (Italy), two WWTPs had many operational problems [78]. Liquefaction and soil movements caused the destruction of two sewage wells, which were observed after the earthquake occurred in Canterbury (New Zealand) in 2010. Indirect effects, such as public health issues, drinking water pollution in building taps, stream pollution and groundwater pollution, were observed. The Maule earthquake (Chile) in 2010 resulted in massive soil vibrations, liquefaction and a tsunami. Systems of gas and water supplied to four-million people were affected. Damage to medium and large-diameter pipes, causing the direct discharge of raw sewage into the Biobio river, was detected [79].

After the Christchurch earthquake (New Zealand, 2011), the 6% of network pipes were destroyed, while 27% were only partially operational. In some areas, sewage discharges went directly to the water receivers, while the inflow of sediments into the pipelines caused them to become clogged. Pollution of the river was also detected [80]. The earthquake caused more than 180 deaths. During the post-seismic period, only 30% of WWTPs were operational. Untreated sewage was discharged into the river. Groundwater infiltrated the pipeline network, increasing the need for treatment. The most extensive damage was found near the river banks due to soil liquefaction [74].

The Great East Earthquake (Japan, 2011) has killed about 16,000 people. The direct results included failures in the 102 km pipeline, soil liquefaction and severe malfunctions in more than 120 WWTPs for a three-month period, while many households had no access to clean water or sanitation. Untreated sewage and effluents were also discharged into water bodies [81]. Moreover, the earthquake in Kumamoto (Japan, 2016) had many impacts on groundwater quality [82].

3. Methodology

3.1. Application of the Experts Judgement Method

According to Kassem et al. [1], experts estimate the seismic risk in combination with other empirical methods, such as Rapid Visual Screening assessment. This contributes to the vulnerability index methods, such as the National Group of Defense from Earthquakes, denoted by the Gruppo Nazionale per la Difesa dai Terremoti-GNDT approach, where the weight values are dependent on the experts' opinion. The behavior modifier and the regional vulnerability are significant factors in the empirical method of the EMS98 approach (RISK-UE), which relies on expert judgment [1].

The methodology of this study is based on expert judgment, which includes questionnaires to record the experts' opinions and observations about vulnerability. The process comprises the administration of a questionnaire to a representative sample of WWTPs. Five Likert scales are implemented, and each number represents a range of 20%, as shown in Table 1.

Table 1. Definitions of classes of percentages according to the Likert Scale.

Class	Classification According to Likert Scale	Percentages (%)
A	1	0–20
B	2	20–40
C	3	40–60
D	4	60–80
E	5	80–100

Another similar case is the implementation of the method where a District's responsibilities already include the rapid visual estimation for existing buildings in the Earthquake Planning and Protection Organization-EPPO [7,12] and Federal Emergency Management Agency-FEMA [11].

3.2. Representative Sample

The SSW demonstrates that the amount of WWTPs in Greece is 256, which are owned by Athens EYDAP S.A. and the 126 Municipal Companies of Water and Sewage Supply (called DEYA) [21]. However, the total number of WWTPs is 241 (using SSW data) after removing facilities with missing data.

The examined WWTPs are classified into four categories: (a) The Earthquake Hazard Zone (EHZ), (b) the degree of the sewage treatment, (c) their processing capacity and (d) the receiving water body.

The method of proportional stratified sampling, as suggested by Robson [83], was selected for this study. Kirchhoff and Watson [84] also applied the same approach to study the adaptation of WWTPs to climate change. The percentage of examined WWTPs (n = 116) is identical to the corresponding percentage of existing WWTPs (n = 241) for each category (Table 2).

The first categorization was completed according to the seismicity of the WWTPs' region. The Greek EHZ is presented on a map containing three types of predictable seismic accelerations on the ground and shows three Zones in the whole territory, according the Greek Official Gazette 1154/vol.B/12.8.2003 [52].

The second categorization was completed according to the degree of wastewater treatment of the WWTPs. This infrastructure uses three treatment processes (primary treatment-PT, secondary treatment-ST and tertiary treatment-TT), according to what is needed [85]. By default, the study argued for only two categories (ST and TT) because PT does not stand alone in the catalogue.

The third categorization was completed according to the processing capacity of WWTPs in the settlements [21]. In Greece, WWTPs are categorized in three types according to the capacity (equivalent population): (a) 2000–10,000, (b) 10,000–100,000 and (c) more than 100,000 [27].

Table 2. Percentage of the WWTPs, according to EHZ, treatment, capacity and receiving water body (n = 241).

A/A	Categorization	Number of Existing WWTPs	Number of Examined WWTPs	Percentage (%)
1	Hazard Seismic Zone I	96	38	39.80
	Hazard Seismic Zone II	136	78	56.40
	Hazard Seismic Zone III	9	0	3.70
2	Secondary treatment	37	18	15.40
	Tertiary treatment	204	98	84.60
3	Capacity 2000–10,000	73	35	30.30
	Capacity 10,000–100,000	153	73	63.50
	Capacity > 100,000	15	8	6.20
4	Sensitive receiving water body	30	15	12.40
	Normal receiving water body	211	101	87.60

Furthermore, the fourth category included the receiving water bodies. There are two types in relation to this (sensitive and normal receiving water bodies), according to the SSW.

Percentages of the Statistical Population of WWTPs

The percentages of the WWTPs, applied treatment, capacity and receiving water body are presented in Table 2.

The categorization of WWTPs, based on the proportional stratified sampling, is shown in Figures 1–3.

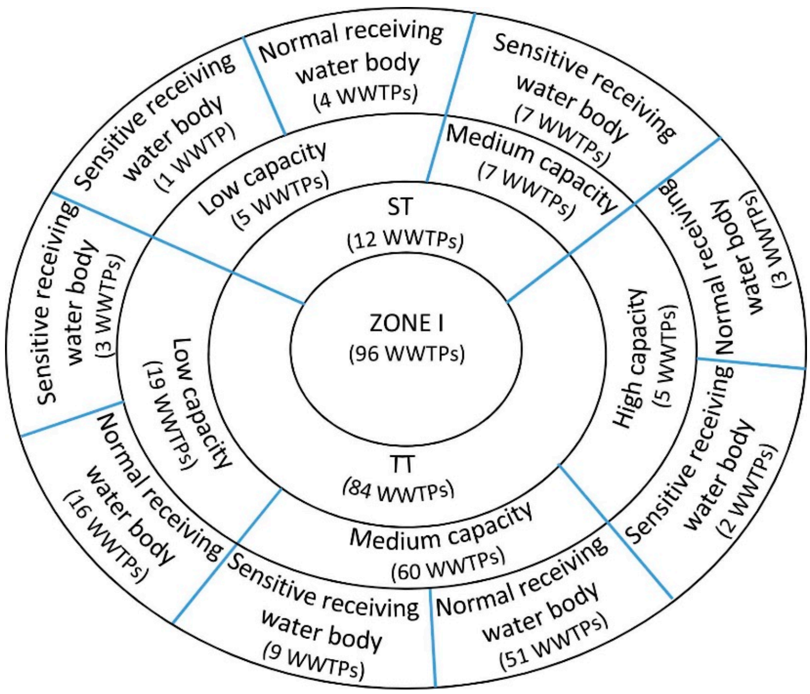


Figure 1. Categorization of WWTPs for Zone I of EHZ.

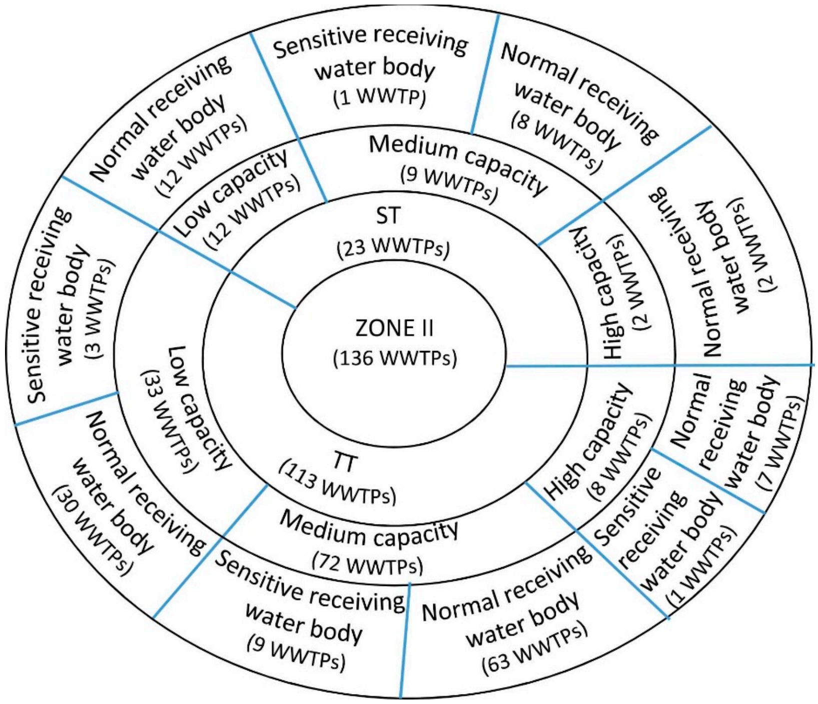


Figure 2. Categorization of WWTPs for Zone II of EHZ.

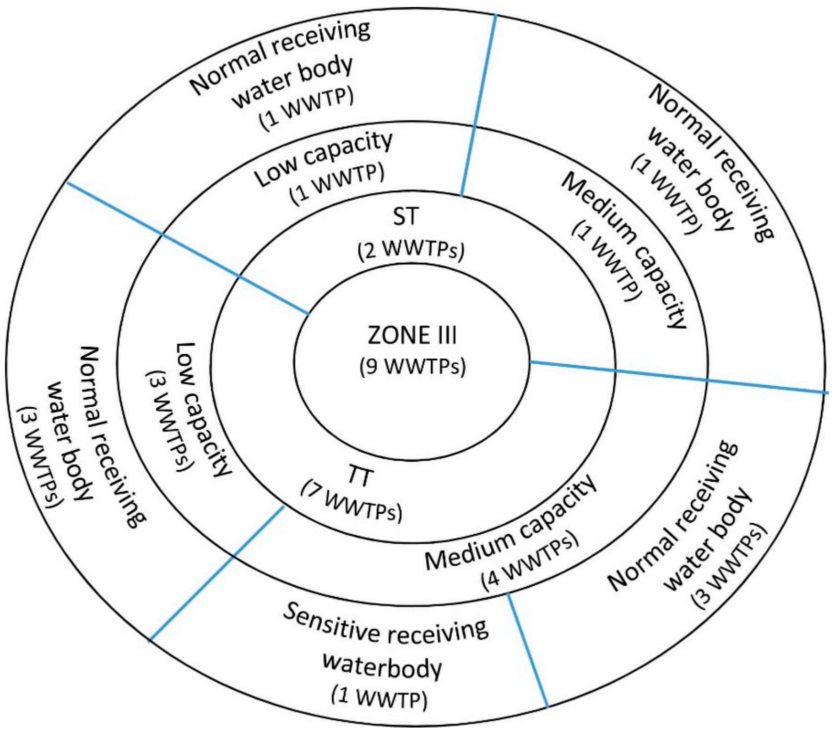
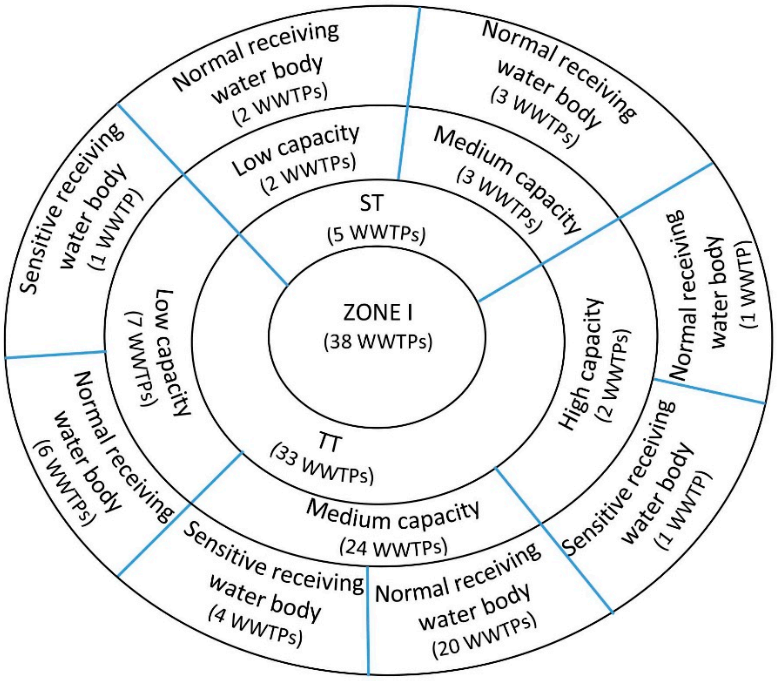
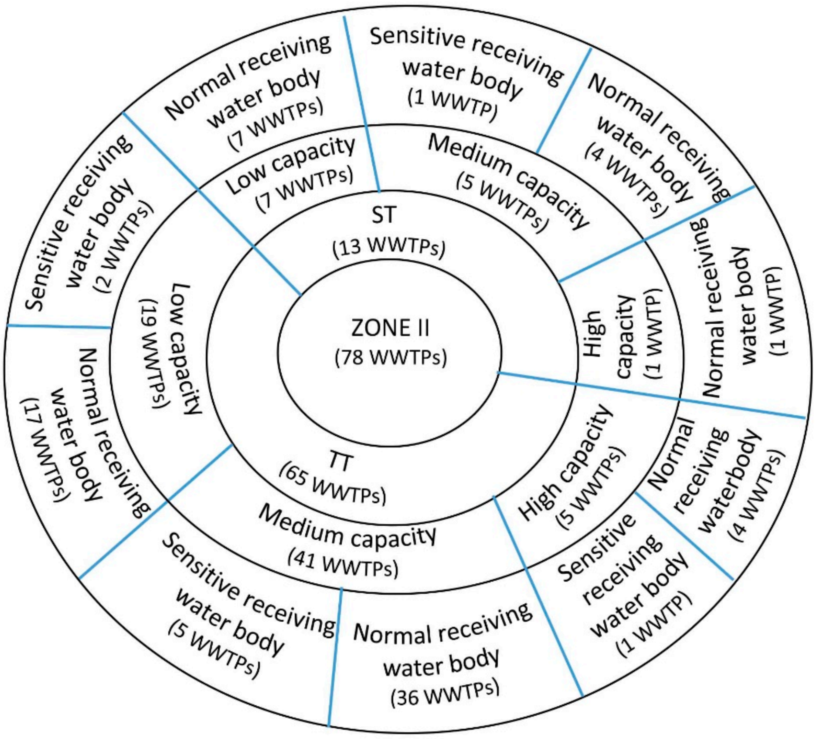


Figure 3. Categorization of WWTPs for Zone III of EHZ.

The final sample was selected using random sampling from the above sub-categories (Figure 4a,b).



(**a**)



(**b**)

Figure 4. Categorization of the WWTPs samples examined in this study for: (**a**) Zone I of EHZ and (**b**) Zone II of EHZ.

The EHZ III category (the country's riskiest earthquake area) does not participate in the sample composition's sub-categories.

3.3. The Questionnaire

In the present study, it was assumed that the Structural Vulnerability (SV), Non-Structural Vulnerability (NSV) and Operational Vulnerability (OV) contributed to seismic vulnerability, and that these parameters must be estimated through a questionnaire. The use of variables was supported in many other studies [86,87]. A comparative study of global building seismic vulnerability assessment methods highlights the factors affecting it [88]. Seismic impacts on buildings have been recorded [89]. The seismic vulnerability depended on the soil and terrestrial data [90,91]. Structural and non-structural parameters have been presented by researchers [91] and Scientific Organizations, such as the EPPO [54,92]. Similar parameters to evaluate seismic vulnerability in this study have been applied for both building structures [54] and WWTPs [27,93,94].

The final questionnaire used in the present survey consisted of 48 questions, which were organized into six subsections [95]: (a) Demographics (eight questions), (b) SV (seven questions), (c) NSV (ten questions), (d) OV (thirteen questions), (f) chronic evolution of the soil–water pollution (six questions) and (g) coefficients of the variables (four questions). Coefficients were used in similar surveys [6,96].

The questions were of a closed type and used a five-degree Likert Scale to be easy for the recipients to answer [97]. To ensure the reliability of the answers, some questions were repeated.

3.4. Recipients of the Questionnaire

The recipients of the questionnaire were the operators of the WWTPs. The recipients preferably had a professional role in the plant to ensure that the answers were valid. The experience and unbiased disposition of the recipients were among the essential criteria for selecting experts. The anonymity of the recipients was declared and ensured during the completion of the questionnaire.

3.5. Pilot and Primary Survey

A pilot survey was essential for the final writing of the questionnaire [98], and this required a random set of WWTPs. The anonymity of the recipients was preserved during the survey. The completion of the questionnaire required at least 60 min. The questionnaire was distributed through the internet using the Google® Forms platform following telephone communication with the recipients. The duration of the primary survey was seven months (April to November 2021).

4. Results and Discussion

4.1. Validity and Reliability

Similar previous findings cannot justify the results of this study. The reason is that an estimation of WWTPs in Greece that considers the SV, NSV and OV using a questionnaire has not been conducted yet. Analytical methods are focused on certain pollutants, processes of the infrastructure or specific geographic areas (such as Thessaloniki at Syner-G project), thus focusing on parameters such as interoperability among the people involved.

The Content Validity of the questionnaire was one, as the whole number of recipients (100%) completed the questionnaire [99]. The Pilot distribution of it and the characteristics of the recipients (as expert operators of the WWTPs) assist the Construct Validity of it. The Face Validity is ensured by the fact that the recipients agree that the questionnaire is suitable for the estimation of seismic vulnerability, and they completed it. Similar surveys only checked the validity by the Pilot distribution of the questionnaire (65%) [84].

The Split-half reliability of the partial questions of Chapter 2, 3 and 4 (concerning SV, NSV and OV) revealed a Spearman-Brown Coefficient of 0.877, which is greater than the criterion for reliable surveys of 0.70 proposed by Galanis [99]. The Internal Consistency Reliability of all the partial questions (after the removal of trap-questions) was found to be 0.906 [99,100]. The inspection of the reliability between the trap-questions and the original questions was over 0.628, which is considered to be a tolerable limit by some researchers [101]. The reliability of the collective questions concerning soil–water pollution in comparison to the seismic vulnerability of each chapter (SV, NSV and OV) was 0.831.

4.2. Descriptive Statistics

Using descriptive statistics revealed the following percentages for the frequencies of the questionnaire's variables:

(a) Part 1: Demographic characteristics of the recipients and their general judgment of seismic vulnerability of the WWTPs are shown in Figures 5–7.

Gender	Men	62.9%
	Women	37.1%

Education in Sanitary	Yes	54.3%
	No	45.7%

Experience	>10 years	46.6%
	5–10 years	20.7%
	<5 years	32.8%

Estimation of seismic vulnerability	34.5% of recipients	Class A
	31% of recipients	Class B
	25% of recipients	Class C

Age of recipients	<30 years	10.3%
	30–40	23.3%
	40–50	30.2%
	>50	36.2%

Professional role	Directors	18.1%
	Major	24.1%
	Employee	49.1%

Pollution at the post seismic period	41.4% of recipients	Class A
	28.4% of recipients	Class C

Figure 5. Demographic characteristics of the recipients and estimation of seismic vulnerability of the WWTPs.

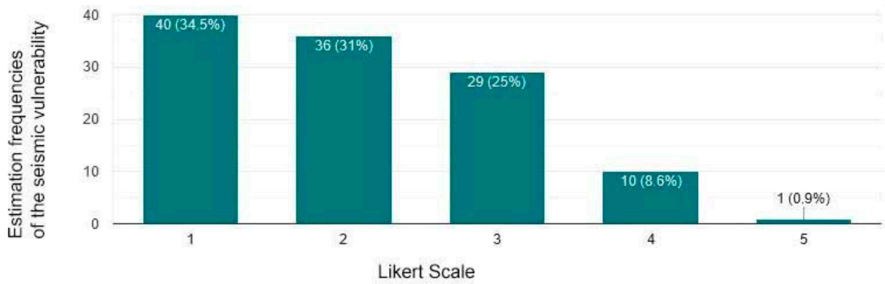


Figure 6. Seismic vulnerability of the WWTPs.

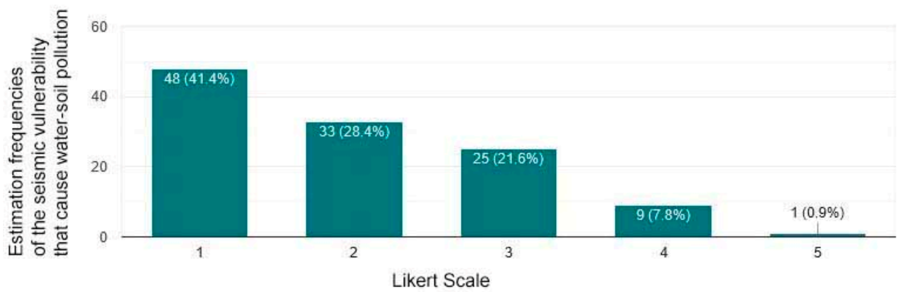


Figure 7. Seismic vulnerability of the WWTPs that cause water–soil pollution in the post-seismic period in Greece.

(b) Part 2: Structural vulnerability is presented in Figure 8. It was noticed that, after the year 2000, new anti-seismic codes were implemented for the structures in Greece.

Year of the Construction of WWTPs	>2000	44.8%
	1995–2000	27.6%

Contribution to seismic vulnerability (Class A)	Soil failure	61.2%
	Cracking of structural elements	63.8%
	Damage of sewers, tanks and underwater pipelines	53.4%

Estimation of SV	41.4% of the recipients	Class B
	32.8% of the recipients	Class A

Estimation if SV will cause soil-water pollution	49.1% of the recipients	Class A
	26.7% of the recipients	Class B

Figure 8. Structural vulnerability of the WWTPs in the post-seismic period in Greece.

(c) Part 3: NSV parameters and their estimation from the recipients during the post-seismic period are presented in Figure 9.

Sludge inflow into pipes and wells	38.8% of the recipients	Class B
	32.8% of the recipients	Class A
Insufficient support will cause seismic vulnerability	59.5% of the recipients	Class A
	24.1% of the recipients	Class B
Fire detection and fire safety	50% of the recipients	Class A
	30.2% of the recipients	Class B
Electro-mechanical installations	49.1% of the recipients	Class A
	31% of the recipients	Class B

No monitoring, alarm, communications, and notice	49.1% of the recipients	Class B
	31% of the recipients	Class A
Emergency plan, no lighting, signing, or escape routes	49.1% of the recipients	Class A
	31.9% of the recipients	Class B
Insufficient maintenance and machinery inspection	41.4% of the recipients	Class A
	36.2% of the recipients	Class B

Estimation of NSV	38.8% of the recipients	Class B
	31% of the recipients	Class A

Estimation if NSV will cause soil-water pollution	40.5% of the recipients	Class A
	36.2% of the recipients	Class B

Figure 9. NSV of the WWTPs in the post-seismic period in Greece.

(d) Part 4: OV characteristics of WWTPs and their estimation by the recipients are shown in Figure 10.

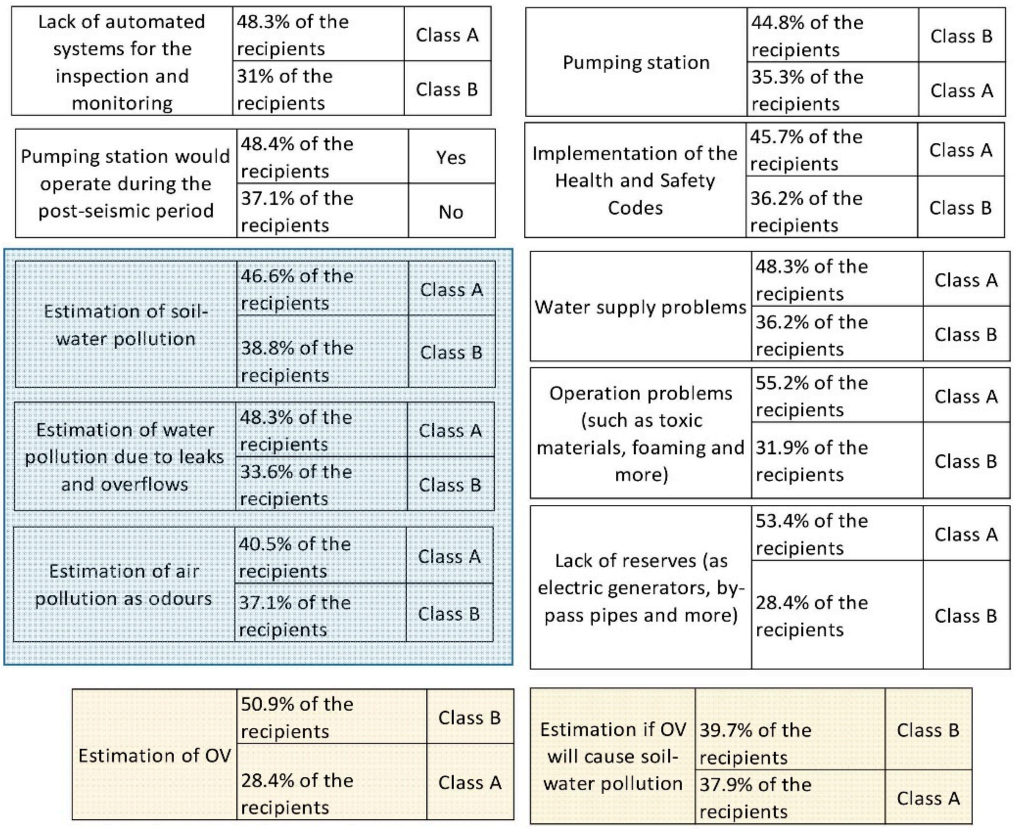


Figure 10. OV characteristics of the WWTPs in the post-seismic period in Greece.

(e) Part 5: Soil–water parameters estimate the seismic vulnerability during the first 24 h after the main seismic strike (Figure 11).

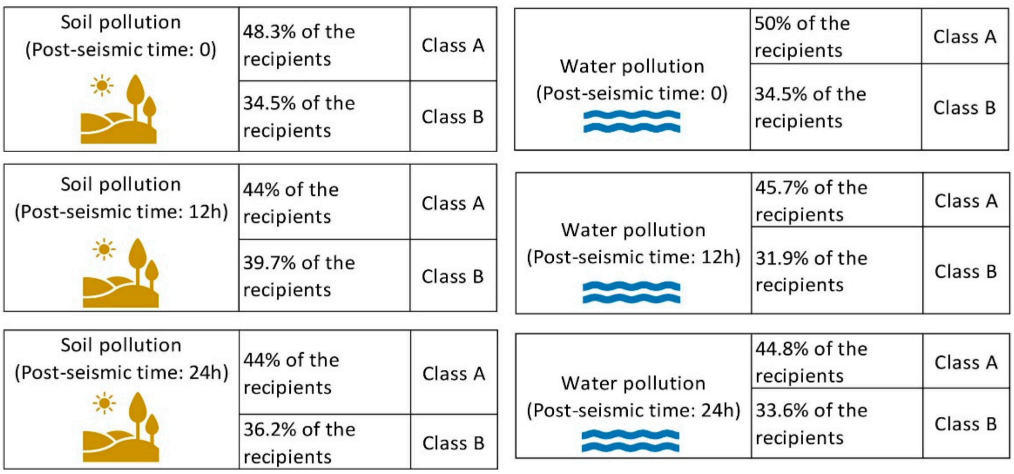


Figure 11. Estimation of soil–water pollution due to the potential release of contaminants from WWTPs during the post-seismic period.

(f) Part 6: The recipients compared the three types of vulnerability (SV, NSV and OV) to each other to obtain coefficients of the variables. Specific questions were distributed to 43 random recipients (37% of the 116 WWTPs) over three months (August to November 2021). Comparing each question of Parts 2–4 with the other questions of the same Part also showed negligible differences (Table 3).

Table 3. Comparison between the seismic vulnerabilities of WWTPs.

Seismic Vulnerabilities	Percentage of the Recipients (%)	Class
SV	34.5	A
NSV	37.9	A
OV	27.6	A

4.3. Synopsis of Main Results

The recipients of the questionnaire were men (62.9%), over 40 years old (66.4%), educated in sewage treatment (54.3%) with a great experience over ten years (46.6%) and most of them hold a responsible position (42.2%). According to the Likert scale (Table 1), the percentages of the most popular answers of the recipients were the following:

- 34.5% judged that the seismic vulnerability as Class A (which was the only direct question);
- 41.4% judged that the seismic vulnerability can cause soil–water pollution (Class A);
- 32.8% answered that the seismic vulnerability depends on the SV (Class A);
- 49.1% answered that the SV can cause soil–water pollution (Class A);
- 38.8% answered that the seismic vulnerability depends on the NSV (Class B);
- 40.5% answered that the NSV can cause soil–water pollution (Class A);
- 46.6% judged that the OV contributes to soil pollution (Class A);
- 48.3% judged that the OV contributes to water pollution (Class A);
- 40.5% judged that the OV contributes to air pollution (Class A);
- 55.2% answered that the problems of operationality can be attributed to seismic vulnerability (Class A);
- 50.9% answered that seismic vulnerability depends on the OV (Class B);
- 37.9% (Class A) and 39.7% (Class B) judged that the soil–water pollution can be attributed to seismic vulnerability;
- During the 24 h post-seismic period, the degree of soil–water pollution remains constant; and
- 46.5%, 51.2% and 37.2% answered, respectively, that the SV, NSV and OV contribute to seismic vulnerability (Class A).

The judgement of the recipients concerning seismic vulnerability (Class A) is justified by the fact that these treatment plants are modern facilities that have been operating after 1995 (of the new Anti-seismic Codes in Greece) (72.4%).

After the exclusion of the trap-questions and the direct questions about seismic vulnerability, the group of questions relating to SV consisted of four (4) questions, the group of NSV consisted of six (6) questions, and the group of OV consisted of nine (9) questions. Each question represented a variable concerning its group. The statistical average of each group's questions and the average of the three groups were revealed.

The analysis of the groups SV, NSV and OV revealed that the seismic vulnerability was 1.8795, representing 37.6%, using linear interpolation according to the Likert Scale (Table 4). 41.4% of the recipients estimated that seismic vulnerability could cause soil–water pollution (Class A). 49.1%, 40.5% and 55.2% of the recipients reported that, in the case of SV, NSV and OV, respectively, it could cause potential soil–water pollution (Class A). Nevertheless, there exists a sensitivity of WWTPs concerning the issues of OV as the processes during the wastewater treatment are very sensitive and significant parameters are involved. Their percentage for the caution of problems is Class B, in contrast to the answers (Class A) for SV and NSV (49.1% and 40.5%, respectively). Additionally, when they judged the OV partially for its contribution to soil, water and air, the answers belonged to Class A for soil, water and air pollution (46.6%, 48.3% and 40.5%, respectively). Low estimations (Class A) were recorded due to the modern legislation concerning safety and health, and the infrastructure was constructed using new Seismic Codes.

Table 4. Seismic vulnerability of WWTPs after analysis of a group of questions.

Descriptive Statistics	N	Minimum	Maximum	Mean	Std. Deviation
Questionnaire: Average of the Parts 2, 3, 4 (without trap-questions and direct questions)	116	1.17	3.52	1.8795	0.55311
Valid N (listwise)	116				

A significant difference was observed between the SV and the NSV–OV. The percentages for the SV ranged from 0% to 20%, while both the percentages for NSV and OV varied between 20% and 40%. This difference can be attributed to the non-existence of strict legislation for NSV, and the experts treat the issue of heavy elements dispersion or release of hazardous materials as unimportant. Sensitivity about the problems that may arise from the soil and water can explain the differences recorded by the experts' replies. The recipients assumed that, during the first 24 h of the post-seismic period, the operators will suggest the appropriate actions to control the contamination.

All the recipients agreed on the coefficients of each question, as compared to other coefficients of the same group (SV, NSV and OV). Comparing the magnitude between SV, NSV and OV, the experts' answers showed that all categories of vulnerabilities have the same coefficient. Most recipients judged that there was insufficient space to use coefficients and this was probably due to the accepted assumptions.

5. Conclusions

The seismic vulnerability of the WWTPs falls into Class A according to 34.5% of experts, based on a direct and single question. An alternative approach, according to the analysis of the three groups of variables (for SV, NSV and OV) revealed 37.6%. 32.8% of recipients answered that the SV falls into Class A, while 38.8% and 50.9% of the recipients answered that NSV and OV falls into Class B, respectively. The results of NSV and OV were according to the findings derived by the approach of the total number of parameters (37.6%). According to 41.4% of experts, the seismic vulnerability controls soil–water pollution (Class A). The 49.1% and 40.5% of the experts have answered that the contributions of SV and NSV, respectively, to seismic vulnerability corresponds to Class A, while 50.9% of the experts replied that the OV contribution to seismic vulnerability corresponds to Class B. These results highlighted differences among the recipients' answers using the seismic vulnerability variables.

Rapid estimation of the seismic vulnerability of WWTPs could increase the protection of ecosystems and water bodies in parallel with new and old sewage treatment processes. According to the present study, the seismic vulnerability of WWTPs will boost the pre-estimation to save time and money because the analytical methods need extra resources. Further, indicators must be defined for each of these case studies, especially in the case of emerging contaminants (mentioned in the introduction). Authorities cooperating with civil protection can implement proactive planning and propose protective measures. The initial results of the survey can be combined with quantitative surveys in the future to estimate the seismic vulnerability of WWTPs. Additionally, the implementation of the method can be used for different types of investigations, such as risk disaster estimations, vulnerability estimations of climate change and more other studies.

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