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Master Thesis

**Mapping the distribution of Austrian wastewater treatment plants smaller than 500 PEs**

Submitted by

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in the framework of the Master programme

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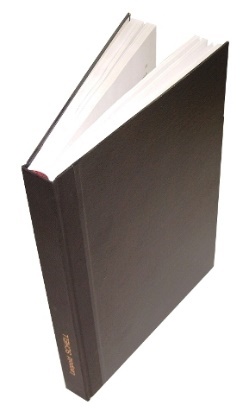
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Antoine de Saint-Exupéry, Citadelle, 1948

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# Acknowledgements

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# Introduction

In Austria about 95% of the population is connected through sewage channels to wastewater treatment plants (WWTPS) bigger than 500 PE. The remaining inhabitants rely on a high number of cesspools or small decentralized systems. Although each WWTP must be approved by the authorities, there is no national database for the latter category. All 9 federal states recently implemented individual online databases, facilitating research on the topic.

Using these databases the BOKU [Institute for Sanitary Engineering and Water Pollution Control](https://forschung.boku.ac.at/fis/suchen.orgeinheit_uebersicht?sprache_in=en&menue_id_in=201&id_in=H811) identified a significant gap between the previously estimated and the registered number of WWTPS up to 500 PE. The institute developed an Austrian-wide dataset, containing information on technology type, installation year and treated volume of WWTPs up to 500 PE.

This newly retrieved information generated interesting questions on the distribution and role of decentralized wastewater systems in the country. For example, Lendl and Muller pointed out that 20% of them are out of date, not satisfying Austrian nitrification regulations for wastewater quality.

Using the mentioned dataset to map the Austrian-wide distribution of small-scale wastewater system, this work aims at highlighting spatial information and represents the first spatial analysis on this subject.

# Goals

The first goal of this work is to analyse the dataset from a spatial perspective and describe the distribution of decentralized (<500 PE) wastewater systems on a municipality level, the smallest administrative division in Austria. The outcome of the first goal is maps thematized by design size and percentual population coverage.

Lendl and Muller reported that 20% of WWTPS are outdated, because not designed for biological nitrification according to national law1. Building on this statement, the second research goal is to identify clusters of outdated infrastructure and the municipalities that mostly rely on them. The outcome of the second goal is maps showing the location of outdated WWTPs by design size and percentual population coverage.

Furthermore, this works specifically aims at facilitating research on the topic. To do so the original datasets will be harmonized for future research and updates. The entire source code will be published to ensure reproducibility.

In the order they will be discussed later, the goals of this work are:

* To unify the existing datasets in a single database
* To describe the distribution of WWTPs at cadastral municipality level
* To identify clusters of non-nitrifying WWTPs and the municipalities that mostly rely on them

In *Fundamentals* the theorical background is set, describing the legal framework and summarizing the state of knowledge on Austrian wastewater coverage. The *Methods* part discusses the workflow from raw data to the desired dataset and its analysis. In *Result and discussion,* the outcomes of the goals are presented and analysed. In *Interpretation*, the results are interpreted and compared to literature. Finally, conclusions and a future outlook are drawn.

# Fundamentals

## Legal Framework in Europe and Austria

On a European level, the Urban Wastewater Treatment Directive (UWWTD 91/271/EEC) sets minimum wastewater requirements and has been translated into Austrian national law with the 1. Wastewater Emission Directive (WED)2. Together with the General Wastewater Emission Directive (GWED)3 this piece of law forms the essential pillar of national wastewater regulations. Their juridical background, as for any other Austrian water related law, is set in the Water Rights Act (WRA) issued in 1959. It regulates the use, protection and quality of water resources4.

In Austria WW is defined in the GWED §1 as water that, after being used for human purposes (industry, cleaning, consumption) has been so affected that its reintroduction to natural water bodies would negatively affect them3. The goal of wastewater (WW) treatment is to ensure that all pollutants are removed according to WED. This piece of law defines general minimum treatment requirements according to plant size. In Austria biological nitrification belongs to the state-of-the-art treatment and is required for all WWTPs bigger than 50 population equivalents (PE).

Table 1 Austrian wastewater treatment requirements (WED)



As stated in WED, minimum requirements for emission quality are only compulsory for design sizes bigger than 50 PE. Nonetheless authorities usually apply the same requirements for smaller WWTPs5,6. Note that not all WWTPS are subject to same requirements. For example, WTTPs in isolated areas, such as mountain shelters, are subject to less stringent requirements described in the 3. GWED7. Design guidelines are describe in Ö-NORM B 2502-1 (2012) and ÖNORM EN 12566-3 (2016) for technical plants up to 50 PE and Ö-NORM B 2505 (2009) for treatment wetlands5. Once the requirements have been respected and no damage is expected for the receiving water body, a discharge permission is issued by the authorities. The permission procedure is described in WRA § 32. Permissions are granted for specific periods , like 15 years in Upper-Austria8.

EmRegV-OW 2017 describes the national database for wastewater emissions, where WWTP bigger than 2000 PE and industrial WWTPs according to 2010/75/EU and 91/271/EWG must be recorded9. This register also contains WWTPs smaller than 2000 PE and is publicly available in the Water Information System Austria (WISA) database as promulgated by WRG § 59. All 9 federal states operate their own WIS, where all WWTPs on their territory shall be listed.

The UWWTD 91/271/EEC sets out a timeline for the implementation of wastewater treatment in settlements of all sizes, where bigger settlements have priority. This sparked a run for sanitation and several countries invested in WWTPs to fulfil the European goals according to timeline10,11. In case of non-compliance member states faced monetary sanctions like Spain and Italy11. Member states must report their progress in reaching the Water Framework Directive goals every 2 years to the European commission, in accordance with 91/271/EWG. In Austria the national WISA is one of the base datasets for the biennial report to European authorities. Information about WWTPs smaller than 200PE are issued from federal authorities to their national counterpart12. There is no unified national database for WWTPs smaller than 2000PE.

## Research on small WWTPs in Europe and Austria

According to 91/271/EEC Article 7 the sanitation of settlement smaller than 2000 inhabitants had to be implemented by 200513. Aragon reports 2 school of thoughts in the national implementations of this Article. Some countries, like Spain, decided that small agglomerations must comply with the same requirements valid for bigger ones. Other countries, like Austria, France and Finland established specific requirements14.

To fulfil the goals and avoid sanctions, member states had to invest in the sanitation of small settlements (<2000 PE). Furthermore, collecting reliable data on the topic became essential to report to the European commission and interest was sparked also in scientific circles. In fact, most of papers on the topic have been published in the last decade. It has to be mentioned that the compliance with Article 7 seems not to be a priority for the European Commission, as it is not mentioned in the 10th and most recent report on the implementation of the UWWTD15.

European research on the topic usually focuses on surveying the existing infrastructure16–19, the analysis of legal framework14,20,21 and monitoring of treatment and operation & maintenance (O&M) quality16,18,22. No spatial analysis was found.

In 2013 Aragon found that less than 50% of small Spanish settlements (<2000 inhabitants) are properly sanitized. Furthermore the research highlighted that information about sanitation of small settlements was very limited14. Generally, the absence of a central database is evident and researchers often must cope with sparse sources. Tsagarakis surveyed WWTPs up to 10.000 PE in Greece using data from “*information given by the personnel and management of plants, available design data, and on-the- spot investigations. Additional data were acquired by post or telephone contact.”* Nonetheless this work produced interesting results, stating that less than 50% of the built infrastructure was operational at the time and highlighted an overall poor O&M16.

In fact, maybe because it has remained unaddressed for long time, the topic of small WWTPs seems to deliver relevant pieces of information. A 2011 survey in Ireland found that 2 thirds of the population rely on decentralized WWTPs. Less than 1% of the households had no treatment facility but the treatment was overall inadequate. In fact most of the on-site treatment systems consisted of a cesspool and a percolation structure18. Improper treatment has also been reported in Italy, Sweden and Finland 17,21.

There is little literature available on the environmental effects of decentralized WWTPs. Because of the small discharge quantities involved, negative outcomes are considered negligible especially on a basin level. The few sources available report high P concentrations in surface waters, usually at low flow conditions18. Nonetheless, the potential environmental effects of decentralized WWTPs should not be underplayed. For example, in Finland where over 2 million PE are not connected to municipal sewers, rural areas were reported to discharge 50% more Phosphorus than urban ones. This issue, caused by improper decentralized treatment may have significantly contributed to local eutrophication20.

Similarly to the European trend, Austrian popular topics for small wastewater research are treatment technologies development23 and O&M quality24,25. Only few published articles address the distribution of the infrastructure5,26 and no exhausting spatial analysis could be found either. Although relatively digitized, information on small WWTPS is not easy to collect because each federal state runs its own database.

The first Austrian work on the subject seems to be the 1971 paper by H. Donner where the “uncontrolled” status of small WWTPs and lack of data is strongly addressed. The author reports that only 19% of the small WWTP in the federal state of Styria had a treatment and discharge permission. Furthermore the work suggests that an inappropriate treatment consisting of cesspool and inadequate percolation, thus similar to the Irish reports of above, was extremely frequent27.

In two recent articles Langergraber surveyed small WWTPS (<500 PE), reviewing the state of knowledge on the subject, including technology trends and missing information. The work is based on research accomplished by several bachelor and master studies5,26.

Dopplinger and Feigl accurately described the situation of small WWTPs in Austria and firstly identified a gap in the estimated and real number of those28,29. Gersthofer analysed the situation in Upper-Austria focusing on P removal6. Although readily noted in previous works, Lendl and Muller were the first to valorise the information that about 20% of small WWTPs don’t comply with national law because not designed for the prescribed biological nitrification1. Engstler reported on the treatment performance of small WWTPs in Upper-Austria8. Finally Sacken worked on sludge treatment in Upper-Austria and could collect recent data on local WWTPs30.

## Austrian wastewater landscape

Austria counts 8.9 million inhabitants distributed over 9 federal states. The total WWTP capacity is of 21.5 Mio. PE31.

The connection rate, calculated as the houses relying on municipal sewage channels is a typical measure used to describe the extent of wastewater services in a given area31. With 95%, Austria has one of the highest connection rates in Europe. According to EUROSTAT, the Netherlands are first with 99%, followed by Germany and Great Britain with 97%. In the last 40 years the Austrian connection rate almost doubled, following an average yearly increase of 1.2 %. The remaining 5% of the population uses private small WWTPS or cesspools31. In urban areas the connection rate is generally higher whereas rural areas show significantly lower values (Fig.1.)

Map

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Figure 1 Connection rate to municipal infrastructure by district according to OWAV 2020

The Austrian wastewater review 2020 counts 17.500 WWTPs with direct discharge into water bodies. They are categorized into WWTPs under <50PE, WWTPs addressed by the WED categories and industrial WWTPS. The review cites Langergraber 2018, stating that there are 27.450 small WWTPs if exclusively mechanical WWTPs are also counted31.

Generally, the smaller the design size, the larger the number of plants and the smaller the contribution to total capacity. According to the 2020 Austrian Wastewater overview there were 15.554 WWTPs smaller than 50PE, accounting for 0.7% of the total PE capacity and 1040 WWTPs between 50 and 500 PE accounting for 0.8% of total capacity.

Table 2 Austrian treatment capacity by design size (OWAV)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **category** | **nr. of WWTPs** | **% of total** | **PE (Mio)** | **% of total PE** |
| <50 PE | 15.554 | 88.98 | 0.16 | 0.74 |
| >50-<500 PE | 1.040 | 5.95 | 0.18 | 0.83 |
| >500-<5.000 PE | 505 | 2.89 | 1.13 | 5.22 |
| >5.000-<50.000 PE | 316 | 1.81 | 6.1 | 28.20 |
| >50.000 PE | 66 | 0.38 | 14.06 | 65.00 |
| total | 17.481 |  | 21.63 |  |

Fig 2 shows the geographic distribution of the small WWTPs counted by the Austrian wastewater overview31. The comparison with Fig. 1 clearly shows that their number is higher where the connection rate is lower.

Map

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Figure 2 number of WWTPs <50PE per 1000 inhabitants by municipality

Furthermore, it is interesting to observe the projected population change for Austria (Fig.3). As usual the highest increase is foreseen in urban areas, meaning that especially centralized systems will have to cope with more users in the next years.

Map

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Figure 3 Population change projection based on OROK data.

## Definitions

**BOD5**: biochemical oxygen demand in 5 days2.

**PE**: Austrian law defines population equivalents in the first paragraph of the WED as “the water pollution load of 60g BOD5 per inhabitant per day”2.

**Decentralized WWTPs**: relatively small (<500 PE) WWTPs that are built in areas where a centralized solution is inconvenient because of economic or technical reasons. Depending on their side they may treat single houses or small settlements. They are mostly used for treating household waste28,29.

**Small and medium WWTPs**: For this work decentralized WWTPs will be further split in two categories. The term **small WWTP** is applied to the design size **up to 50 PE** and **medium WWTP** for the design size between **50 and 500 PE**.

**Nitrification**: microbial process by which **ammonia**, toxic to waterborne species, is sequentially **oxidized to nitrate**32. By reducing the Nitrogen content, nitrification also helps preventing eutrophication and nutrient pollution.

**Primary treatment**. **Physical treatment** aiming at the **removing** of 20% BOD5 and 50% **suspended solids**13. Purely physical treatments are compost toilets and filter-sack methods. Septic tanks are considered **partially biological treatments** because they reach some degree of microbial conversion. Nonetheless they don’t satisfy Austrian WW quality standards. According to state-of-the-art treatment, mechanical methods like filtering and screening are used for supporting secondary biological treatment29.

**Secondary treatment**: **Biologic treatment** aimed at reaching wastewater quality higher than mere primary treatment. They take advantage of **microbial metabolism** to convert organic suspended substances into their mineral components. Usual methods are the continuous activated sludge processes (CAS) and 2 activated sludge variations: the suspended batch reactor (SBR) and the membrane bioreactor (MBR). Further treatment types are fixed bed reactors like the trickling filter (TF), the biofilter (BF) and the rotating biological contractor (RBC). Constructed wetlands (CW) have gained importance in recent years29. According to the **GWED**, each WWTP must be implemented with **biological removal of carbon and nitrification**3.

For a detailed description of each primary and secondary treatment type see the detailed work of Feigl, 201629.

**Not-state-of-the-art treatment:** WWTPs implementing **only primary treatment.** They don’t respect Austrian WW regulations as they don’t reach sufficient nitrification values2,3. Technologies that fall into this category are mere mechanic processes like Compost toilets and filter-sack, and partially biologically treatments like the septic tank. Another term referring to this category is **non-properly nitrifying WWTPS.**

# Methods

## Short overview of methodology

The complete workflow, including plots and graphics has been executed using Python 3.8. The most used packages are pandas 1.3.3 and geopandas 0.9. For the sake of open science and ensure the reproducibility of this work, a code protocol including a complete list of packages and requirements was produced and is freely accessible online under https://github.com/anakarpow/small\_WWTPs\_MSC

The raw data was firstly rearranged to a unified format and compared with a control publication to check for differences in the key categories, such as amount of WWTPs, PEs and technology type. The obtained database was linked to governmental geodata to obtain the spatial dataset. During this process some data was lost because of insufficient spatial reference. To monitor data losses, the spatial dataset was compared with the control publication and the obtained dataset for the same key parameters as above.

Diagram

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Figure 4 data workflow

## Original dataset

The original dataset contained basic technical and geographical features of Austrian WWTPS up to 500 PEs. It consisted of several categories like treatment type, design size and some geographical reference. The dataset was arranged in 9 different excel files originated from different publications1,6,8,29,30. Each of the files covers a federal state and was created using data from its online water-infrastructure registry (WISA). The dataset was started in 2016 and updated last time in 2021, although not in uniform way. In fact, while last data on Upper-Austria has been collected in 2021, data on some federal states has never been updated since 2016.

Table 3 dataset updates by federal state

|  |  |  |
| --- | --- | --- |
| **2016** | **2018** | **2021** |
| Vorarlberg | Carintia | Upper-Austria |
| Styria | Salzburg |  |
|  | Tyrol |  |
|  | Vienna |  |
|  | Burgenland |  |
|  | Lower-Austria |  |

## Workflow of data preparation and spatial referencing

The original files were not uniformly compiled and therefore individual processes had to be applied to perform the first three steps of the data preparation workflow: data wrangling, categorization and reformatting. In the first step, data types such as integers, floats and string had to be harmonized. Furthermore, misleading data entries, such as typos had to be disposed. This step ensures the correct functioning of further data processes. In the second step, categorization, the existing data categories were unified. For example, the technology type category has been harmonized according to ÖNORM standards. Furthermore, new data categories have been created. The reformatting step harmonizes tabular data in a single format ensuring that further data processes will work smoothly. To make sure no data was mistakenly altered or lost, the dataset obtained from these steps has been confronted with a control publication that used the same data source. The divergence was calculated as the percentual difference between the number of WWTPs in the dataset and the number of WWTPs in the control source (Fig. 5). To obtain Fig.6, the percentual difference between the number of WWTPs by state and technology in the dataset and in the control source was calculated.

Most of the original data did not contain spatial information in form of coordinates, but only as to which municipality it belonged to. Using the identifying number of the municipality as key, the data was merged with geodata provided by the Austrian government33. In this process the data that originally had no geographic reference was dropped. The resulting dataset contains only WWTPs that could be aggregated to at least their cadastral municipality. To monitor data losses in the spatial referencing process, the spatial dataset was compared to the previously obtained dataset by percentual difference as above (Fig.7)

To obtain the number of inhabitants by administrative unit, the spatial dataset has been merged with population data by *Statistik Austria*. In this case, using the cadastral municipality as linking key led to unacceptable data losses, because some cadastral municipalities have been renamed and/or assimilated with others since the collection of the original data. For this reason, all maps containing population data are projected on a political municipality level which has not been renamed or modified and allowed to maintain the integrity of the data.

After merging with the cited supplementary datasets, the data has been aggregated by cadastral municipality and concatenated to a single national dataset.

## Workflow of data analysis

After gathering it in a single dataset, referencing it to spatial coordinates and checking any irregularities the data has been analysed and interpreted. To study the distribution of Austrian infrastructure the dataset has been analysed in all its dimensions: temporal, technical and spatial.

Outdated WWTPs have been identified according to the treatment type. In fact, exclusive mechanical treatment doesn’t comply with the actual regulation that requires a biological nitrification step. The most accurate way to measure which municipalities mostly rely on outdated system would be to relate them to a dataset containing WWTPs of all sizes. Unfortunately, it does not exist because the design size between 500 and 5000 PE has not been surveyed yet. For this reason the total population per administrative unit was used as proxy of PE, which is a common approach in literature31,34.

# Results and discussion

## Unified dataset

The unified dataset is derived from the original data and contains WWTPS up to 500 PEs. Categories, like technology type, have been unified and made comparable. Each data entry contains a unique identifier, all original categories (year, technology type, PE) and the most precise geographical reference available. Most of WWTPs are tracked to their political municipality at least, whereas for other there was no further information available than federal state. In Fig.4 the obtained database is compared to a control publication35.

Chart, bar chart

Description automatically generated

Figure 5 percentual difference between control and own dataset

The number of tops of each bar shows the percentual difference in the number of WWTPS, where 0.0 means no difference at all. In 7 out of 9 federal states the obtained dataset is identical to its source. The control dataset of Lower-Austria is 0.03% bigger than the own data, probably because some WWTPs have been dismantled since then. On the other hand, the Upper-Austria dataset is bigger than the control source. This was expected because the own data is more recent than the control source. Due to the increased number of WWTPs in Upper-Austria the own dataset is 0.16% bigger than the control source. Burgenland and Vienna have such a small dataset that they are not visible at this scale.

Because the control publication only offers a technology type overview for WWTPS < 50 PE, the comparison for this category refers exclusively to this design size. Here the number of WWTPs by technology is compared between the datasets and its percental difference is calculated as the divergence within each technology group. For example, the datasets report a 20% difference in the number of exclusively Primary WWTPs in Upper-Austria (Fig.5).

Calendar

Description automatically generated

Figure 6 Percentual difference between data and control by state and technology for WWTPs <50 PE

In fact, the federal state of Upper-Austria shows significant divergences with the original dataset. As explained before this is due to its later update compared to the control source. Carintia, Salzburg and Tyrol show minor differences, especially in the primary treatment category. The continuous activated sludge process (CAS) category in Vorarlberg shows relevant difference. It must be mentioned that the dataset for this state is very small (n=23) and thus not very relevant for the whole analysis. Overall, the category Primary shows most differences. The categories constructed wetland (CW) and sequencing batch reactor (SBR) show negligible difference with the control source.

## Spatial dataset

This dataset contains only WWTPS up to 500PEs from the unified dataset that could be linked to their cadastral municipality. This is the dataset that has been analysed to answer the main goals of this work. All following thematic maps are based on this dataset.

Fig. 6 monitors the data losses due to spatial referencing, comparing the obtained dataset with the spatial data. About 95% of the WWTPs were tracked down to their cadastral municipality. Three federal states (Vienna, Vorarlberg and Burgenland) have been excluded because they completely lacked any spatial reference.

Chart, bar chart

Description automatically generated

Figure 7 data losses after the spatial aggregation

Lower-Austria has the highest loss percentage. All lost entries belong to the district of Amstetten and had not further spatial reference. Generally, the data losses here are due to missing cadastral municipality reference in the original data.

## Distribution of WWTPs

### Distribution by federal state

Most of WWTPS up to 500 PEs have been built between 1995 and 2015 (Fig.7). In fact, in all states the construction of WWTPs of this size has peaked in this twenty-year period. Since 2010 a pronounced degrowth is evident.

It is interesting to note the differences in the temporal activity of the federal states. While small WWTPs in Lower-Austria were built between 2003 and 2015, Carintia has built them before 2003. All other states have a relative homogenous distribution.

Chart, histogram

Description automatically generatedStyria has the highest number of WWTPS, followed by Carintia and Lower-Austria (Fig.8). Nonetheless Lower-Austria leads with the number of PEs covered, before Carintia and Styria. As expected, the number of small WWTPs < 50PE is overall higher than the number of WWTPs >50 PE. Styria is the only state where the coverage of WWTPs > 50PE is higher than their smaller counterpart.

Figure temporal distribution of WWTPs up to 500 PEs

Chart, bar chart

Description automatically generated

Figure 9 Distribution of WWTPs and PEs by design size

In Fig.9 the PE of small and medium WWTPs were plotted against the total population, to obtain a measure of how much of the population relies on them. Carintia has by far the highest coverage with 17.5%. In Austria 2% of the population relies on WWTPS between 50 and 500 PE and 3% rely on smaller decentralized WWTPs.

A picture containing graphical user interface

Description automatically generated

Figure 10 Percentage of population covered by WWTPs up to 500 PEs

### Distribution by tech type

The 1991 update of the WED clearly marks a turning point in the development of technology types, both in their quantity and treatment diversity. Whereas before most of the infrastructure was built with exclusively primary treatment, afterwards the diversification of treatment has developed. Especially Activated Sludge Process (CAS), Sequencing Batch Reactor (SBR) and Constructed Wetlands (CW) were built after 1991 (Fig.10). The trend appears similar for both design sizes. Fixed bed systems like the semi-fixed bed (SFB), trickling filter (TF) and bio-filter (BF) play a minor role.

Chart, histogram

Description automatically generated

Figure 11 temporal distribution of treatment technologies

Clearly most WWTPS with exclusively primary treatment were built before the 1991 WED that requires biological nitrification (Fig.11). Although not respecting the legal requirements for biological nitrification, about 280 WTTPs with exclusively primary treatment have been built after 1995 anyway. The last reported implementation was in 2014.

Chart, histogram

Description automatically generated

Figure 12 construction of primary treatment only WWTP by year

Fig.12 shows the percentual PE coverage by treatment technology. Note that the categories accounting for less than 1% of the total organic pollution in both design sizes (MBR, SFB,TF,RBC) are not included to maintain readability. The technology distribution follows a similar pattern in both design sizes. SBR, CAS and primary treatment are the major components, accounting together for about 60% of all the total capacity. Constructed wetlands are more frequent in smaller design sizes. As mentioned before, the category other (minor technologies like composting) is more developed in WWTPs from 50 to 500 PE. Rotating biological contractors are rare. On the other hand, WWTPs with only primary treatment are common and account for about 20% of the PEs in both design sizes. In more than 12% of the medium WWTPs the treatment type is unknown, whereas it is 1.8% for small WWTPs.

Chart, treemap chart

Description automatically generated

Figure 13 percentual distribution of treatment technologies

### Spatial distribution

The topographic map is based on data obtained from the Open Data Austria website at <https://www.data.gv.at/katalog/dataset/4369268e-e8c0-4255-b296-01e3a174caad>.

WWTPS up to 50 PEs are popular in Austria, as most municipalities contain at least one. The WWTPs are in mid to high altitudes and are nearly absent in lowlands (Fig.13). Given the mountainous character of Austria, they are evenly distributed overall the country. Only central Upper-Austria and most of Lower-Austria are largely without. Those areas have high connection rates as showed by Fig. 1.

Map

Description automatically generated

Figure 14 topographic distribution of small WWTPs (<50 PE)

Carintia has most municipalities with the largest number of small WWTPS. Also, Styria and Tyrol show an elevate presence of them (Fig.14). About the three missing federal states no statement can be done yet.

A picture containing text

Description automatically generated

Figure 15 Number of WWTPs < 50 PE by municipality

Because most of WWTPs in the dataset are smaller than 50PE, their distribution also defines the overall pattern. For this reason, Fig.15 only shows medium sized WWTPs (50-500PE). Tyrol has the most WWTPs between 50 and 500 PE, followed by Carintia. Otherwise, this design size is sparsely distributed throughout the country.

A picture containing text

Description automatically generated

Figure 16 Number of WWTPs >50 PE < 500 by municipality

In Fig.16 the number of PEs per municipality is projected. The overall distribution is identical to the WWTPs distribution in Fig.14.

Map

Description automatically generated

Figure 17 distribution of PEs by design size and municipality

In most of the municipalities less than 10% of the population relies on WWTPs up to 500 PEs (Fig.17). In Carintia a high population coverage is common and several municipalities even have a coverage higher than 90%. A similar pattern is observed in north-western Lower-Austria. These areas also contain municipalities where the entire population is covered by WWTPs of this size.

A map of the world

Description automatically generated with low confidence

Figure 18 percentage of population covered by WWTPs < 500 PE by municipality

## Distribution of non-state-of-the-art WWTPS

### Distribution by federal state and design size

In all analysed states at least 10% of the WWTPs up to 500 PEs are not state-of-the-art because unable to reach nitrification standards set out by WED and GEWD2,3 (Fig.18). By far Tirol has the largest share of outdated infrastructure. Furthermore, all federal states still have medium sized WWTPs with only primary treatment.

A picture containing chart

Description automatically generated

Figure 19 percentage of population covered only by primary treatment

Fig.19 shows the occurrence of medium sized non-state-of-the-art WWTPs by federal state. The highest number is in Carintia, where 60% of them are outdated. Tirol, Lower-Austria, and Styria follow with about 50 WWTPS. Salzburg and Upper-Austria have very few, with the latter having only one. About 35% of WWTPs up to 500 PE in Styria and Tyrol are outdated.

Chart

Description automatically generated

Figure 20 number of WWTPS with only primary treatment

To see the amount of medium sized WWTPS with only primary treatment in relation to the whole dataset, Fig.20 shows the number of WWTPS and PE together. In Carintia non-state-of-the-art nitrified PEs are equally distributed between small and medium sized WWTPS. In lower-Austria and Tirol most of them are treated by medium sized infrastructure. The remaining states show the opposite pattern, where most of the improperly non-state-of-the-art PEs are treated by WWTP up to 50PE.

A picture containing chart

Description automatically generated

Figure 21 Distribution of WWTPs up to 500 PEs with primary treatment only by federal state

Because federal states have varied sizes and number of inhabitants, to understand the distribution of non-state-of-the-art infrastructure the percentage of population covered by only primary treatment is shown in Fig.21. 7% of Carintia’s population relies on non-state-of-the-art WWTPS, by far the largest share in Austria. In fact, all other analysed states float around 1%.

A picture containing chart

Description automatically generated

Figure 22 percentage of population covered by primary treatment only

### Spatial distribution

Fig.22 identifies where most of non-state-of-the-art nitrified PEs are released. They are more usual in Tyrol and Carintia. Tirol shows one municipality where the WW equivalent of more than 1000 PEs is daily released without sufficient nitrification. Carintia has a few very small municipalities where also about 1000 PE are not treated according to nitrification standards. These are the by far the highest national values. In fact, most of others affected municipalities only have about 200 non-properly nitrified PE.

A picture containing text

Description automatically generated

Figure 23 distribution of PEs discharged after primary treatment only

Overall, in Austria the percentage of population relying on non-state-of-the-art infrastructure is about 1%. Styria and Tirol show some cluster-like pattern of municipalities where between 10% and 30% of the population relies on outdated WWTPS (Fig.23). Carintia shows another pattern, where the municipalities with at least 10% are evenly distributed, 30% to 60% values are not uncommon and one municipality reaches 100%. Another municipality where the entire population relies on non-state-of-the-art WWTPs is in in Salzburg.

A picture containing text

Description automatically generated

Figure 24 percentage of population relying on not state-of-the-art WWTPs

Fig. 24 shows the distribution of medium sized WWTP with only primary treatment. A clear cluster is visible in Tirol. This municipality in Tyrol has 10 medium sized WWTPS and all of them operate only primary treatment. Further municipalities with only primary treatment are sparsely distributed.

Map

Description automatically generated

Figure 25 distribution of not state-of-the-art WWTPs < 500 PE

## Spatial points analysis

In this section the 2 states that provided data with spatial points are plotted.

The datasets of Lower-and-Upper-Austria contained coordinates for most of their WWTPS. Of the 7.615 listed WWTPs, 704 (all belonging to Lower-Austrian district of Amstetten) did not have point coordinates. Of the WWTPs without point coordinates 50% use SBR treatment and 45% use CAS or CW. 6 WWTPs with only primary treatment had no point coordinates.

### Topographical distribution

To maintain readability Fig.25 only shows the main treatment types. The remaining treatment technologies have been incorporated into the *Other* category.

Most of the WWTPs are in Lower-Austria, where the mountains degrade into lowlands. Here hill land, submontane and mid-montane altitudes merge into each other, creating a complex topography. WWTPs are also frequent in mid-and-high montane areas in the northern part of the country. As expected, they are almost absent in lowlands and very high areas such as alpine environments.

Map

Description automatically generated

Figure 26 topographic distribution of WWTPs <500 Pe by treatment type

### Temporal distribution

Chart, histogram

Description automatically generatedLike the national trend, Lower-and-Upper Austrian WWTPs construction also has been more active in in the last 30 years (Fig.26). Most of the infrastructure was built between 1990 and 2019.

Figure temporal distribution of WWTPs <500 PE in Lower-and-Upper-Austria

Fig.27 shows the WWTPs up to 500 PE categorized by decades. The time between the beginning of the 20th century and 1950 has been categorized in a single bin, because of the low number of WWTPs built in it. The Mistelbach district (NÖ), in the north-eastern part of the country, has 95 WWTPs built before 1990, Scheibbs, Lilienfeld, Melk, St. Pölten Stadt have around 30 each. Upper-Austria has more than 300 WWTPs originally built before 1950.

Chart, map, scatter chart

Description automatically generated

Figure 28 administrative distribution of WWTPs <500 PE by time periods

### Only primary treatment

There are 328 WWTPs implementing only primary treatment in Upper-and-Lower Austria, of which 85% are in the latter federal state. They are mostly concentrated in the Mistelbach district (40%). 4 districts in central-western Lower-Austria (Scheibbs, Lilienfeld, Melk and St. Pölten Stadt) account for 50% of WWTPs with only primary treatment (Fig.28).

Map

Description automatically generated

Figure 29 topographic distribution of non-state-of-the-art WWTPs <500 PE

# Interpretation

### Data gathering and handling

For 8 out of 9 federal states an accuracy of over 99% with the control publication was achieved, practically meaning a perfect match. Deviations may be due to errors in the present or in the control workflow but are anyway not statistically relevant. For Upper-Austria, the nineth federal state, the 5% difference is assumed to be caused by the more recent version of data used in this work. In fact, the control publication has been published in 2018 whereas the Upper-Austria dataset was updated in 2021. Overall, the database is considered valid and identical with the original data. The first goal is thus achieved.

After the spatial referencing about 5.5% of the original data was lost. Unfortunately, there is no way to further minimize this loss because of data incompleteness. Three states were excluded from the analysis because they completely lacked any spatial reference: Burgenland, Vienna and Vorarlberg. They have a very small number of WWTPs (0.007% of the total) and their absence did not affect the results.

### Distribution of WWTPs

There are at least 27.418 small WWTPs (<50 PE) in Austria, covering 258.514 PE. Considering the infrastructure that may have been built since the update of the dataset and interpreting Fig.4 for an approximate growth rate, the real number of small WWTPs is at about 28.500. This means that about 3% of the Austrian population rely on WWTPs smaller than 50 PE. As stated by the Austrian wastewater report 2020, the remaining 2% of the population relies on cesspools that are regularly emptied to a WWTP31.

Small WWTPs are evenly distributed over the hilly and highland parts of the country (Fig 13.). In fact, their high number and population coverage is a result of the mountainous characteristics of Austria. Some clusters with higher concentrations are visible in Carintia, Styria and Lower-Austria.

Table 6 small WWTPs (<50 PE)

|  |  |  |
| --- | --- | --- |
| **State** | **WWTPs** | **PE** |
| Burgenland | 19 | 194 |
| Carintia | 6,958 | 61,459 |
| Lower-Austria | 4,544 | 50,653 |
| Salzburg | 1,649 | 20,573 |
| Styria | 10,488 | 83,708 |
| Tirol | 1,096 | 9,436 |
| Upper-Austria | 2,522 | 30,880 |
| Vienna | 13 | 280 |
| Vorarlberg | 129 | 1,331 |

The dataset reports 1.279 medium sized WWTPs covering 181.596 PE. Considering the growth trend, the real number is at about 1.450. They are sparsely distributed and mostly in Lower-Austria, Tyrol and Carintia.

WWTPs up to 500PEs are essential for WW coverage in Austria because of the geomorphological barriers that do not allow a uniform centralized coverage. In fact, of the 2.095 Austrian municipalities, about 5% (105) have most of their population covered by these design sizes.

Such municipalities account for 107.330 PE and most of them are in Lower-Austria (55.000 PE) and Carintia (36.000 PE). In Austria there are 1.138 and 105 municipalities with respectively less than 2.000 and 500 inhabitants. In 10% of both categories at least half of the population relies on WWTPs smaller than 500PE.

Observing the temporal development of small and medium WWTPs, the UWWTD seems to have had a remarkable impact on it. In fact, most of the infrastructure has been built in the last 20 years. Styria has the most WWTPs of this design size (about 10.000), followed by Carintia with 7.000 WWTPs. Although Lower-Austria has about 4.000 WWTPs, they cover about 120.000 PE because many of them are medium sized. In fact, Lower-Austria is first by absolute PE coverage, followed by Carintia (100.000) and Styria (90.000) (Fig.).

Nonetheless, when it comes to population coverage in percentage, as to say how much of the state’s population is covered by such infrastructure, Carintia is by far first with 17.5%. Lower-Austria and Styria follow with about 7%. The remaining states and the national average are at about 5% (Fig. 6). When it comes to small WWTPs, Carintia is first with 10%, followed by Styria (7%) and Salzburg (4%).

### Non-state-of-the-art WWTPs

If the UWWTD signed a pivotal point for the development of small wastewater infrastructure, the 1991 update of the WED did so for the development of treatment technologies. The update requires all infrastructure to be able to nitrify biologically. In the early phase of Austrian WWTPs most of them only had primary treatment. Starting with the early 90s this technology dropped nearly completely and SBR, CAS and CW started to be very popular (Fig.4). Today every second WWTP up to 500 PE operates one of these three technologies (Fig. 5).

The Austrian wastewater report 2020 states that there are 27.450 small WWTPs and that about 12.000 (44%) of them have only mechanical treatment. According to the present dataset about 23% of WWTPs up to 50 PEs (and up to 500 PE) have only primary treatment, as similarly stated by Langergarber5. It is unclear from where the mentioned report gathered its data and why the results differ so much from this work. To estimate the real number of WWTPs operating only primary treatment we must consider that not all states in the dataset are fully updated (Table.3) and that some of these plants may have been renovated since the survey. Furthermore, some inconsistencies have been found in the original data.

The dataset reports about 300 WWTPs operating only primary treatment that have been built after 1991. During a sample wise research in the respective water register, many of them where either they were not found or their treatment was not exclusively primary. The inconsistency with the technology type has been tracked back to the original data and was not influenced by the method. In fact, also Dopplinger reported inconsistencies in the Upper-Austria WIS regarding primary treatment only WWTPs built after 201028. It is likely that if some have been built after 1991, the real number is probably much lower. Finally, we can say that less than 23% of the WWTPs up to 500 PE operate only primary treatment and that probably the real number is between 15 and 20%.

Considering that the entire population has access to some form of sanitation (WWTPs or cesspools) and that the areas where decentralized WWTPs are more common (hilly rural areas) will not be subject of considerable population growth (Fig.3), the number of decentralized WWTPs is likely to stagnate in the future. In this optic, the maintenance and development of existing infrastructure becomes even more important.

In every analysed state at least 10% of the WWTPS up to 500 PE operate only primary treatment. Tyrol has the highest percentage (60%), followed by Carintia (33%) and Styria (20%). When it comes to organic load, Carintia leads with about 40.000 of non-state-of-the-art nitrified PE. More than half of them is treated by medium sized WWTPs. Carintia is also the state in where the percentage of population relying on non-state-of-the-art infrastructure is highest (7%), whereas all the others are at about 1%.

Furthermore, the discharge of non-properly nitrified WW is particularly concentrated in Carintia, where 3 very small municipalities (Pörtschach am See, Hüttenberg, Reifnitz) discharge the WW equivalent of more than 800PE/day. Tyrol also has one high discharge municipality (1000 PE) but its area is way larger and the discharge distributed over several WWTPS. Because of the high discharge and the very tiny area, the municipalities in Carintia may be a good study area to research the effect of small non-state-of-the-art nitrified discharge on the environment.

On the other hand, the situation is particularly good in Upper-Austria where only one WWTP is operating exclusively primary treatment. Interestingly most of non-state-of-the-art nitrified PEs in Tirol and Lower Austria are due to medium sized WWTPS. Renovating such systems, respectively 75 and 45 WWTPs, would mean a quick and effective improvement and would get rid of most of the non-state-of-the-art infrastructure in these states. This would mean a very effective transition towards complete compliance with the 1991 WED update. The federal state of Salzburg, having only 10 WWTPS between 50 and 500 PE that account for about 25% of non-state-of-the-art nitrified PEs, would also easily find a way towards compliance.

More difficult and costly would be in the remaining states, where most of non-state-of-the-art nitrified PEs are due to small sized WWTPS. Especially Styria has about 2.000 non-state-of-the-art small WWTPS, which makes it more difficult to improve quickly. Lower Austria has 500 non-state-of-the-art WWTPs. Most difficult would be in Carintia, where a high number of both small and medium sized WWTPS equally contribute to the total non-state-of-the-art nitrified organic load.

# Conclusion

In areas with regular or low steepness, such as the lowlands in eastern Lower-Austria, building a sewage system around a big WWTP is the most efficient wastewater management strategy. On the other hand, mountains and irregular geomorphological structure increase the investment and maintenance cost of a sewage channel. For this reason, in mountainous areas like Tyrol and Vorarlberg, the sewage channel was historically built along the bottom of the valley. But in large parts of Carintia and Styria the irregularity of terrain and settlement structures requires a decentralized WW management. In fact, these states have the most developed landscape of small WWTPS.

In Styria the development of small and medium WWTPS has historically been comparably high (Fig.4). Because of this and the massive infrastructure extension between 2003 and 2014, Styria has today the highest number of WWTPs up to 50 PE (10.000). They cover about 80.000 PE, corresponding to 7% of the population. About 2000 WWTPs operate only primary treatment, making Styria the second worse state by amount of non-state-of-the-art nitrified PE.

Carintia has the highest number of exclusively primary treatment PEs and WWTPs, leading to 7% of the population relying on such systems and the wastewater equivalent of 40.000 non-state-of-the-art nitrified PEs being released daily. More than half of them is treated by medium sized WWTPS. Carintia has also been historically active in the development of its decentralized WW management but unlike Styria, the main activity point was in the early 2000s. Carintia has about 7.000 WWTPS up to 500 PE covering 17.5% of its population. 10% of its population rely on decentralized WWTPs smaller than 50 PE.

Although it has only about 4.000 WWTPs up to 500 PE, Lower-Austria has the highest PE coverage because many of them are medium-sized. In fact, of 120.000 PE about 80.000 are covered by WWTPs >50 PE. Overall, 7.5% of the population relies on them and only 2.5% relies on smaller systems. In Lower-Austria the consistent extension of decentralized systems began relatively late (early 2000) and this could explain the relatively good compliance with biological nitrification requirements. In fact, Lower-Austria has the lowest percentage (10%) of WWTPs up to 500 PE operating only with primary treatment.

In Upper-Austria the sanitation of small settlements has been slowly but steadily increasing. There are about 2.500 small WWTPs covering 2.5% of the population. They are mostly distributed in the south-eastern northern part of the state, whereas large parts of central Upper-Austria don’t have any. Upper-Austria is first by compliance with the biological nitrification update of the WED with about 400 small WWTPs with only primary treatment.

This work highlights a high renovation potential for several areas in Austria, as about 23% of WWTPs up to 500 PE are still running only primary treatment, releasing daily the wastewater equivalent of more than 81.000 PEs.

There is very limited research on the impact of small discharges on natural water bodies. Nonetheless their effect shouldn’t be belittled. In fact, small WWTPs usually discharge in small water bodies that are more easily put out of balance. This work highlighted the areas in Austria where the discharge of not state-of-the-art nitrified PEs is more concentrated. Such areas would properly serve the research and monitoring of such yet unstudied effects.

In his 1971 seminal work on Austrian WTTPs, H. Donner states observes that “*As known in expert circles, an absolute representation [of the existing small WWTPs] is nearly impossible. On the one hand because the evaluation of single discharge permissions would mean an enormous bulk of work, on the other hand because of the high number of illegal (Dunkelziffer), and thus not registered, infrastructure.”*

About 50 years later the situation has changed but Donner’s statement is still partially valid. Today we can consistently exclude the presence of a relevant number of illegal WWTPs, knowing that all Austrian population is managing its WW according to European standards31. Compared to Donner and his research workflow, we obviously have the advantage of computers that make it faster and easier to collect and convey information. Nonetheless, the quality of information and its accessibility are still an issue that must be considered. Because of the relatively recent start in data collection, information on the topic is relatively difficult to gather and several European countries seems to suffer from it14,16. Austria, although highly digitalized, is no exception. Information on WWTPs smaller than 2.000 PE is collected by local authorities and there is no regular dataflow between them and their national counterpart. This led to the development of 9 different online registers that are freely accessible, but don’t support research purposes. In fact, the data on which the present work is based, required years of patience collection.

# Summary

## 2 to 4 pages :

This chapter should be two to four A4 pages at most and should answer the following questions in the context of the thesis: **Why? What? How? Where? When?**

In other words:

* The motivation driving your thesis, i.e. what topic did you choose? Why did you choose it? Why is this issue/problem relevant? For whom?
* The specific purpose of your research, i.e. what research question(s) you addressed (which is narrower than the overall topic)
* How you addressed it, i.e. what methods you used, what data you collected
* What your results are, i.e. the answers to the research questions
* The significance of your research, i.e. what new insights have you generated? What contribution does your thesis make to the literature? How as it advanced the state of knowledge?

The essential results of the thesis are to be summarised in clear sentences and if viable in one or two tables/figures.

The summary definitely gains clarity and clearness, if logically related results and the conclusions derived are structured in short sentences, which may be numbered continuously.

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# List of abbreviations

This section is optional. If relevant include a list of abbreviations and/or acronyms. This is mostly necessary if you are using many and/or uncommon abbreviations. If you only use a few abbreviations or only common abbreviations (e.g. EU for European Union), it is sufficient to spell them out the first time you use them in the Introductory summary.

# List of tables / figures

This section is optional. Lists of tables and figures can be included, if you feel these are helpful to the reader. For this you need to use the tool ‘add caption’ under references in MS Word to add figure captions (see section 2.4), this then allows MS Word to generate a list with the captions of all figures.

# Appendix

Larger graphical figures, construction plans, minutes, tables etc. can be added at the end of the thesis as an appendix or attachment. However, an attachment has to be numbered continuously. Furthermore, the number and content of the attachment has to be quoted on a separate sheet. In the text the attachment is shortly quoted by mentioning the attachment number (e.g. Attch. 1, appendix, etc.)

# Curriculum Vitae

As last part of the master thesis the curriculum vitae is to be included. Besides personal data (incl. picture) it should give information on the educational career in schools and universities, and possibly on the professional course of education including internships as well as exams taken.

The format of the curriculum vitae is optional (e.g. in table form).