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Editorial

As the Executive Editor of the International Journal of Sanitary Engineering Research, I am pleased to introduce the latest issue of our journal, Volume 15, Issue 1 for the year 2022. In this edition, we present three compelling articles that contribute significantly to the field of sanitary engineering.

The first article, authored by Ben Kingston and Graeme Mitchell, investigates food handlers' knowledge, attitudes, and behaviors regarding food safety in Liverpool's restaurants. The second article, by Urška Rozman, Tanja Kontič, Nataša Uranjek, and Sonja Šostar Turk, focuses on the optimization of chlorine disinfection in drinking water supply networks. The third article, authored by Petra Dolšak Lavrič, Andreja Kukec, and Rahela Žabkar, provides a comprehensive literature review on emission inventories and their applications.

Together, these articles represent a diverse range of topics within the field of sanitary engineering, addressing crucial issues related to food safety, water quality, and environmental considerations. We invite our readers to explore these articles to gain a deeper understanding of the latest developments and research in our field.

Aleš KRULEC
Executive Editor

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A survey study to investigate food handler's knowledge, attitudes and behaviour towards food safety and food practices in restaurants in Liverpool

Original scientific article

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Ben Kingston, Graeme Mitchell*

ABSTRACT

Food establishments are on the rise in the United Kingdom, producing a wide variety of cuisine to cater for a variety of tastes in a global market. However, a significant proportion of the population will experience a foodborne illness at some point in their lives, and in 2018 alone there were estimated to be 2.4 million food borne illness related cases in the UK [1]with a resulting 180 deaths per year. Whilst Local Authorities monitor and inspect these establishments periodically, the importance of those who work within food business cannot be underestimated. As such the aim of this research study was to explore food handlers' knowledge, attitudes, and behaviour towards food safety and food handling practices in restaurants within Liverpool. Using both convenience and snowball sampling, the research employed a quantitative online questionnaire to gather data from the target population of food handlers. The responses from 52 participants were then analysed using a combination of Microsoft Excel and SPSS version 28. The results of the study reveal that food handlers in Liverpool food businesses have a generally satisfactory level of food safety knowledge; their attitudes expressed demonstrated a strong positive approach and they engage in safe behaviour. However, the results show some areas of concern: knowledge surrounding harmful pathogens was lacking; behaviour in relation to the use of mobile phones in the kitchen and attitudes towards attending work whilst unwell. Therefore whilst the overall knowledge, attitude and behaviours of food handlers appears acceptable that does not mean they do not pose risk to customers. Whilst all participants had received training, this did not always translate into improved food handling knowledge, attitudes or behaviours. Training, therefore, must be tailored to reflect the needs to the individual with the understanding that knowledge, attitudes and behaviours are linked.

Key words: Food safety, foodborne illness, food handler, knowledge, attitude, practices

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INTRODUCTION

Food-borne illnesses are a substantial burden to public health and the nation's economy [2] A large majority of the population will experience a foodborne illness at some point in their lives, and in 2018 alone there were estimated to be 2.4 million food borne illness-related cases in the UK [1] with a resulting 180 deaths per year caused by foodborne illnesses from 11 pathogens [3] The WHO regards Salmonella, Campylobacter, and E.Coli among the most common foodborne pathogens that affect millions of people annually, sometimes with severe and fatal outcomes [4]. This signifies the importance of making sure food is not contaminated with potentially harmful bacteria, viruses, toxins, parasites, and chemicals. Food contamination has far-reaching effects beyond direct health consequences and has significant economic impacts on society through direct healthcare costs and indirect costs such as lost productivity. The cost of food-borne illness is estimated at around €1.14 billion each year, including the impact of illness on individual well-being, loss of earnings, and the cost of hospital admission [5].

Food has the potential to become contaminated at any point during its production, distribution, and preparation, and the primary responsibility lies with food producers. However, a large proportion of food-borne illness incidents are caused by food improperly prepared in food establishments and not all food handlers understand the roles they must play when it comes to protecting the health of the wider community [4]. There are many opportunities for food contamination to take place during the preparation process before the food reaches the consumer. Contamination of food can be compounded by people's limited knowledge of food safety practices, potentially increasing the risk of food-borne illnesses. A large proportion of food poisoning is attributed to food served in restaurants and is completely preventable. Reasons for its occurrence include: negligence, ignorance, failure to implement good hygiene practices, and in the case of commercial food premises poor management. Food businesses are responsible for ensuring that their food is safe under food regulations. It is also recognised that some food handlers do not always apply these practices, despite being aware of them, and the reasons why the kitchen can become a risky place are complex [6]Inappropriate handling practices can cause food contamination and food-borne illness consequently, impairing the health of the consumer [6]. Research by Griffith and Redmond [7] report that food safety is not just a microbiological problem but that it also has a major behavioural component. The top three factors resulting in foodborne illness outbreaks are: poor personal hygiene, cross-contamination, and time/temperature control. All are directly related to food-handler error [8].

Food businesses are legally obliged under food regulations to ensure that their practices minimise the risk of harm to the consumer. They must comply with food safety legislation to manage food hygiene and food standards to ensure food is safe to eat. The Food Standards Agency (FSA) [9] reported that inspections by both Environmental Health in the public sector and audit reports in the private sector of food businesses have identified significant degrees of non-compliance with either statutory requirements or industry codes of practice. Whereas some non-compliance may only affect food quality, other areas may have a major impact on food safety. A more recent survey conducted by the FSA found that 45% of consumers in England reported that the safety of food served by UK restaurants and takeaways was a concern to them [5].

However, this has not stalled the industry. Spending on restaurants, cafes, and similar food outlets in the United Kingdom on the rise: in 2019, consumer spending reached approximately €114 billion [10] In recent years local authorities have seen a decline in resources (staff, money, time) that aid the delivery of food safety controls. According to the FSA, between 2012 – 2018 spending on food hygiene controls fell by 19% from €142 million to €114 million [5]. This relates to staff reduction, at a time when demand for their services is increasing.

Purpose of the study

While numerous research has identified the importance of food handling practices [8], it is generally considered that good overall levels of knowledge of food safety will lead to beneficial behavioural changes involving food practice [11] Bandura [12] suggests that several constructs underlie the process of human learning and behavioural change, and one such variable known as "Outcome Expectations" is the judgement of the likely consequences a behaviour will produce. In relation to food safety the importance of these expectations may also be a driver.

However, concerns expressed by Griffith and Clayton [13] suggested that other factors, including staff attitudes can limit or prevent improvements in staff practices. The effective application of such knowledge with regards to influencing attitudes and behaviours are essential in ensuring the consistent production of safe food in restaurant operations.

This research aims to explicitly look at the knowledge, attitudes, and behaviours (KAB) of restaurant food handlers in Liverpool to understand and identify any limitations and inadequacies. KAB is an important theoretical model of health education, which asserts that behaviour change is affected by knowledge and attitude [14] Understanding the knowledge, attitudes, and behaviours of food handlers are important for identifying where the risks to consumers' health is coming from and how it may be possible to prioritise actions in order to develop more efficient training methods in food safety.

METHODS

Study Design

The research adopted a quantitative methodology approach using a survey design. Quantitative research has the advantage of determining how common a phenomenon is, can detect associations between measured variables and make generalisations [15]. Quantitative data also allows for knowledge, attitudes, and behaviours to be quantified and the results can be generalised from the sample population to a larger population.

Questionnaires

A descriptive survey design was the chosen method of data collection for this study. Descriptive surveys can be used to gather demographic, attitudinal and behavioural information [16] which is concerned with summarizing and describing data [17]. This fitted in well with the aim of the study as it was also important to gather participants' behavioural information with the other elements.

The questionnaire was constructed specifically for this research and consisted of 4 distinct sections: demographic information, food safety knowledge; food safety attitudes and food safety behaviours.

The demographic information section captured information such as the age, gender and role of the participants. The food safety knowledge section of the questionnaire included 15 questions, each consisting of 4 possible options (one option was correct and the other 3 incorrect) and participants could select one option. The food safety attitudes section of the questionnaire consisted of 10 statements and participants indicated their strength of agreement with each statement using a Likert scale. Similarly, the food safety behaviours section of the questionnaire also consisted of 10 statements, with participants indicated their strength of agreement with each statement using a Likert scale. The questionnaire was piloted with 3 food handlers before going live to participants and some minor amendments were made to the questionnaire to ensure greater clarity. Those participants who took part in the piloting were not included in the final sample for data analysis.

Sampling Process

Different types of data collection methods were reviewed before deciding upon a combination of strategies known as convenience and snowball sampling.

According to Denscombe [18] convenience sampling is a type of nonprobability sampling strategy that allows the researcher to gather information from participants that are easily accessible and when there are time and cost limitations in collecting feedback. Snowball sampling was also used to encourage respondents to refer the survey on to other potential participants - in theory the sample then snowballs in the process of accumulation as each located subject suggests other subjects [19]. Each person that completed the survey was asked to nominate some other person who they felt would be relevant for the purposes of the study. This technique is effective for building up a reasonably sized sample, especially when used as part of a small-scale research project [18]. The target population was food handlers, aged 18 years and over, and currently working within the hospitality sector in Liverpool was chosen.

Data Collection

As this research was undertaken as part of the BSc (Hons) Environmental Health degree programme, prior to collection of any data, ethical approval was obtained from Liverpool John Moores University. Whilst the secondary researcher is a qualified Environmental Health practitioner and is currently programme leader for the degree programme, the primary researcher has a background within the food industry and has worked extensively in the hospitality sector within Liverpool. Therefore using existing contacts within the hospitality industry to act as gatekeepers, a link to the questionnaire was circulated to the employees of four different food businesses. Participants could then access the link to the questionnaire, which enabled them to complete it online. The questionnaire was available in October 2021 for two weeks, and initially the researchers received forty responses. As previously stated, all participants were asked to forward the link on to any other food handlers and so a further twelve participants took part in the survey, as a result of this snowball sampling. In all there were 52 participants in the research. The design of the questionnaire did not allow the researcher to determine which responses were from convenience sampling compared to snowball sampling.

Data Analysis
Descriptive data from the questionnaires was analysed using Microsoft Excel. In order to undertake a statistical analysis of the data, SPSS was used to perform a chi squared test, which explore the relationship between variables. In these tests, a p value was generated and if the p value was less than 0.05, it was held that the relationship between the variables was statically significant.

RESULTS

Demographic data
In total 52 participants were recruited to the research. The majority of respondents were male 71% (n=37) with female (n=13) and 4% (n=2) preferring not to say.
In terms of age distribution, 25 – 34 years olds represent the largest percentage with 50% (n=26). The second largest age group was the 35 – 44-year-olds with 21% (n=11); the third largest age group was the 18 – 24 year olds with 17% (n=9) and fourth age group was 45 – 54 year olds with 10% (n=5) and finally the last group was 55 year olds at 2% (n=1).

For participants, 44% (n=23) are employed in chef de partie roles, 21% (n=11) are managers in food handling businesses, 11% (n=6) are currently in head chef roles, 11% (n=6) are sous chefs, 6% (n=3) work as prep chefs and 6% (n=3) are kitchen porters.

Figure 1 shows the years of experience gained by the participants, with over half (55%, n=34) having over 10 years' experience within the industry.

Figure 1: Participants Years of experience as a food handler

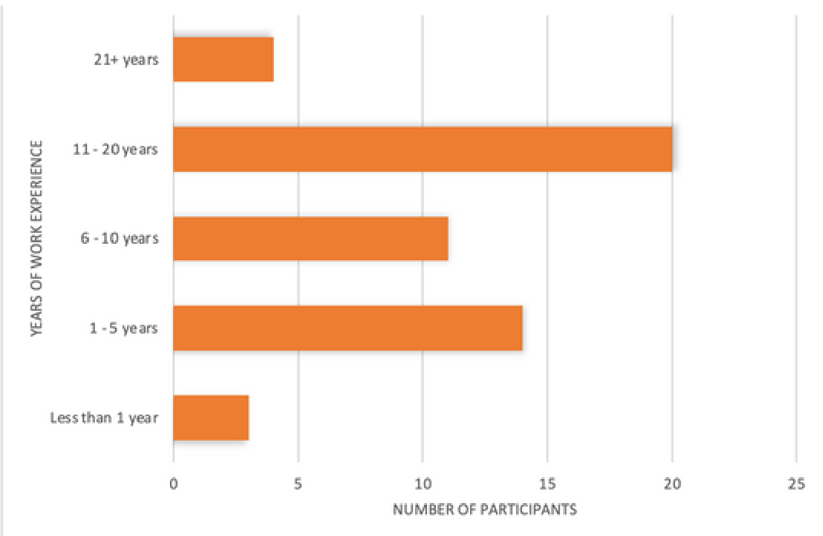
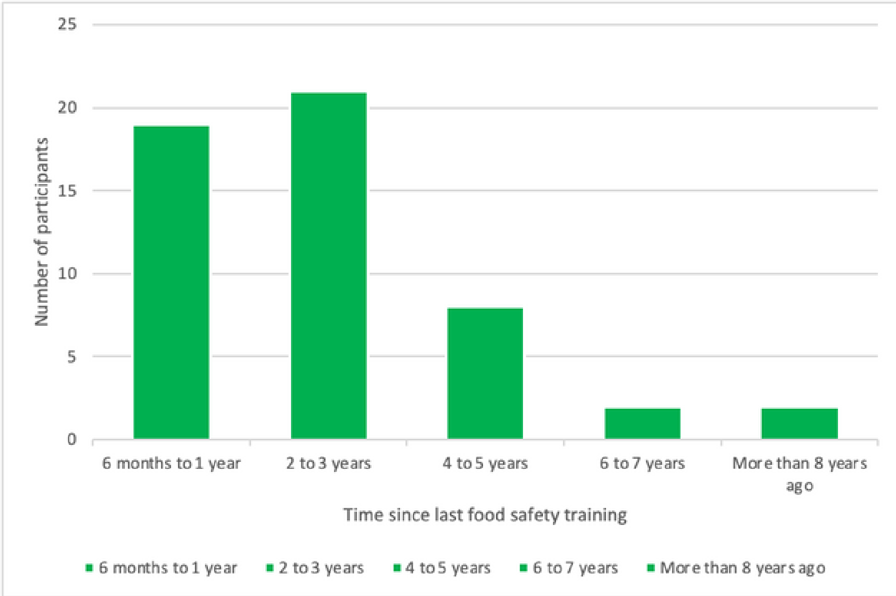


Figure 2 shows the most recent training experience the participants have gained. This training was provided in house by each of the food business involved and consisted of short online courses for employees to complete

Figure 2: Time since participants' last food safety training



Participants Food Safety Knowledge

Table 1 below shows participants responses to a range of food safety knowledge questions. For each question the participant was asked to select one answer from a number of possible responses, with only one of the responses being correct. The table shows the percentage of participants who answered each question correctly (total number of respondents n=52)

Table 1: Participants responses to food safety knowledge questions

Question asked	Correct response %	Incorrect response %
Food contaminated with food poisoning bacteria would most likely?	47%	53%
In which of these will bacteria multiply fastest?	94%	6%
What is the best method of controlling bacterial growth on food?	33%	67%
Which one of these statements about bacteria is true?	81%	19%
Which pathogenic bacteria is most commonly associated with chicken and eggs?	97%	3%
Food poisoning bacteria will multiply readily between what temperatures?	100%	0%
Food regulations require that you cool hot food ready for refrigeration within how long?	65%	35%
In the UK, food businesses must inform you under food law if they use any of the __ allergens as ingredients in the food and drink they provide.	84%	16%
The temperature in your freezer should be?	92%	8%
Which of the following is not a high-risk food?	85%	15%
A refrigerator has 3 shelves; on which shelf do you think raw meat should be placed?	97%	3%
At what temperature should food be hot-held for service?	75%	25%
The best way to wash your hands is by using?	92%	8%
At work, the best way to dry your hands after washing is?	90%	10%
Food should not be left at room temperature for more than?	89%	11%

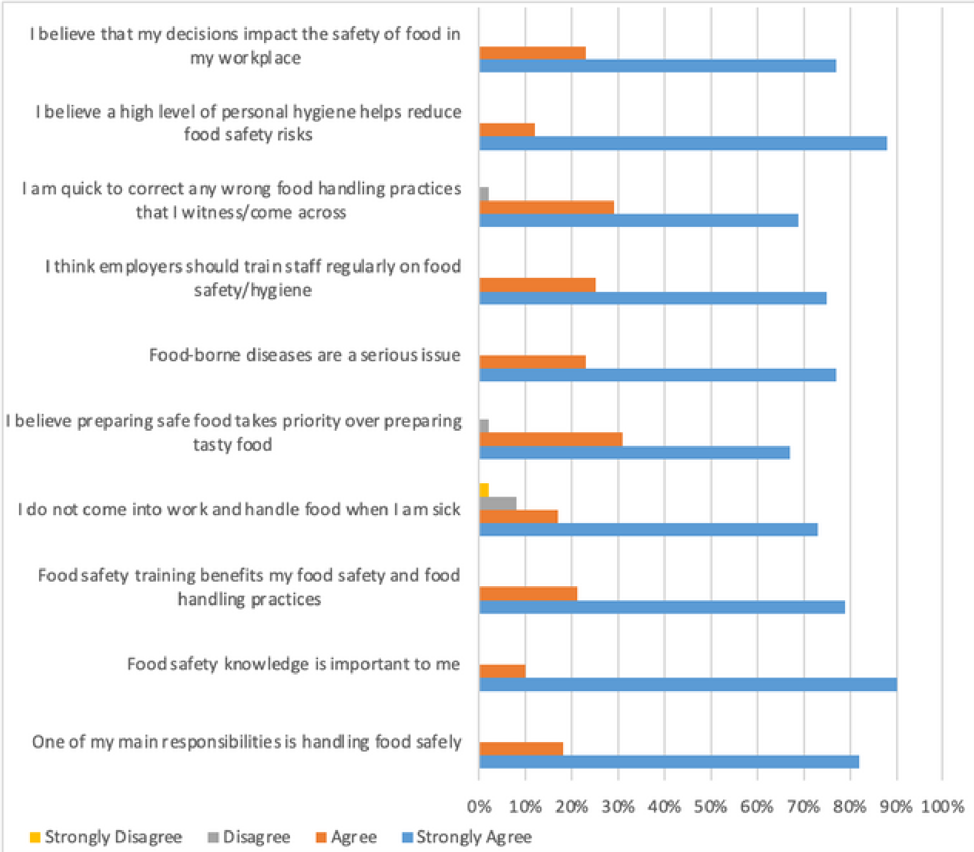
The average score achieved by participants was 78%, with no participant achieving 100%. The highest individual mark was 93% achieved by 5 respondents and the lowest individual mark was 53% achieved by 2 respondents.

Food handlers have the ability to reduce food poisoning by either preventing the growth or survival of bacteria or by preventing contamination of foods. The findings from this study show that, based on the sample that took part in the questionnaire, the overall food safety knowledge of food handlers was found to be good. However overall knowledge of bacteria was found to be poor, with 67% unable to correctly identify the best method of controlling bacterial growth on food. Over half 53% of food handlers did not know that food poisoning can be caused by food that looked, smelt, and tasted normal. This mirrors findings by Walker et al [20] that clearly revealed "food handlers did not understand that organoleptic assessment of food was insufficient to identify food contaminated by pathogenic bacteria and therefore they were relying on incorrect physical attributes for food safety control". Thirty-five of the respondents were also unaware of the importance of time/temperature control required when cooling cooked foods ready for refrigeration. Previous studies support these findings, and emphasize that a lack of knowledge from exists from food handlers around time-temperature control of foods [21] [22]. According to the WHO, time and temperature abuse by food handlers is one of the main reasons for causing foodborne outbreaks [23].
It is a possibility that the lack of continuous or recent training and food safety reinforcement may have contributed to the lack of food hygiene knowledge concerning a number of key questions. When individual knowledge scores were analysed, this produced an average score of 78% (calculated by looking at the average score achieved for each participant). This can be considered satisfactory if compared with the level 1 Basic Food Hygiene Certificate that has a twenty-question multiply-choice test and carries a 75% pass mark. The importance of satisfactory food knowledge is expressed by Bas et al [24] "the significant presence of knowledge is a motivation for adequate practices and justify the necessity of training. Knowledge allows the handler to modify its practice since he has motivation to change his behaviour". However, concerns expressed [13] suggests that "it is unwise to automatically assume that improved knowledge will lead to behavioural changes involving improved practice, and also suggested that other factors, including staff attitudes can limit or prevent improvements in staff practices".

Participants Food safety attitudes

The attitudes of participants towards food safety is illustrated in figure 3, in which participants where asked to indicate the extent to which they agreed with each statement.

Figure 3: Participants food safety attitudes.



Additional statistical analysis was undertaken to compare the level of participant's knowledge with their attitudes. Only the relationship between the variables: knowledge score and attitude statement, 'I do not come into work and handle food when I am sick' was proven to be statistically significant, with a p-value of 0.041 (where $p<0.05$ is statistically significant)

Food handler attitude is a critical factor that can affect food safety behaviour and practices leading to foodborne illnesses. Zanin explains that, "attitude can be seen as the main link between knowledge and practices; food handlers demonstrating a positive attitude are more likely to translate them into safe practices" [24]. Therefore, it may be appropriate to say that a food handler demonstrating a negative attitude may practice risky behaviour. The findings from this study show that respondents demonstrated significantly positive results for food safety attitudes. However, there was a more varied response to the statement, 'I do not come into work and handle food when I am sick', with 8% disagreeing and 2% strongly disagreeing. Although this percentage is low it is still concerning that 10% of food handlers felt it was acceptable for them to work in food preparation areas while sick. A statistical analysis revealed that the level of participant's knowledge was related to this attitude, with those scoring lowest on the knowledge scale, more likely to attend work when ill. This can be viewed as a significant given that an infected food handler has been described as a contributing factor in 12% of outbreaks in England and Wales [25]. FSA best practice recommends food handlers displaying symptoms of illness should be excluded from the business until such time as evidence to the contrary is received, removing the potential risk of contamination of food [9].

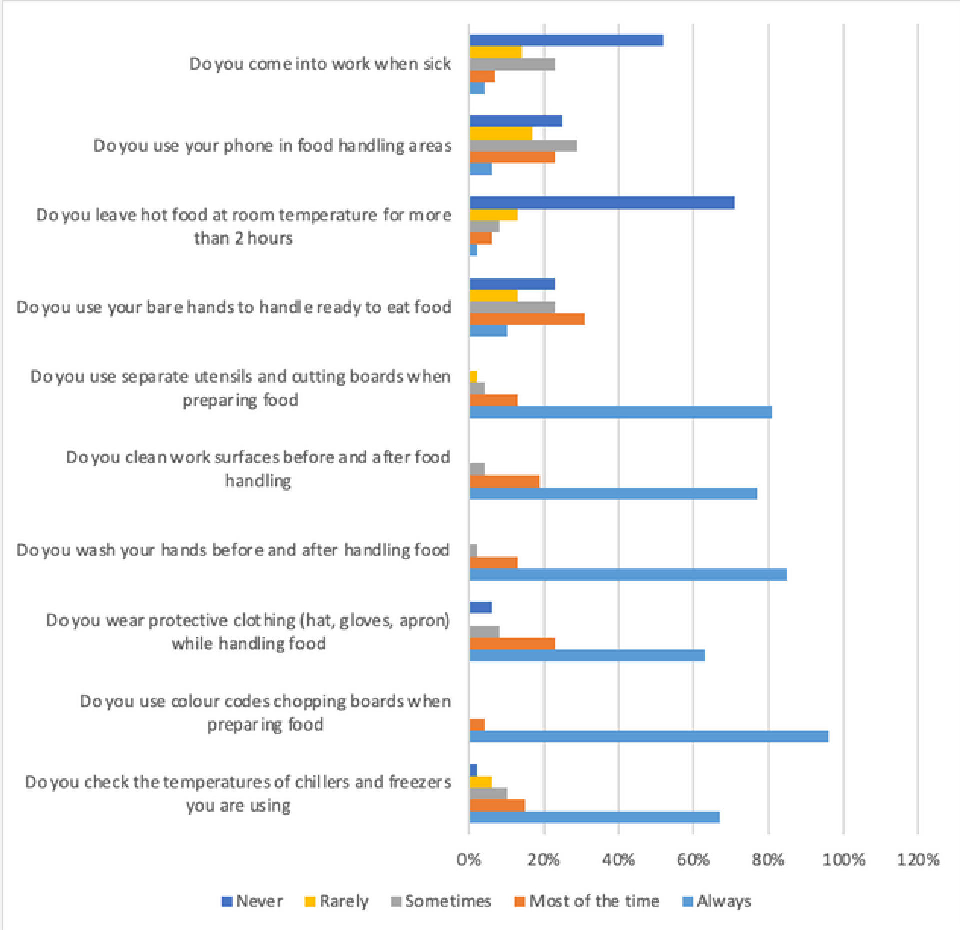
These findings are lower than those published by Al-Kandari et al [23] who evaluated the knowledge, attitudes and practices of 402 food handlers in Kuwait restaurants and had 24.4% of respondents who did not strongly agree that food handlers should not come to work when sick. This concept is sometimes termed as presenteeism, which is used to describe the phenomenon of working through illness and injury. This was not a surprising result to uncover for the researcher as social and financial pressures in the workplace can influence people's behaviours Hospitality employees not in senior roles are often paid on an hourly basis and the impact that being sick can have on an individual's income often drives them to work even when sick, regardless of the consequences. Dewe, Keefe and Small [26] propose there may be a number of issues that can prevent staff absence, including attitudes of managers and work colleagues, sickness presenteeism may be more likely where staff replacements are hard to find. The Sainsbury Centre for Mental Health come this with research that suggests "the larger effect and mental ill-health is particularly likely to be manifest in the form of presenteeism rather than absenteeism" [27]

Further results gathered suggested that 77%, 75%, and 82% of the respondents strongly agreed with the following statements respectively: their decisions impact the safety of food in the workplace, that employers should provide regular training on food safety/hygiene and one of their main responsibilities is handling food safety. All of which demonstrate positive attitudes towards food safety practices but it would be wise to inject a note of caution at this point. Research [28] indicates that food handlers believe that they are less likely to cause food borne illness compared to their peers, perhaps giving a false level of their perceived skills and knowledge. So even with a positive attitude it is critical that effective training, strong knowledge foundation, awareness and implementation of good food handling practices is applied. According to Ko [29] "Positive attitudes are a necessary factor for the transformation of knowledge into appropriate practices by food handlers, being a mediator between knowledge and practices".

Participant's behaviours towards food safety practices

The Participant's behaviours towards food safety practices is illustrated in figure 4, in which participants were asked to indicate the extent to which they agreed with each statement.

Figure 4: Participant's behaviours towards food safety practices



TThe responses to the food safety practices questions were then divided into 2 groups – a group which indicated behaviour that posed a risk to food safety (risky behaviour) and group which indicated behaviour that would maintain food safety (safe behaviour).

The safe behaviour group was comprised of those responses to questions 1-4, which were never and rarely and forquestions 5-10, which were always and most of the time.

The risky behaviour group was comprised of those responses to questions 1-4, which were sometimes, most of the time and always and for questions 5-10, which were never, rarely and sometimes. For each question these responses were added together provide an overall indication of each behaviour.

Table 2 shows the results of the food safety practices questions divided into safe and risky behaviour, with overall 78% of the answers given displayed safe behaviour towards food safety practices. While 22% of respondents' answers demonstrates risky behaviour towards food safety practices

Table 2 – Food safety behaviours divided into Safe and Risky behaviour.

Food Safety Practices	Risky (%)	Safe (%)
Do you come into work when sick?	34%	66%
Do you use your phone in food handling areas?	58%	42%
Do you leave hot food at room temperature for more than 2 hours?	16%	84%
Do you use your bare hands to handle ready to eat food?	59%	46%
Do you use separate utensils and cutting boards when preparing food?	6%	94%
Do you clean work surfaces before and after handling food?	4%	96%
Do you wash your hands before and after handling food?	2%	98%
Do you wear protective clothing (hat, gloves, apron) while handling food?	14%	86%
Do you use colour coded chopping boards when preparing food?	0%	100%
Do you check the temperature of chillers and freezers you are using?	18%	82%

Table 3 summarises the relationship between the knowledge scores and all ten variable behaviour questions. The table shows no significant relationships between knowledge and the majority of the behaviour variables, generating no statistical significance except for the question, 'Do you use separate utensils and cutting boards when preparing food?' with a p-value of 0.03 (where $p<0.05$ is statistically significant).

Table 3: Statistical analysis for the relationship between participant knowledge scores and behaviour

Food Safety Practices	Significance
Do you come into work when sick?	0.727
Do you use your phone in food handling areas?	0.491
Do you leave hot food at room temperature for more than 2 hours?	0.401
Do you use your bare hands to handle ready to eat food?	0.615
Do you use separate utensils and cutting boards when preparing food?	0.03
Do you clean work surfaces before and after handling food?	0.067
Do you wash your hands before and after handling food?	0.357
Do you wear protective clothing (hat, gloves, apron) while handling food?	0.665
Do you use colour coded chopping boards when preparing food?	n/a
Do you check the temperature of chillers and freezers you are using?	0.222

When assessing the overall behaviour of participants their overall scores were categorized into protective and risky behaviours. Up to 58% of respondents demonstrated risky behaviour by using their phones in food preparation areas. In addition, 59% of them handle ready to eat foods with their bare hands while working. Only one relationship provided a statistically significant result, which was between knowledge score and behaviour question, 'do you use separate utensils and cutting boards when preparing food?' which generated a value of $p=0.03$This shows that participants' knowledge translates into safety behavioural practices regarding cross contamination. For the majority of food safety behaviours, the results were not statistically significant as the p-value was greater than $p>0.05$. In this study it translates to there being no significant relationship between respondents' knowledge and their protective behaviours towards food safety. This mirrors findings by Bas et al [30] who found that good food safety knowledge does not necessarily result in good handling practices. Although a study conducted by Abdul-Mutalib et al [31] which evaluated the knowledge, attitudes and practices of 64 food handlers working in restaurants in Malaysia found evidence to suggest good knowledge led to good practice.

It has been suggested that knowledge is the main precursor to behavioural change and over the years much of the existing training, particularly formal training is designed using the knowledge, attitudes and practices (KAP) model [25]. Rennie [32] argues that this model is flawed, and that, "too little emphasis is placed on changing individuals' beliefs and attitudes and that the model fails to take into account cultural, social and environmental issues". Although training may bring about an increase in food safety knowledge this does not always translate in a positive change in food handling behaviour

CONCLUSION

In conclusion, the results of this study show participating food handlers' knowledge, attitudes and behaviour levels to be satisfactory. This appears to be in line with the findings of Ahmed et al [33], who similarly established that food handlers had a good attitude to food safety and practices Therefore, if we applied these results to the wider population of food handlers across Liverpool, consumers should be fairly safe when eating out. Even though this is the case certain aspects of participants' food safety knowledge are limited and require improvement, particularly relating to foodborne pathogens. The consequences of poor food safety knowledge in areas such as these could increase the risk associated with food borne illnesses.

The knowledge, attitude and behaviours of food handlers cannot be viewed as separate entities that can be tackled or addressed in specific ways but are interconnected. Each variable is interlinked, each affecting the other. What is clear is that no one method or tactic can be used to drive all three towards perfect food safety practices.

These findings support previous research that suggests whilst food safety and hygiene training should always be encouraged it does not always translate into improved food handling attitudes or behaviours. There is also the argument put forth by Clayton et al [25] that food safety and hygiene training will only be effective if the systems and resources are in place to encourage food handlers to implement good practice.

Individuals learn and adapt in different ways and so any effective training must be tailored towards the needs to the individual. It is also the case that many people enter the hospitality and food industry without formal training, so the value of in-house training cannot be underestimated. The effectiveness of such training is very much dependent on the attitudes of managers and senior staff members and the culture of an organisation. Indeed Griffith et al [34] see the development of a food safety culture, where employees see the responsibility for ensuring food safety is shared equally is key to ensuring food safety. A continuous and varied training approach can prove to be most beneficial in these circumstances. Positivity is key to driving food safety forward, but food handlers must also be made fully aware of the consequences of risky behaviour.

REFERENCES

[1] FSA (2020a) The Burden of Foodborne Disease in the UK 2018 [online] Available at: https://www.food.gov.uk/sites/default/files/media/document/the-burden-of-foodborne-disease-in-the-uk_0.pdf [Accessed: 06/04/2021]

[2] Young I, Waddell L. Barriers and Facilitators to Safe Food Handling among Consumers: A Systematic Review and Thematic Synthesis of Qualitative Research Studies. PLoS One. 2016 Dec 1;11(12):e0167695. doi: 10.1371/journal.pone.0167695. PMID: 27907161; PMCID: PMC5132243.

[3] Holland, D., Thomson, L., Mahmoudzadeh, N. and Khaled, A. (2020) Estimating deaths from foodborne disease in the UK for 11 key pathogens. BMJ open gastroenterology, 7 (1), e000377.

[4] WHO (2020a) Advancing food safety initiative: strategic plan for food safety including foodborne zoonoses 2013-2022. 2014.

[5] NAO (2019) Ensuring food safety and standards [online] Available at: https://www.nao.org.uk/wp-content/uploads/2019/06/Ensuring-food-safety-and-standards.pdf [Accessed: 21/3/2021]

[6] Greig, J.D., Todd, E.C., Bartleson, C.A. and Michaels, B.S. (2007) Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 1. Description of the problem, methods, and agents involved. Journal of food protection, 70 (7), 1752-1761.

[7] FSA, C. and Redmond, E. (2009) Good practice for food handlers and consumers. In: (ed.) Foodborne Pathogens.Elsevier. pp. 518-543.

[8] FDA (2018) Report on the Occurance of Foodborne Illness Risk FActors in Fast Food and Full-Service Restaurants 2013-2014 [online] Available at: https://www.fda.gov/media/117509/download [Accessed: 5/04/2021]

[9] FSA (2005) UK Survey of hygiene standards in food premises 2005 [online] Available at: https://old.food.gov.uk/sites/default/files/multimedia/pdfs/premisessurvey05.pdf [Accessed: 12/01/2022]

[10] Satista (2021) Consumer spending on recreational and cultural services in the United Kingdom (UK) from 2005 to 2021 [online] availabel at https://www.statista.com/statistics/429767/consumer-spending-on-culture-and-recreation-in-the-united-kingdom-uk/ [accessed 13th November 2021]

[11] Naing, Claire L.; Bayer, Steven H.; Van Elslande, Pierre; Fouquet, Katel (2007): Which factors and situations for human functional failures? Developing grids for accident causation analysis. Loughborough University. Report. https://hdl.handle.net/2134/8438

[12] Bandura, A. (1987) Social Foundations of Thought and Action: A Social-Cognitive View Social Foundations of Thought and Action: A Social-Cognitive View, by Bandura Albert. Englewood Cliffs, NJ: Prentice-Hall, 1986, 617 pp., cloth. The Academy of Management review, 12 (1), 169-171

[13] Griffith C. J. and Clayton D. (2005), "Food Safety Knowledge, Attitudes and Practices of Caterers in the UK," in Bolton D. J. Maunsell B., Eds., Restaurant and Catering Food Safety, Teagasc, Dublin, Ireland,.

[14] Schneider, B.P. and Cheslock, N. (2003) Measuring results. Citeseer.

[15] Dahlberg, L. and McCaig, C. (2016) Practical research and evaluation : a start-to-finish guide for practitioners. London : SAGE.

[16] O'Leary, Z. (2017) The essential guide to doing your research project. 3rd edition. ed. Los Angeles : SAGE.

[17] Punch, K. (2014) Introduction to social research : quantitative & qualitative approaches. Third edition. ed. Los Angeles: Los Angeles : SAGE.

[18] Denscombe, M. (2017) The good research guide : for small-scale social research projects. Sixth edition. ed. London : Open University Press, McGraw-Hill Education.

[19] Babbie, E.R. (2016) The practice of social research. Fourteenth edition. ed. Boston, MA, USA: Boston, MA, USA : Cengage Learning.

[20] Walker, W.E., Harremoës, J., Rotmans, J.P., Van der Sluijs, J.P., van Asselt, M.B.A., Janssen, P.H.M. and Krayer von Krauss, M.P. (2003) 'Defining uncertainty: a conceptual basis for uncertainty management in model-based decision support', Integrated Assessment, Vol. 4, No. 1, pp.5–17.

[21] Gomes-Neves, E., Araújo, A.C., Ramos, E. and Cardoso, C.S. (2007) Food handling: Comparative analysis of general knowledge and practice in three relevant groups in Portugal. Food control, 18 (6), 707-712.

[22] Al-Kandari, D., Al-abdeen, J. and Sidhu, J. (2019) Food safety knowledge, attitudes and practices of food handlers in restaurants in Kuwait. Food control, 103, 103-110.

[23] WHO. (2020b) Food Safety [online] Available at: https://www.who.int/news-room/fact-sheets/detail/food-safety[Accessed: 15th November 2021]

[24] Zanin, L.M., da Cunha, D.T., de Rosso, V.V., Capriles, V.D. and Stedefeldt, E. (2017) Knowledge, attitudes and practices of food handlers in food safety: An integrative review. Food Research International, 100, 53-62.

[25] Clayton, D.A., Griffith, C.J., Price, P. and Peters, A.C. (2002) Food handlers' beliefs and self-reported practices. International journal of environmental health research, 12 (1), 25-39.

[26] Dewe K, Keefe V, Small K. (2005) 'Choosing' to work when sick: workplace presenteeism. Soc Sci Med. 2005 May;60(10):2273-82. doi: 10.1016/j.socscimed.2004.10.022. Epub 2004 Dec 7. PMID: 15748675.

[27] Cooper, C., & Dewe, P. (2008). Well-Being: Absenteeism, Presenteeism, Coasts and Challenges. Occupational Medicine, 58, 522-524 [Online] available at http://dx.doi.org/10.1093/occmed/kqn124 [Accessed: 5/04/2021]

[28] Diogo Thimoteo da Cunha, Anna Rafaela Cavalcante Braga, Estevão de Camargo Passos, Elke Stedefeldt, Veridiana Vera de Rosso, “The existence of optimistic bias about foodborne disease by food handlers and its association with training participation and food safety performance”, Food Research International,Volume 75,2015,Pages 27-33, [Online] available at https://doi.org/10.1016/j.foodres.2015.05.035. 9accessed on 22/12/22)

[29] Ko, W.-H. (2013) The relationship among food safety knowledge, attitudes and self-reported HACCP practices in restaurant employees. Food control, 29 (1), 192-197

[30] Baş, M., Ersun, A.Ş. and Kıvanç, G. (2006) The evaluation of food hygiene knowledge, attitudes, and practices of food handlers’ in food businesses in Turkey. Food control, 17 (4), 317-322.

[31] Abdul-Mutalib, N.-A., Abdul-Rashid, M.-F., Mustafa, S., Amin-Nordin, S., Hamat, R.A. and Osman, M. (2012) Knowledge, attitude and practices regarding food hygiene and sanitation of food handlers in Kuala Pilah, Malaysia. Food control, 27 (2), 289-293.

[32] Rennie, D.M. (1995) Journal of the Royal Society of Health, 115 (2), 75-79.
[33] Ahmed MH, Akbar A, Sadiq MB. Cross sectional study on food safety knowledge, attitudes, and practices of food handlers in Lahore district, Pakistan. Heliyon. 2021 Nov 17;7(11) [Online] available at https://www.ncbi.nlm.nih.gov/pmc/aticles/PMC8606342/ (accessed on 23/12/22)

[34] Griffith, C.J., Livesey, K.M. and Clayton, D. (2010), "The assessment of food safety culture", British Food Journal, Vol. 112 No. 4, pp. 439-456. [Online] available at https://doi.org/10.1108/00070701011034448 9(accessed 23/12/22)

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Optimisation of chlorine disinfection in drinking water supply network

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ABSTRACT

Chlorination is one of the most commonly used procedures for drinking water disinfection. The research aimed to soptimise the subsequent disinfection of drinking water with chlorine in the water supply network in the city Velenje, taking into account the applicable legislation. The gradual reduction of chlorine dosage was implemented with simultaneous monitoring of selected physico-chemical and microbiological parameters of drinking water. During the two-month period, 418 samples were taken at 22 previously defined different sampling spots. Free chlorine values were reduced from the initial 0,18 mg/L to the final 0,08 mg/L at the outlet, while values at some remote sampling sites reached only 0,01 mg/L of free chlorine. Microbiological analyses of samples showed that the drinking water met the limit values in the regulations, despite the low values of free chlorine. Based on the results, a modified chlorination of drinking water was introduced in the tested supply area, and the introduction of a similar regime in other supply areas is being actively considered. In this way, we reduce the consumption of disinfectants and ensure the supply of quality and healthy drinking water to consumers.

Key words: drinking water, chlorination optimisation, microbiological parameters, Slovenia – Velenje.

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INTRODUCTION

Drinking water distribution networks are one of vital infrastructures for our society. The deterioration of water quality is one of the major concerns for water utilities when transporting water through the distribution network [1]. Water quality deterioration can be due to several physical, biological and chemical phenomena such as re-growth and accumulation of microbial species, decay of disinfectant residuals, formation of disinfection by-products or leaching of metals from pipes due to corrosion [2, 3, 4]. Therefore, maintaining adequate water quality is important in water supply through distribution systems [5].

In Slovenia, drinking water comes from 858 supply areas standard control or monitoring is being supplied to more than 90 % of the population [6]. Monitoring of drinking water is determined by the statutory regulation Rules on Drinking Water [7] for ensuring control, taking measures, and supervising risks for human health at the stages from the collection, preparation, storage and distribution of drinking water. Where disinfection is part of the preparation or distribution of drinking water, the operator must verify the procedure's effectiveness and ensure that any contamination by disinfection by-products is as low as possible without compromising the disinfection effect [7]. As part of the monitoring, the microbiological parameters of drinking water are also controlled and must be under the regulations.

The cause of numerous water-borne diseases could also be the microbial contamination of drinking water inside the distribution system [8]. To prevent the spread of water-borne diseases, disinfection is usually necessary for the preparation of drinking water, where chlorination is one of the most commonly used procedures [9, 10]. Among disinfectants, chlorine is the most frequently used because it is comparatively cheap, easy to handle and, above all, ensures long-term free residual chlorine inside a water distribution network [11]. Chlorine is an oxidising agent that reacts with organic impurities, ammonia, metallic compounds, such as ferrous and manganese ions, biofilm, tubercles formed on pipe walls, and pipe wall material [12 – 22].

Although widely used, chlorination can lead to the formation of toxic disinfection-by-products (DBPs) due to the reaction of residual free chlorine with natural organic matter-based precursors and precursor compounds from the microbial population in biofilms on pipe surfaces [2, 23]. The World Health Organization (WHO) has established a guideline value of 5 mg/L for chlorine in drinking water, meaning that such concentrations are acceptable for lifelong human consumption [24]. The global drinking water standards also mandate the stringent control of residual disinfectant levels to prevent microbial contamination and, on the other hand, to limit the formation of disinfection by-products [24]. Numerous research indicated secondary disinfection with booster chlorination for providing uniform and adequate free residual chlorine concentration in the network [25]. This practice can also reduce the disinfectant dose, cost, and contact time of chlorine which, as well as minimise disinfection by-products, taste and odour complaints [13, 25 - 29]. Different studies aimed to define threshold concentration values of free residual chlorine for optimising dosage and the number and location of booster points [27 – 35]. However, various free residual chlorine thresholds are generally defined to ensure acceptable microbial, chemical, and aesthetic water quality.

In the case of water supply network in the city Velenje, the ultrafiltration process is used for pre-treatment of drinking water. After that, chlorine is added in a concentration of 0,18 mg/L [36] for safe drinking water distribution for all users, including those at remote abstractions.

The research aimed to soptimise the subsequent disinfection of drinking water with chlorine in the water supply network of Velenje. The aim was also to determine the minimum concentration of chlorine that ensures the disinfectant effect of drinking water during transport to the last user. Based on the optimization performed in the representative supply area named R1 Velenje, the soptimisation in other supply areas will be considered.

We set up two working hypotheses:
H1: The prepared drinking water with a chlorine concentration of 0,05 mg/L will ensure healthy drinking water in accordance with the legislation.
H2: In the most remote parts of the water supply area, prepared drinking water with a chlorine concentration of 0,05 mg/L, will no longer provide healthy drinking water in accordance with the legislation.

METHODS

Study design (sampling area and sampling protocol):
The research was conducted at the supply area (R1 Velenje) in the network Čujež on the water supply system of Šaleška dolina (Figures 1, 2) which supplies 19,109 users.

Figure 1: Location of research at the water supply system of Šaleška dolina (R1Velenje – water supply area; VG1 and RZ Preska - validation control points of temporary chlorine measurements on the network)

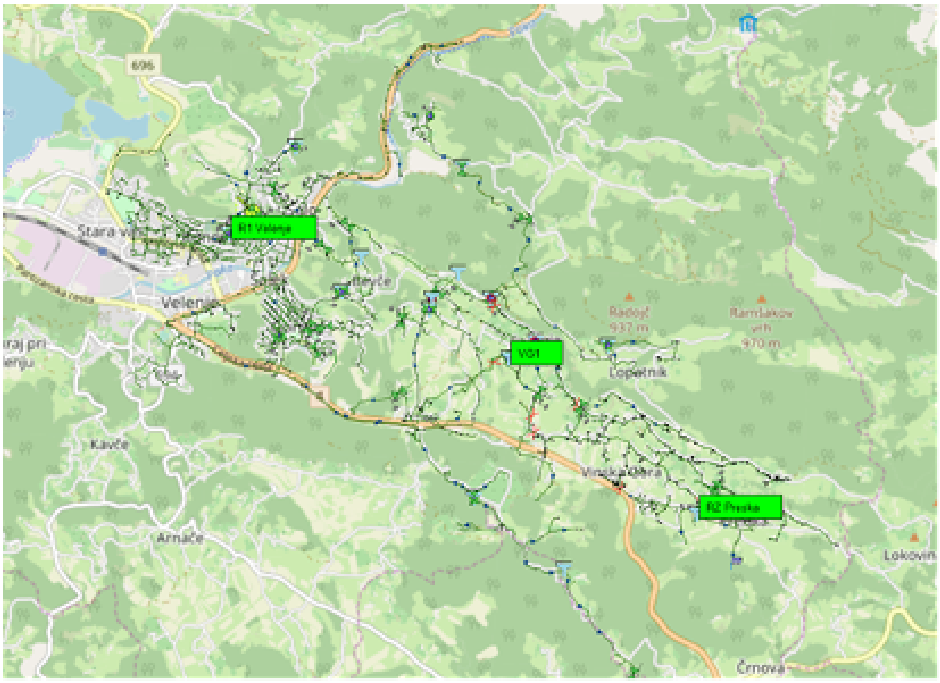
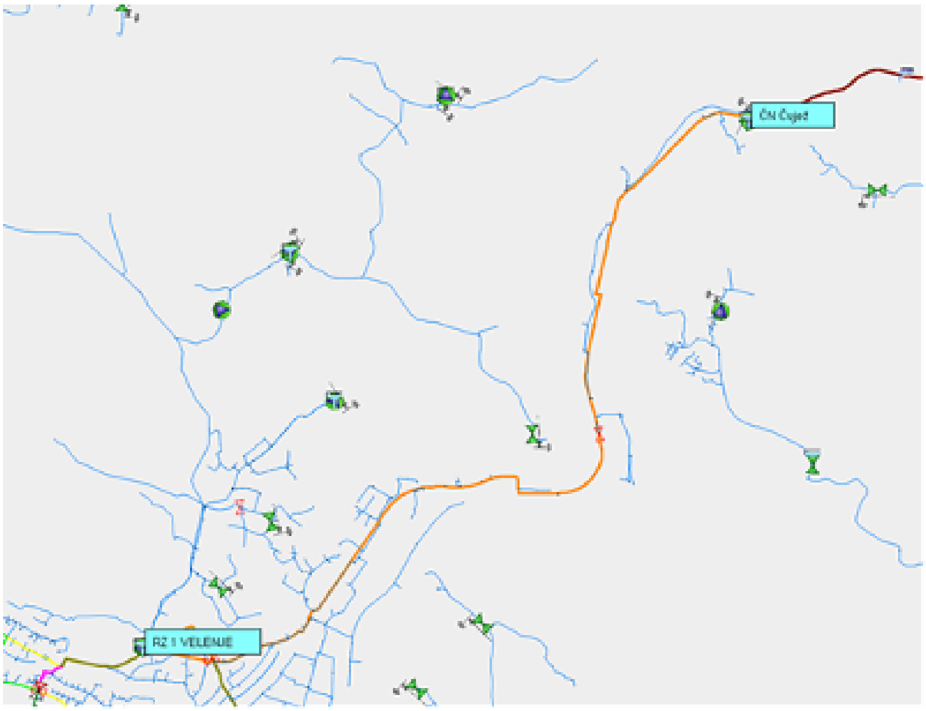
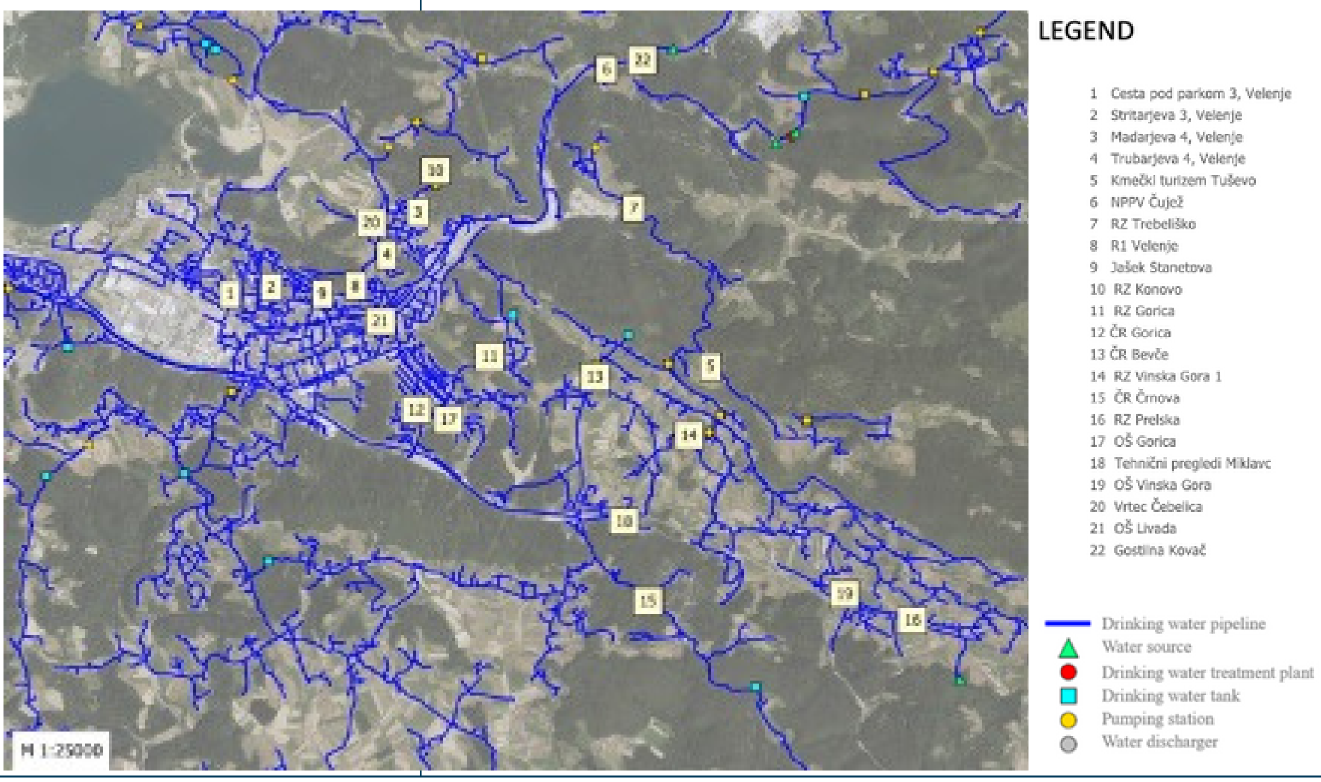


Figure 2: Location of research in the network Čujež



The selected supply area represents 45 % of all users, 25 % of the total volume of the water supply network and 35 % of the average daily distributed quantity of drinking water in the entire water supply system of city of Velenje. The systematic sampling of water was conducted at 22 pre-defined measuring points (Figure 3), which were distributed throughout the supply area at intermediate water supply facilities and at the outlets of end users.

Figure 3: Selected sampling points at R1 Velenje for measurement of chlorine concentration and microbiological parameters.



Water sampling was performed by Komunalno podjetje Velenje before and after water treatment, at water reservoirs, on the network and at the taps of fifteen users (residential buildings, schools, kindergartens, companies). The measurements for free chlorine and measurement of microbiological parameters were conducted twice a week in two months (May-June 2019).

Gradual reduction of chlorine dosage:

Different operating regimes have been defined to monitor the actual network responses by recording measurements of free chlorine:

- The first operating mode represents the unchanged state of operation. The regulated value of chlorine on R1 Velenje is 0,18 mg / l.
- The second operating regime is unreduced chlorination at the NPPV Čujež and the washed water supply network, carried out by rinsing with water from hydrants.
- The third operating mode represents the state when a lower chlorine concentration is dosed into the network than otherwise under normal operating conditions. The reference chlorination limit on NPPV Čujež is reduced to 0,13 mg / l.
- The fourth operating mode represents the state when chlorination at NPPV Čujež is further reduced from 0.13 mg / l to 0.08 mg / l.

Microbiological monitoring:

The BactiQuant (Mycometer, Denmark) method was used to analyse bacterial activity in the water sample. This method allows the measurement of microbial enzyme activity.

In samples where the value of free chlorine was lower than 0,01 mg/L additional parameters were measured:

- E. coli and total coliform bacteria using the Colilert, IDEXX (U.S. EPA approved and included in Standard Methods for Examination of Water and Wastewater) - IDEXX (SM 9223)
- Enterococci using the Enterolert, IDEXX (U.S. EPA-approved and included in Standard Methods for Examination of Water and Wastewater) - IDEXX (9230 D).
- total number of microorganisms at 22 ºC and 37 ºC using The SimPlate for HPC test, IDEXX (U.S. EPA approved and included in Standard Methods for Examination of Water and Wastewater) - IDEXX (SM 9215E).

Chlorine concentration monitoring:

Sampling was performed in accordance with the standard SIST ISO 5667-5: 2007 (Water quality - Sampling - Part 5: Guidance on sampling of drinking water from water supply systems). To measure free chlorine concentration a portable chlorine meter (HACH DR 300) was used.

Ethical issue:

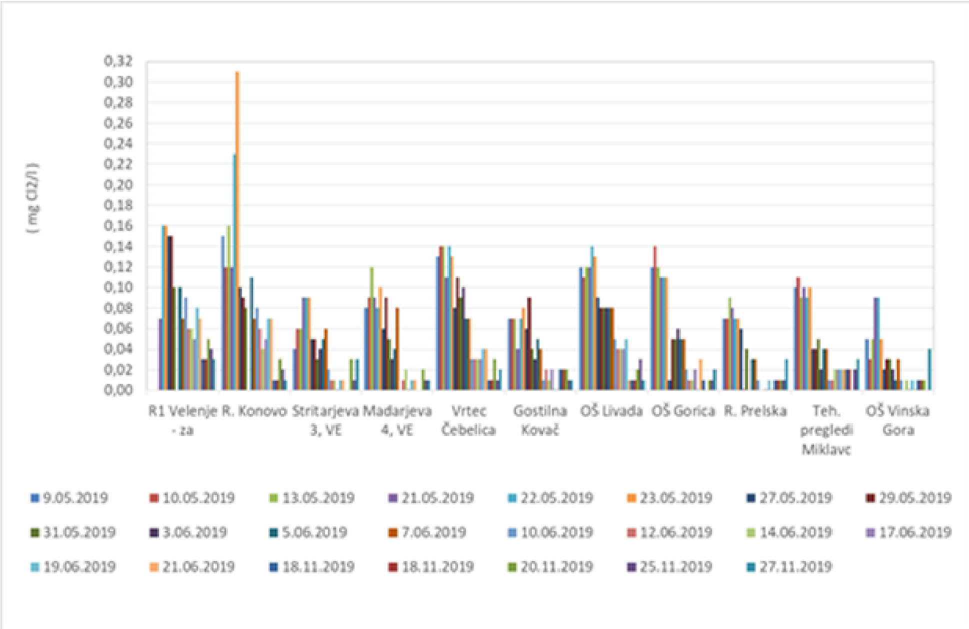
The research was conducted on a functioning water supply system, which is why the security of supply was ensured during the research by a more frequent sampling of drinking water daily. The measuring points were facilities managed by the utility company (tanks, pumping stations) and permanent measuring points in public facilities (schools, kindergartens) or inns and private facilities from which we obtained a sampling permit.

RESULTS AND DISCUSSION

The key goal of the project was soptimisation or reduction of chlorine concentration or even complete elimination of chlorine use in the water supply network. We focused on the R1 Velenje water supply area, where we gradually reduced the chlorine concentration from the initial 0,18 mg/L to 0,08 mg/L over two months. To eliminate the addition of chlorine to drinking water, a perfect hygienic condition must be ensured in the water supply system and in the tanks [37]. The main risks are the age of the water supply system, the oversized system and the fact that there is no online equipment for detecting microorganisms which could monitor the water supply system in real-time [38].

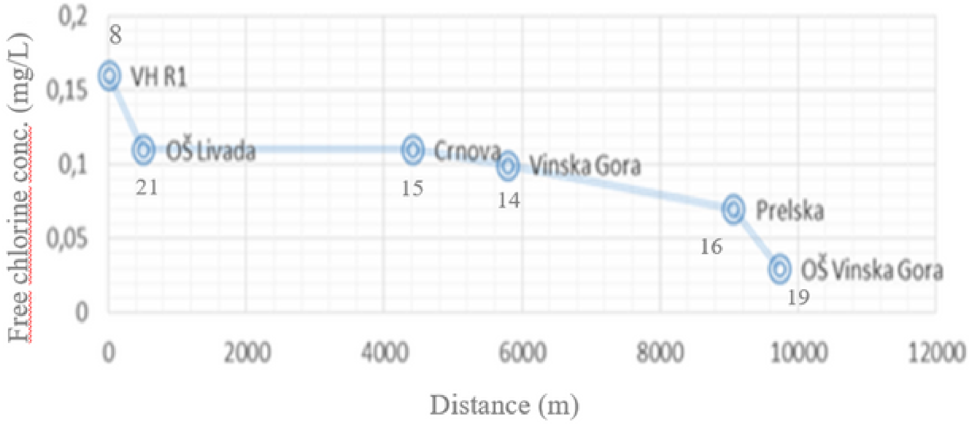
At the time of research, 418 samples were taken and analysed. The values of free chlorine at 11 sampling points were decreased due to lower initial concentrations (Figure 4). The average values decrease rom the initial 0,18 mg/L at sampling point R1 Velenje to the final lowest average concentration 0,08 mg/L - less than 0,01 mg/L (trace-free chlorine)at the farthest measuring point OŠ Vinska Gora (Primary school Vinska Gora).

Figure 4: Free chlorine concentrations at 11 measuring points from 9.5.2019 till 27.11.2019.



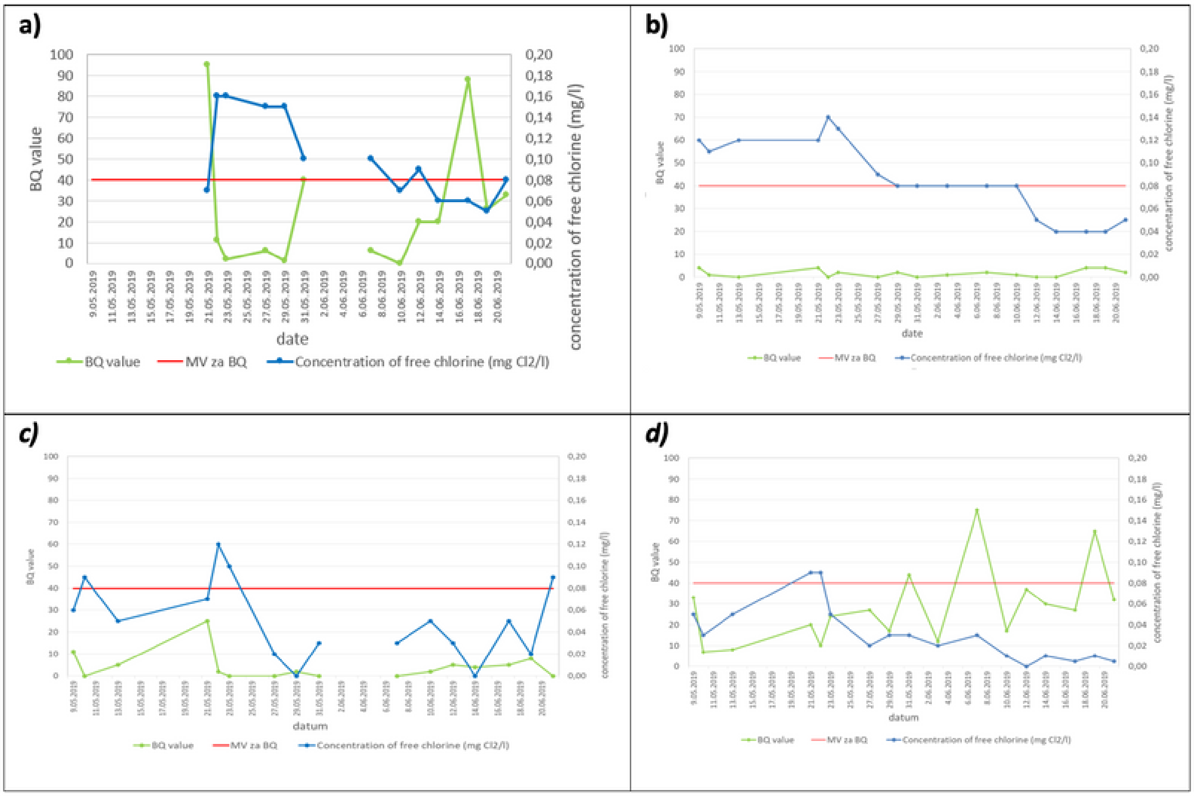
A gradient of free chlorine concentration reduction at the water supply system in the direction of water flow from the chlorination reference point to the farthest chlorine measurement location was constructed (Figure 5). The trail from R1 Velenje to OŠ Vinska Gora represents a distance of more than 9 km.

Figure 5: Reduction of free chlorine concentration concerning the distance from the dosing location to the final measuring point.



Since the chlorine concentration significantly affects the number of bacteria present in the water, microbiological parameters were also checked in the water samples (Figure 6). To determine microorganisms in water, we chose the Bactiquant method (BQ), as it allows us to quickly obtain results on the state of the system in terms of contamination, which means a proactive approach to monitoring. The Bactiquant®-water test for quantifying bacteria in water and other liquids and the Bactiquant® surface (now Mycometer® surface Bacteria) for quantifying bacteria on surfaces was presented to the market in 2007.

Figure 6: Concentration of free chlorine and BQ value at four sampling points (a) R1 Velenje, b) OŠ Livada, c) črpališče Črnova, d) OŠ Vinska Gora

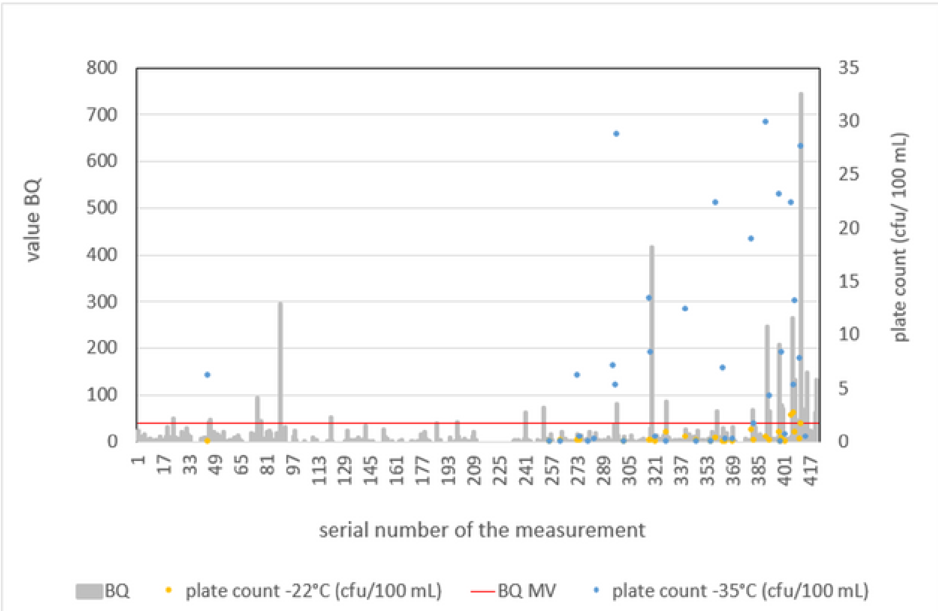


The introduction of the BQ method for the determination of microorganisms, which in contrast to classical methods allows the detection of microorganisms in 30 minutes instead of 24, 48 or 72 hours, allowed active monitoring of the microbiological state of drinking water in the system [39]. Reducing free chlorine in the drinking water system would be impossible without this, as the risk of possible uncontrolled growth of microorganisms would be too high. As a result, such a condition could lead to inadequate microbiological quality of drinking water and possible acute infections of users. We followed the example of other countries which introduced the BQ method for quality control of drinking water production or control of microbiological quality in the water supply system. The study on 976 samples of drinking water made in Copenhagen set the BQ value < 40 as less than 1% probability of exceeding 200 cfu on Plate count (DS/EN ISO 6222) at 22 and 36 °C [40]. According to this study, the BQ value of less than 40 was adopted as a safety value for our drinking water supply system.

In the samples with free chlorine concentration lower than 0,01 mg / l, additional parameters for E. coli, total coliform bacteria and - the total number of microorganisms at 22 ºC and 37 ºC were measured (Figure 6). The results show that despite the low concentration of free chlorine, the drinking water complied with the requirements of the Drinking Water Regulations, namely:

- total number of microorganisms at 22 ºC (parameter limit value 100 cfu/mL [10000 cfu/100 mL]),
- total number of microorganisms at 37 ºC (parameter limit value 20 cfu/mL [2000 cfu/100 mL]).

Figure 7: Motion of BQ, the total number of microorganisms at 22°C and the total number of microorganisms at 37°C



Hypothesis 1 can be confirmed, as despite the reduction of chlorine concentration to 0,08 mg/L, the health adequacy of drinking water was ensured in accordance with the legislation.
Hypothesis 2 can be rejected, as drinking water was compliant with the statutory regulation Rules on Drinking Water even at the most remote sampling points.
In many countries, chlorine is the primary disinfectant, but there are quite a few dilemmas about its use. One of the challenges in maintaining water quality is determining the right dosage of chlorine-based disinfectants and, at the same time, limiting disinfection by-products [41]. Although chlorination prevents the presence and development of pathogenic microorganisms in drinking water, the use of chlorine also has some adverse side effects, as it can lead to the development of various potentially toxic disinfectant by-products (trihalomethanes) [42, 43] which can be associated with many diseases. Therefore, we want the concentrations of free chlorine and, consequently, the concentrations of disinfectant by-products in drinking water to be as low as possible. The sustainable effect of the innovation of reducing chlorine dosing in the water supply system is mainly in reducing the consumption of disinfectant (i.e. chlorine gas), supplying quality drinking water to users and, consequently, a positive impact on user satisfaction.

CONCLUSIONS

The research results within the project contributed to improvements and better quality of drinking water, as well as tracking trends at the global level. With the introduction of a new way of drinking water chlorine disinfection, a sustainable effect has been achieved, primarily in reducing the consumption of disinfectants and supplying high-quality drinking water to users right up to the last user on the system.

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REFERENCES

[1] Masters, S., Parks, J., Atassi, A., Edwards, M.A., 2015. Distribution system water age can
create premise plumbing corrosion hotspots. Environ. Monit. Assess. 187 (9), 18.
[2] Abokifa, A.A., Yang, Y.J., Lo, C.S., Biswas, P., 2016. Water quality modeling in the dead
[3] end sections of drinking water distribution networks. Water Res. 89, 107–117.Chowdhury, S., Kabir, F., Mazumder, M.A.J., Zahir, M.H., 2018. Modeling lead concentration in drinking water of residential plumbing pipes and hot water tanks. Sci. Total Environ. 635, 35–44.
[4] Wang, Z.M., Devine Hugh, A., Zhang, W., Waldroup, K., 2014. Using a GIS and GISassisted water quality model to analyze the deterministic factors for lead and copper corrosion in drinking water distribution systems. J. Environ. Eng. 140 (9), A4014004.
[5] Maheshwari, A., Abokifa, A., Gudi, R.d., Biswas, P. 2020. Optimization of disinfectant dosage for simultaneous control of lead and disinfection-byproducts in water distribution networks. Journal of Environmental Management. 276 (2020) 111186.

[6] Agencija Republike Slobvenije za okolje. Dostop do pitne vode. http://kazalci.arso.gov.si/sl/content/dostop-do-pitne-vode-0 (27.7.2022)

[7] Pravilnik o pitni vodi. Uradni list RS, št. 19/04, 35/04, 26/06, 92/06, 25/09, 74/15 in 51/17.

[8] Digiano, F.A., Zhang, W.D., 2004. Uncertainty analysis in a mechanistic model of bacterial regrowth in distribution systems. Environ. Sci. Technol. 38 (22), 5925–5931.

[9] Kleijnen, R.G., Knoben, B.G.M., Hoofwijk, B.L., Pol, D.G.J., Heintges, G.H.L., De Visser, J.F., The Chlorine Dilemma Final Report, Eindhoven University of Technology /department of Chemical Engineering and Chemistry. 2011.

[10] Helbling, E.Damian, VanBriesen, M.Jeanne, 2009. Modeling residual chlorine response to a microbial contamination event in drinking water distribution systems. J. Environ. Eng. 135 (10), 918–927.

[11] Brown, D., Bridgeman, J., & West, J. R. (2011). Predicting chlorine decay and THM formation in water supply systems. Reviews in Environmental Science and Bio/Technology, 10(1), 79–99. doi:10.1007/s11157-011-9229-8.

[12] Al-Jasser, A. O. (2007). Chlorine decay in drinking-water transmission and distribution systems: pipe service age effect. Water Research, 41(2), 387–396. doi:10.1016/ j.watres.2006.08.032.

[13] Carrico, B., & Singer, P. C. (2010). Impact of booster chlorination on chlorine decay and THM production: simulated analysis. October (October 2009), 2005–2010.

[14] Courtis, B., West, J., & Bridgeman, J. (2009). Temporal and spatial variations in bulk chlorine decay within a water supply system. Journal of Environmental Engineering, 135(3), 147. doi:10.1061/(ASCE)0733-9372(2009) 135:3(147).

[15] Fisher, I., Kastl, G., & Sathasivan, A. (2011). Evaluation of suitable chlorine bulk-decay models for water distribution systems. Water research, 45(16), 4896–4908. Elsevier Ltd. doi: 10.1016/j.watres.2011.06.032.

[16] Hallam, N. B., Hua, F., West, J. R., Forster, C. F., & Simms, J. (2003). Bulk decay of chlorine in water distribution systems. Journal of Water Resources Planning and Management, 129(1) , 78. d o i :10.1061/(ASCE)0733-9496(2003)129:1(78).

[17] Jabari Kohpaei, A., & Sathasivan, A. (2011). Chlorine decay prediction in bulk water using the parallel second order model: An analytical solution development. Chemical Engineering Journal 171(1):232–241. doi: 10.1016/j.cej.2011. 03.034.

[18] Yang, J. Y., Goodrich, J. A., Clark, R. M., & Li, S. Y. (2008). Modeling and testing of reactive contaminant transport in drinking water pipes: chlorine response and implications for online contaminant detection. Water Research, 42(6–7), 1397–1412. doi:10.1016/j.watres.2007.10.009.

[19] Khan, F., Husain, T., & Lumb, A. (2003). Water quality evaluation and trend analysis in selected watersheds of the Atlantic region of Canada. Environmental Monitoring and Assessment 88(1):221–248. Available from http:// www.springerlink.com/index/H7183287VR00814V.pdf.

[20] Ozdemir, O. N., & Ucak, A. (2002). Simulation of chlorine decay in drinking-water distribution systems. Journal of Environmental Engineering, 128(1), 31. doi:10.1061/ (ASCE)0733-9372(2002)128:1(31).

[21] Shang, F., Uber, James G, & Rossman, L. a. (2008). Modeling reaction and transport of multiple species in water distribution systems. Environmental Science & Technology 42(3):808–14. Available from pubmed/18323106.

22] Taylor, P., Ozdemir, O N, & Demir, E. (2010). Experimental study of chlorine bulk decay in water supply pipes Experimental study of chlorine bulk decay in water supply pipes Etude expérimentale de la décroissance volumique du chlore dans les canalisations d ' alimentation en eau. Engineering :37–41.

[23] Ahmed A. Abokifa, Y. Jeffrey Yang, Cynthia S. Lo, Pratim Biswas. Investigating the role of biofilms in trihalomethane formation in water distribution systems with a multicomponent model. Water Research. 2016, 104: 208-219.
[24] World Health Organzation. (2017). Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization. 2017: 631.
[25] Hernandez-Castro, S. (2007). Two-stage stochastic approach to the optimal location of booster disinfection stations. Industrial and Engineering Chemistry Research, 46(19), 6284– 6292. doi:10.1021/ie070141a.
[26] Boccelli, D. L., Tryby, M. E., Uber, J. G., & Summers, R. S. (2003). A reactive species model for chlorine decay and THM formation under rechlorination conditions. Water Research, 37(11), 2654–2666. doi:10.1016/S0043-1354(03)00067-8.
[27] Kang, D., & Lansey, K. (2010). Real-time optimal valve operation and booster disinfection for water quality in water distribution systems. Journal of Water Resources Planning and Management, 136(4) , 463. doi:10. 1061/(ASCE)WR.1943-5452.0000056.
[28] Ostfeld, A., & Salomons, E. (2006). Conjunctive optimal scheduling of pumping and booster chlorine injections in water distribution systems. Engineering Optimization 38(3):337– 352. doi: 10.1080/03052150500478007.
[29] Parks, S. L. I., & VanBriesen, J. M. (2009). Booster disinfection for response to contamination in a drinking water distribution system. Journal of Water Resources Planning and Management, 135(6), 502. doi:10.1061/(ASCE)0733-9496(2009)135:6(502).
[30] Prasad, T. D., Walters, G., & Savic, D. (2004). Booster disinfection of water supply networks: multiobjective approach. Journal of Water Resources Planning and Management, 130(5), 367. doi:10.1061/(ASCE)0733-9496(2004) 130:5(367).
[31] Cozzolino, L., Pianese, D., & Pirozzi, F. (2005). Control of DBPs in water distribution systems through optimal chlorine dosage and disinfection station allocation. Desalination, 176(1–3), 113–125. doi:10.1016/j.desal.2004.10.021.
[32] Gibbs, M. S., Dandy, G. C., & Maier, H. R. (2010). Calibration and optimization of the pumping and disinfection of a real water supply system. Journal of Water Resources Planning and Management, 136(4), 493. doi:10.1061/(ASCE) WR.1943-5452.0000060.
[33] Lansey, K., Pasha, F., Pool, S., Elshorbagy, W., & Uber, J. (2007). Locating satellite booster disinfectant stations. Journal of Water Resources Planning and Management, 133(4), 372. doi:10.1061/(ASCE)0733-9496(2007)133: 4(372).
[34] Propato, M. (2006). Contamination warning in water networks: general mixed-integer linear models for sensor location design. Journal of Water Resources Planning and Management, 132(4), 225. doi:10.1061/(ASCE)0733-9496(2006) 132:4(225).
[35] Tryby, M. E., Boccelli, D. L., Uber, J. G., & Rossman, L. A. (2002). Facility location model for booster disinfection of water supply networks. Journal of Water Resources Planning and Management, 128(5), 322. doi:10.1061/(ASCE)0733-9496(2002)128:5(322).
[36] Komunalno podjetje Velenje. Letno poročilo 2015. http://www.kp-velenje.si/index.php/dejavnosti/komunala/oskrba-s-pitno-vodo (10.1.2019)
[37] Smeets, P. W. M. H., Medema, G. J., van Dijk, J. C., The Dutch secret: how to provide safe drinking water without chlorine in the Netherlands. Drink. Water Engineering and Science, 2009, 2: 1–14.

38] Komunalno podjetje Velenje. Interna navodila za določevanje najverjetnejšega števila skupnih koliformnih bakterij in E. coli - mpn (most probable number). 2020.

[39] BactiQuant, Monitor and take control of the water quality in the production chain from raw water to the end use. https://issuu.com/companybactiquant/docs/bactiquant_water_utility_brochure_production_chain (10.4.2019)

[40] Elga process water, veolia water, 2013. Bactiquant-water Total bacterial analysis in minutes. Bactiquant – water webinar presentation https://www.slideshare.net/vittoriofigurato/bactiquantwater-webinar-presentation (24.9.2020)

[41] Abhilasha Maheshwari, Ahmed Abokifa, Ravindra D. Gudi, Pratim Biswas. sOptimisation of disinfectant dosage for simultaneous control of lead and disinfection-byproducts in water distribution networks, Journal of Environmental Management. 2020, 276: 111186.

[42] CDC – Centers for Deseases Control and Prevention, 2022. Disinfection By-Products. https://www.cdc.gov/healthywater/global/household-water-treatment/chlorination-byproducts.html (11.3.2022)

[43] Thompson, C., Gillespie, S., Goslan E.,eds. Disinfection by-products in drinking water. Cambridge: Royal Society of Chemistry. 2016.

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State of the Art Emission Inventory and Their Application: Literature review

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Literature Review article

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ABSTRACT

Currently, the complex bottom-up emissions inventories are in rise. Its development is essential for both understanding the sources of air pollution and designing effective air pollution control measures. Anyway, the main challenge to get the most reliable emissions evidence is the variety of contributing sources, the complexity of the technology mix and the lack of reliable emission factors. The input data bases are improving constantly, by more reliable statistics and survey-based data. Our study reveals the strengths and deficiency of currently published scientific papers on the topic of emission inventory. With that purpose, 40 crucial scientific papers were selected. We first highlight the period and geographic region, when and where the inventories were made for. We then summarize the sector-based estimates of emissions of different species contained by SNAP sectors in selected inventories. Additionally, the resolution of inventories is analysed. Finally, the last section summarizing common ways of assessing and validating inventories and their main purpose. This review shows that there is still a lot of chance to improve emissions inventories in a way to develop input data and emission factors for different technologies and activities or to develop inventories on fine grids. Those efforts will give us wider knowledge about pollution sources and will lead to accepted better air quality policy.

Key words: Air Quality, Emission Inventory, State of the Art, Validation Process, SNAP Nomenclature

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INTRODUCTIONS

Air pollution poses important risk on our population, because it causes 6,5 million deaths per year or 1/8 of all deaths [1], [2]. According to the United Nation (UN) [3] in year 2018 around 55% of the global population lived in the urban areas. Those percentage will even increase by 60% until year 2030 and by 80% in year 2050. Consequently, the good quality of air in urban area will be important challenge in the future.

Air quality can be measured on monitoring stations using reference methods for different pollutants. Representative locations and minimum density of measurement network are determined by European commission. The accuracy of measurements obtained depends on the maintenance and monitoring of measurement equipment. [4]. The long-term observed and analysed data on permanent locations enable monitoring of improvement or deterioration of local air quality [5].

On the other hand, the spatial distribution of air quality can be assessed by using mathematical air quality models. In complex air quality models the dispersion model is coupled with detailed meteorological model, which take into account meteorological measurements and fine grid terrain information like land-use and altitude. The important part of air quality models is capability to calculate chemical transformations, which enables the model to represent the formation of secondary pollutants [6]. The crucial part, which modellers have impact on, is recognizing the emissions sources and their release, which is still currently the highest uncertainty of those models [6], [7]. Those sources are defined as points such as chimneys, lines such as roads or areas such as fields.

Emission inventory is defined as a comprehensive list of pollutants from all sources in a geographical area during a selected period of time. To get the most novel emission inventory the constant development and accuracy of input data are crucial [8]. Emission inventory can be developed on local, regional or national scale. Broad and precise inventory helps us to manage air quality through applying the most proper policy in the area. It can be used to recognize the highest sources of pollutant emissions and to determine the most endangered areas [9]. Moreover, emission inventory is useful tool for identification of the most appropriate monitoring locations and to identify the most problematic pollutants to be measured [10], [11].

The emission inventory could be conducted by two different methods, top-down or bottom-up. The more basic method is top-down, which holds information about average statistic activities, usually based on national level data, and basic emission factors for those activities. This method is used for rigid spatial distribution and to analyse national or regional emissions [12]. Meanwhile, the more progressive method is bottom-up, which includes information about activity and technology for each particulate source individually and is in addition generated to the desired spatial resolution; local, regional or even national level [13].

Emission factors for different activities are collected in emission inventory guidebook and are based on the previous studies about measurement emissions during the different activities and technologies. In Europe the most common known Emission Inventory Guidebook is EMEP/EEA Emissions Inventory Guidebook from year 2019 [14]. The guidebook holds information about emission factors on three different complex stages. Stage 1 or TIER 1 holds information about emission factors for the most basic activities and technologies. More advanced is stage 2 or TIER 2 method which includes more advanced information about activities, emission factors and technologies.

The most advances method is TIER 3, which presents the most detailed emissions input data. The stage used depends on the availability of input data and the importance of a particular source [7].

The general equation for emission estimations according to bottom-up method is the following:

$$E = A \times E_F \times \left(\frac{1 - E_R}{100}\right)$$

Where E = calculated emissions; A = activity rate needs for develop emissions; EF = emissions factor and ER = overall emission reduction efficiency (%).

Development of emission inventory following these steps:

1. Collecting the data about the sources such as vehicle fleet, national building register, national chimneys database, number and location of livestock or amount of solvent use in household;
2. determine the types of air pollutant emissions from each of the listed sources;
3. find out the emission factors for each of the concerned pollutant, which could be found in EMEP/EEA Emissions Inventory Guidebook [15];
4. determine the number and size of specific sources in the area;
5. repeat steps 3. and 4. to obtain the total emissions;
6. sum up the similar emissions and aggregate them on a desired resolution;
7. validate, analyse and interpretate given results [10].

Aim of our study is to provide an extensive literature review based on a multitude of studies on emission inventories. To the best of our knowledge, there is not yet a review covering all the aspects mentioned here. Throughout the first search the 15.157 articles were given and 40 of those were finally selected for the additional analyse. All the articles included inventory developed by bottom-up methods for anthropogenic sources.

This comprehensive article is organized as follows. Section 1 categorizes the 40 collected articles according to the period of time for which the inventory is reported. Section 2 discusses the analysed geographic area, which can be on local, regional, or national scale. Next section presents the sectors involved in the analysed inventory, which are mostly those which emitted the majority of analyzed pollutants. In this article the SNAP nomenclature was used to report sectors. The section 4 categorizes chosen articles by pollutants included in the inventory. Meanwhile, section 5 analyses the articles by their resolution. Finally, the last section summarizes common ways of assessing and validating inventories and their main purpose. Last section also includes all the additional interesting data about the particulate article. Overall view of the articles is summarized in the discussion chapter.

We believe that this literature review of emission inventories conducted on a global scale from multidisciplinary viewpoints will enable the recommendation of targeted environmental policies for maintaining good air quality, leading to healthier living in cities.

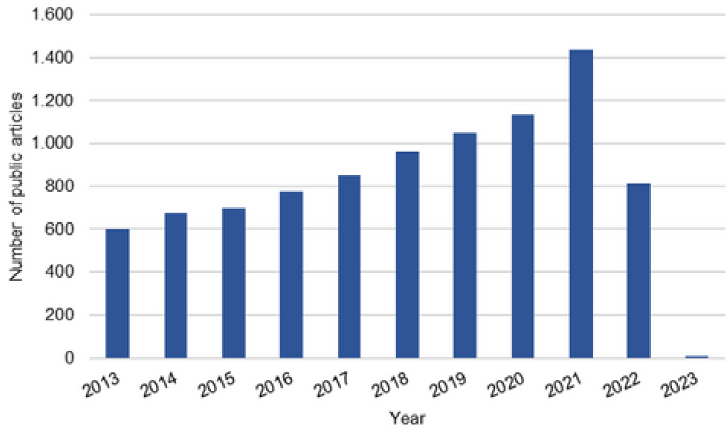
METHODS

The study is focused on the systematic review of the literature addressing the bottom-up emission inventory. The scientific articles were selected from the ScienceDirect database. The Advanced Search Builder was used and the keywords were searched in the title or abstract of the paper. We have filtered only research articles published in English language and selected the following keywords: »emission AND inventory OR evidence OR database«.

The first research found out the 15.157 articles, which are present in figure 1 by years of publication. To eliminate unfitted articles the keywords »transport AND small combustion« were added. The small combustions and transport are known as two main sources of emissions. In that way the 226 articles were selected. Additionally, the 47 articles were duplicate and eliminated.

The full-text articles were assessed for eligibility. One of the criteria was the impact factor of the journals, which should not be less than 2.5. The total of 40 eligible published research articles were obtained in their final version.

Figure 1: The number of articles search by keywords »emission AND inventory OR evidence OR database« in database ScienceDirect by year.



RESULTS

The selected scientific articles were categorized by 7 main categories and 2 subcategories. First category is the year or time period for which the inventory was developed and can be from a month to a few years long. The next category was the area where the inventory was conducted, it can be on local, regional, or national scale. Followed by sectors included in the inventory and reported in SNAP categorization, as briefly describe below. Collection of pollutants included in the study give us information about the most popular pollution covered by inventory. The important information is also the spatial resolution of the model, the most often data is in the grid form. The validation process gave us information about the most frequently used type of inventory validation. Lastly, the information about the purpose of the inventory was collected. This section additionally includes other interesting specific information about the inventories. However, to reach the information the category of article, published year and the journal, where the article was published, was added. Categorized selected articles are present in table 2.

It was decided that pollution sectors in this study will be reported using SNAP nomenclature. The English acronym SNAP stands for Selected Nomenclature for Air Pollution, that was developed under the EMEP/EEA organization in year 2001 with the purpose to synchronise the IPCC/OECD (Integrated Pollution Prevention and Control) nomenclature of source categories for activities resulting in emissions. The SNAP nomenclature is also the official nomenclature for inventory reported under the CLRTAP (Convention on Long-range Transboundary Air Pollution) convention [16]. Table 1 presents the SNAP codes and their description [14], [17].

Table 1: SNAP nomenclature and their description.

SNAP Code	SNAP Description
01	Combustion in the production and transformation of energy
02	Non-industrial combustion plants
03	Industrial combustion plants
04	Industrial processes without combustion
05	Extraction and distribution of fossil fuels and geothermal energy
06	Use of solvents and other products
07	Road Transport
08	Other mobile sources and machinery
09	Waste treatment and disposal
10	Agriculture
11	Other sources and sinks (nature)

In this study, the SNAP codes 3 and 4 are usually treated as common sources, therefore those sources are label as number 34. In the case when all SNAP sectors were used it is signed by "all SNAP sectors", meanwhile where only subcategories were used it is noted.

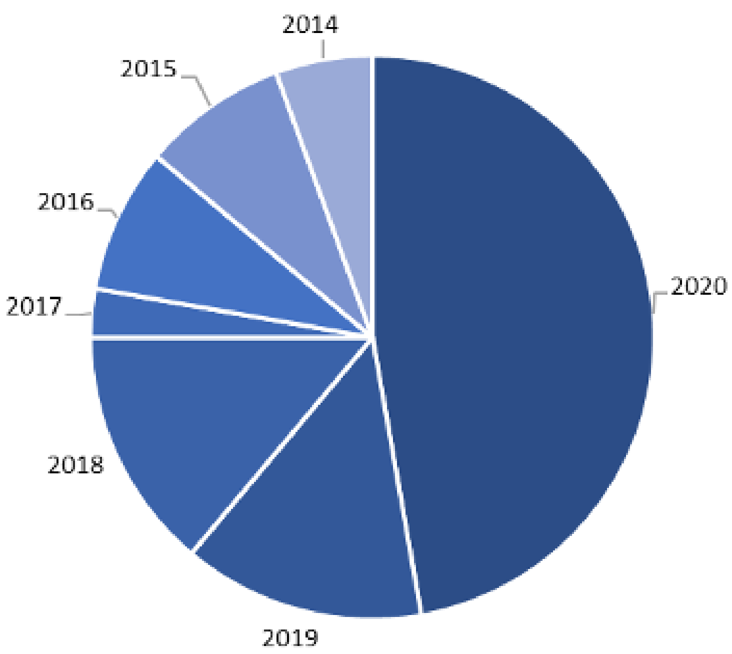
Table 2: Summary table reporting reviewed results on the topic of Emission Inventory.

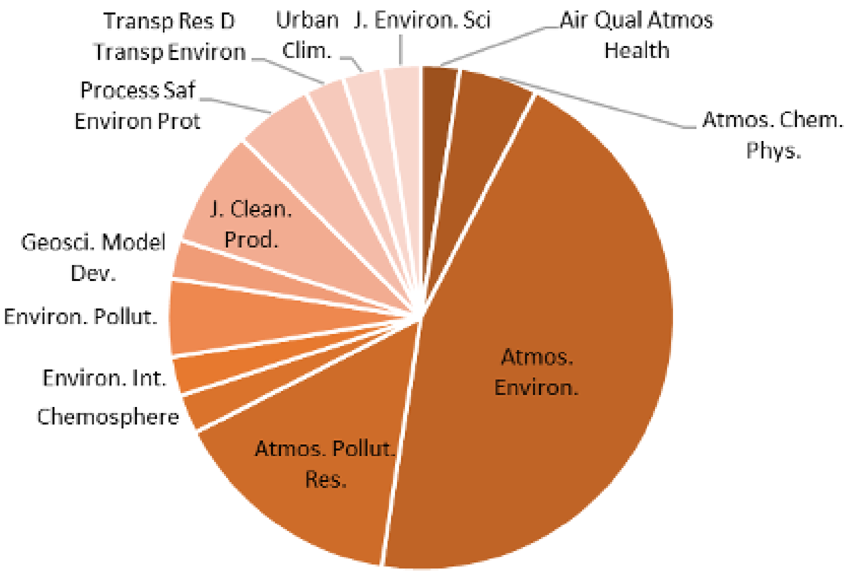
ID number	Year	Area	SNAP Sectors	Pollutants	Resolution	Validation	Purpose and other information	Year of Publication	Journal	Reference
1.	2012 and 2013	Norway: Oslo, Bergen, Trondheim, Stavanger, Drammen, Nedre Glomma, Greenland	2,34, 7, 8- ships	NOx, $PM_{2.5}$, PM_{10}	n. a.	Diamond graph	Inventory	2017	Atmos. Environ.	[7]
2	April 2017 - 2018	Tabriz (Iranian city)	1,2,3,4,5,7,8	CO, NO_x, SO_2, $PM_{2.5}$, PM_{10}, VOC	500 × 500 m	n. a.	16 scenarios	2022	J. Environ. Sci	[18]
3.	2016	Italy: Nice, Savona, Genoa, Spezia, Livorno	2, 34, 7, 8-ships, 10, 11	NOx, $PM_{2.5}$, PM_{10}	3 × 3 km	top-down inventory	CHIMERE dispersion model	2020	Atmos. Environ.	[19]
4.	2007-2009	Evropa	All SNAP sectors	O_3, NO_2, SO_2, $PM_{2.5}$, PM_{10}	8 × 8 km	Measurement network	CHIMERE dispersion model	2015	Geosci. Model Dev.	[20]
5.	2006 - 2012	Greece and Athens	All SNAP sectors	NO_x, NMVOC, CO, SO_2, NH_3, PM_{10}, $PM_{2.5}$	6 × 6 km (Greece) 2 × 2 km (Athens)	Comparison with previous bottom-up inventory	Emissions are hourly based	2016	Atmos. Environ.	[21]
6.	2008	Italy: Torino	7	CO, CO_2, SO_2, NH_3, NMVOC, $PM_{2.5}$, NO_X	n. a.	top-down inventory	Inventory	2014	Atmos. Pollut. Res.	[22]
7.	2005	EU-27	2 – biomass burning	Elemental (EC) and organic carbon (OA)	7 × 7 km	Measurement network	Dispersion model with PMCAMx and EMEP MSC-W	2015	Atmos. Chem. Phys.	[23]
8.	2003 - 2009	All countries under the CLRTAP conventional (51 countries EU and USA)	All SNAP sectors	CO, NO_x, SO_2, NH_3, NMVOC, $PM_{2.5}$, PM_{10}, CH_4	7 × 7 km	Energy use model GAINS and EDGAR	Inventory	2014	Atmos. Chem. Phys.	[24]
9	2015	1. comparison all Europe areas 2. comparison different region: Benelux, Po Valley and Balck Triangle	All SNAP sectors	NO_x, VOC, SO_x, NH_3, PM_{10}, $PM_{2.5}$	11 × 11 km	Comparison of three different models: The EDGAR database, The EMEP emissions, The CAMS-REG-AP	The benchmarking methodology, based on the comparison of modelled and measured data, developed in the frame of the FAIRMODE network	2021	Atmospheric Environment	[25]
10.	2009	Spain: Barcelona	All SNAP sectors	NO_x, SO_2, VOC, PM_{10}	7 × 7 km	Diamond graph	Inventory	2016	Air Qual Atmos Health	[26]
11	2009	France - Paris	2,7	NOx, SO_2, CO, VOC, PM	Spatial unit of Paris	AIRPARIF – regional emission inventory, EMEP	Developing of inventory Model OLYMPUS	2021	Atmos. Environ.	[27]

ID number	Year	Area	SNAP Sectors	Pollutants	Resolution	Validation	Purpose and other information	Year of Publication	Journal	Reference
12.	2010	USA California	All SNAP sectors	VOC, indirectly O_3 and PM	4 × 4 km	Data from article[28]	Dispersion model CMAQ.	2019	Atmos. Environ.	[29]
13.	2015	China: Sichuan	All SNAP sectors	VOC, indirectly O_3 and PM	1 × 1 km	n.a.	Inventory	2019	Atmos. Pollut. Res.	[30]
14.	2016	China: Harbin-Changchun	7	CO, HC, NO_x, NH_3, VOC, $PM_{2.5}$ in PM_{10}	1 × 1 km	n.a.	Scenarios	2020	Process Saf Environ Prot	[31]
15.	January and July 2010	China: Beijing, Shanghai in Guangzhou	1,2,34,7	CO, NO, SO_2, BC and organic carbon (OC)	111 × 111 km 28 × 28 km 55 × 55 km	3. previous made emission inventory: HTAPv2, REASv2 and MACCity, measurement network and satellite data	Dispersion model WRF-Chem	2018	Atmos. Environ.	[32]
16.	2015	China: Wuxi city,	2, 34,7,9,10	NO_x, SO_2, TSP, NH_3, VOCs, $PM_{2.5}$, PM_{10}, CO	1 × 1 km	4. previous made emission inventory and Monte Carlo method	Inventory	2019	J. Clean. Prod.	[33]
17.	2016	China: Shandong	1,2,34, 6,9,7	NO_x, SO_2, VOCs, $PM_{2.5}$, PM_{10}, CO	4 × 4 km	Monte Carlo method	Inventory	2020	J. Clean. Prod.	[34]
18.	2014	Greece: Delphi	1, 2-small combustion and and construction, 34, 7,8-aviation, 9	$PM_{2.5}$ including their composition	2× 2 km	n.a.	Hazard and toxicity analysis of substances	2020	Chemosphere	[35]
19.	2016	China: Henan	2	NO_x, SO_2, VOCs, $PM_{2.5}$, PM_{10}, CO	3 × 3 km	uncertainty analysis	Scenarios	2020	Atmos. Environ.	[36]
20.	December 2017	South Korea: Incheon Port	8 - ships	NO_x, SO_2, PM_{10}, CO	2 × 2 km	top-down inventory	Inventory	2018	Atmos. Environ.	[37]
21.	2015	Malaysia: Kuala Lumpur	7,34 (small industries)	NO_2, NO_x, SO_2, $PM_{2.5}$, PM_{10},	1 × 1 km	Analyse of emission relies (kg/year/person) uncertainty analysis	Inventory	2020	Atmos. Pollut. Res.	[38]
22.	n.a.	n.a.	n.a.	n.a.	n.a.	Diamond graph	Description of Diamond graph	2020	Atmos. Environ.	[39]
23.	1990 - 2008	France	All SNAP sectors	Dioxins	n.a.	Measurement network comparison with program UNEP Toolkit	Inventory	2020	Atmos. Pollut. Res.	[40]
24.	2003-2017	Nepal	11- crop residue open burning	NH_3, NO_x, SO_2, $PM_{2.5}$, CO_2, CO, OC,BC, NMVOC, CH_4	1 × 1 km	Monte Carlo method	Inventory	2020	Environ. Pollut.	[41]
25.	2010	Global word	1,2,34,7	Size distribution of PM	n.a.	uncertainty analysis	Scenarios	2015	Atmos. Environ.	[42]
26.	2010	Europe (Barcelona, Bucharest, Budapest, Katowice, London, Madrid, Milan, Paris, Sofia, Utrecht and Warsaw)	2,34,7	NO_x, SO_2, $PPM_{2.5}$, VOC	7 - 10 km	Comparison of 6 different inventory: EDGAR, TNO_MACCII, TNO-MACIII, INERSinv, EMEP, JRC07 Diamond graph	Use of Diamond graph	2018	Atmos. Environ.	[13]
27.	2017	Brazil: Santa Catarina (Florianópolis São José Palhoça Biguaçu Governor Celso Ramos)	7	CO, HC, NMHC, RCHO, NO_x, N_2O, PM, CH_4	n.a., source is line	n.p.	Scenarios	2019	Transp Res D Transp Environ	[43]
28.	At least year 2010	South America: Argentina, Brazil, Chile, Colombia and Peru	2- small combustion and construction, 34,7,10	NO_x, PM_{10}, SO_2, CO, BC in OC	city	2 emission inventory: EDGAR in ECLIPSE	Inventory	2020	Atmos. Environ.	[44]
29.	2010 and 2015	India: Kolkata	1, 2- small combustion and construction, 34,7,9,10	NO_x, SO_2, $PM_{2.5}$, PM_{10}, BC, VOC, OC, CO, NH_3	n.a.	n.a.	Scenarios	2020	Atmos. Environ.	[45]
30.	August 2013 and 2014	Turkey: Çanakkale	2,34,7, 8 - ships	PM, VOC, CO_2, CO	1 × 1 km	AERMOD and CALPUFF model	Association between air quality and morbidity of lung disease, Modelling with AERMOD	2020	Atmos. Pollut. Res.	[46]
31.	2013	Iran: Teheran	1,2,34,7	NO_x, SO_2, VOC, CO, PM	500 × 500 m	uncertainty analysis	Inventory	2016	Urban Clim.	[47]
32.	2016	Argentina	10 – manure management and crop cultivations, 11 - open burning of biomass	NO_x, $PM_{2.5}$, PM_{10}, NMVOC, NH_3	24 provinces and 512 administrative units	Emission inventory EDGAR	Inventory	2020	Atmos. Environ.	[48]
33.	2018	Iran: Isfahan	7	NO_x, PM_{10}, SO_2, CO, VOC	1 × 1 km	Analyse of emission relies (kt/year) for Asia, uncertainty analysis	Inventory	2020	Atmos. Pollut. Res.	[49]
34.	2001-2017	The tropical part of America, Asia and Africa	11- biomass burning in fires	BC, CO, CO_2, NO_x, $PM_{2.5}$, SO_2, NMOC, NH_3	10 × 10 km	Monte Carlo method	Inventory	2020	J. Clean. Prod.	[50]
35.	2000, 2010 and 2014	Finland, Sweden, Denmark, and Norway. Analysis also at local level: Helsinki area, Copenhagen, Oslo and Vasterbotten	2 – small combustion	$PM_{2.5}$	1 × 1 km	Comparison between local, national, and European TNO inventory	The importance of including the local characteristic of the areas.	2021	Atmos. Environ.	[51]
36.	2017	53 Chinese cities on the East	7	BC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_2, NMVOC, NH_3	4 × 4 km	Analyses of previous scientific articles	Inventory	2020	Environ. Pollut.	[52]
37.	2012	China: Jiangsu,	1,2,34,7,10	NO_X	3 × 3 km	Previous bottom-up inventory and satellite data	Dispersion model CMAQ	2018	Atmos. Environ.	[53]
38.	2016	China: Qingdao City	1,2,34,6,7,8	VOC	2 × 2 km	Analyses of previous scientific articles Monte Carlo method	Inventory	2020	Process Saf Environ Prot	[54]
39.	2006 - 2016	China: Henan	2,7,9,10- manure management, fertilization, biomass burning	NH_3	3 × 3 km	Analyses of previous scientific articles, uncertainty analysis with AuvToolPro|Tool [55] Monte Carlo method measurement of NH_3 in year 2017	Inventory	2018	Atmos. Environ.	[56]
40.	2000 - 2014	Europe	All SNAP sectors	NMVOC, metals, PAH's, dioxins, PCB's	n.a.	Analyses of previous scientific articles, uncertainty analysis	Inventory	2019	Environ. Int.	[57]

It can be note that 1 article was published in year 2022 and 2017, 2 articles in year 2014 and 3 articles in years 2015, 2016 and 2019. 5 articles were from years 2018 and 2019. The majority, 17 articles, were published in year 2020. Most of the articles, 18 altogether, were published in Atmospheric Environment with 4.5 impact factor in year 2021 and 9.2 rated Cite Store[58]. 6 articles were from Atmospheric Pollution Research, 3 articles from Journal of Cleaner Production, whilejournals Atmospheric Chemistry and Physics and Environmental Pollution had 2 articles each. One paper per journal was from Air Quality, Atmosphere & Health, Chemosphere, Environment International, Geoscientific Model Development, Transportation Research Part D: Transport and Environment, Urban Climate and Journal of Environmental Sciences.

Figure 2: Published years (left) and journals (right) of selected articles.

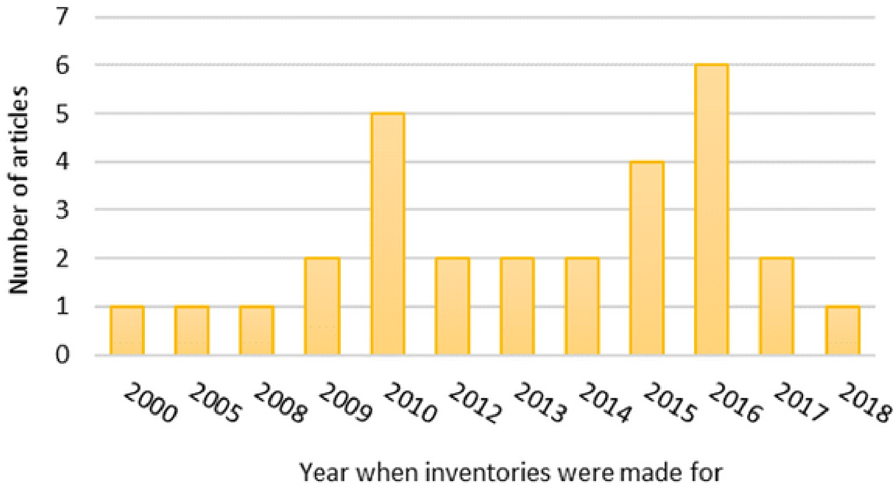




3.1 Period of time

More than half of all inventories (29.) used one-year long time period as shown in figure 3. The most represented years were 2010 and 2016. 8 inventories were prepared for longer time periods, the longest assessed period was 18 years long [40]. One article includes 16 years long period [50] and 2 articles include 14 [41], [57] and 6 years long periods [21], [24]. 1 article each refers to a 10 [56] and 2 year long period [20]. 1 article included only one month, December 2017 [37], besides another article refers on month August in two different years [46].

Figure 3: Distribution of one year long period inventories.



Time lag between the year of inventory and year of paper publication was usually at least 4 years. The highest time lag was 12 years.

3.2 Geographic Area of Inventory

The geographic area of inventories varied from global, national, regional or local scale. Study by Winijkul et. al. [42]included the whole world and collected emission data on the global scale. The same applies to the study by Kuenen et. al. [24], where 51 countries from Europe and North America or countries which reported their emissions under the CLRTAP convention were included [16]. Interesting areas were also discussed in the study by Shi et. al. [50], where main focus was on the tropical area of America, Asia and Africa.
From national point of view, the 14 articles were based on the countries within the Europe, 19 stayed in Chine's region, 7 articles were located in Asia and at least 4 articles include the region within the America. Majority of those were made for cities area, which are the highest sources of anthropogenic emission [59]. The research geographic area depends on the input database accessed [11].

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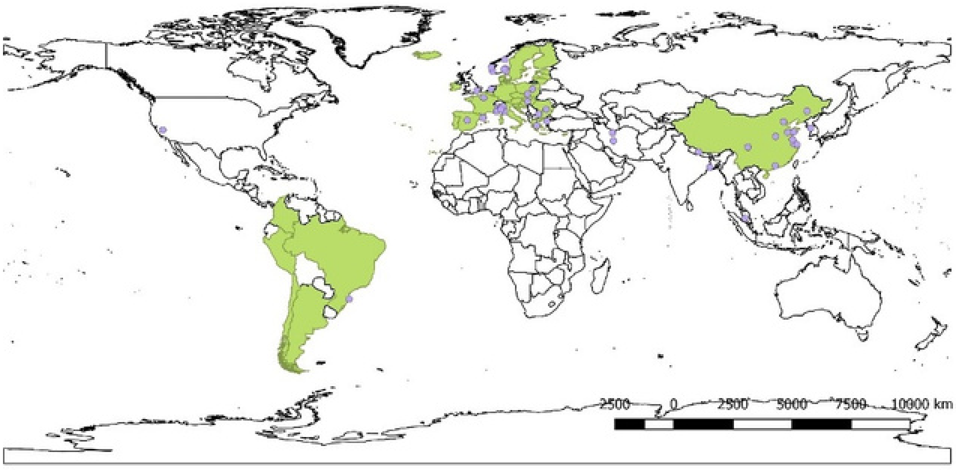
Figure 4: The geographic area of selected articles. Green colours indicate the countries, while purple colours show the cities.



3.3 Including Sectors in the Inventories

9 of all analysed scientific papers covered all SNAP sectors. Extended sectors, but not full SNAP nomenclatures, have been considered in 16 articles. Nevertheless, all of them included SNAP 02 – non-industrial combustion plants or mainly small combustions, 03 – industrial combustion plants and 07 – road transport. Only small combustion sector is involved in 3 studies, while road transport sectors is only included in 5 studies. These two sectors can be found in study by Elessa Etuman et. al [60], while Azhari et. al [38] included road transport sector and small industry. There are two outstanding studies [50] and [41], one focused on biomass burning from fires and another one on burning of crop residual.

3.4 Pollutants included in Inventories

The most common pollutants to be investigated are NOx, SOx and PM10. NOx emissions were included in 25 studies, while SOx was investigated in 20 studies. PM10 emissions can be found in 18 and PM2.5 in 17 studies. CO emissions were researched in 17, NMVOC emissions in 9 studies and NH3 in 10 studies.

The minority of articles, merely in 1 or 2, emissions of O3, dioxins, metals, PAH and PCB were represented, which could be a consequence of less availability and variability of emission factors for certain sectors and technologies [11].

Most studies analyse only one pollutant, but in some cases the precursors of secondary pollutants were investigated, such as VOC [54], [29], [30]. In the study by Z. Zhou et al. [30], where main focus was on VOC emissions, there were 45 VOC profiles and 519 species included, with the purpose of VOC specifications. The aim of the study by E. Winijkul et al. [42] was to analyse size distribution of PM on worldwide scale. In study by A. K. Pathak et al. [35] the toxicity of PM2,5 was researched in the area of Delphi, Greece. On European scale, study by A. Leclerc et al. [57]included the emissions of NMVOC, metals, PAH's, dioxins and PCB's.

3.5 Spatial Resolution of the Inventory

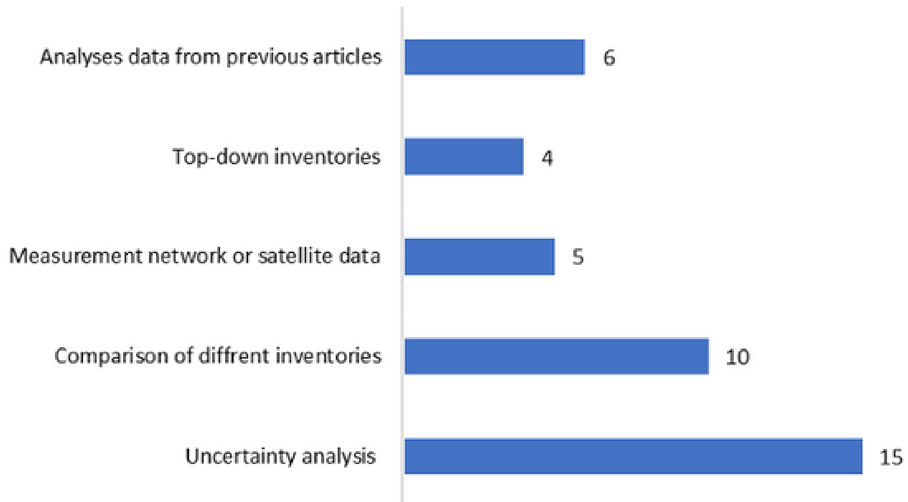
The range of resolution emission's inventories was from 500 × 500 meters [47] to 111 × 111 kilometres or 1° [32]. Majority of them used resolution of 1 ×1 kilometres. Some of the studies have results as common emissions on particulate territories, such as city, municipality, province, or region.

Papers with the main purpose of emission inventory validation, in general did not provide information about the spatial resolution of the inventories, the purpose of those studies was the final result's validation with other methods.

3.6 Validation process and the purpose of inventory

Accuracy of emission inventory is guaranteed through the validation process. Validation can be performed in different ways. In case of previously developed emission inventories, using either top-down or bottom-up principle, for a particular area a comparison between old and new estimated emissions can be done. Even though this approach is a bit rough, it was used in 10 studies [61]. In the case of both bottom-up and top-down inventory availability the comparison with the Diamond graph [62] can be used. This method was developed by The Forum for Air quality Modelling (FAIRMODE), which was lunched under the initiative of the European Environment Agency (EEA) and the European Commission Joint Research Centre (JRC) and is currently chaired by the Joint Research Centre [63]. The Diamond graph recognizes differences between the input data based on the activities and emission factors. This method was used in 4 discussed articles [7], [26], [39] in [13] conducted in European area. 5 of the analysed studies compared emissions based on measurement network or satellite data. The main disadvantage of using satellite data is misleading the secondary emissions, which is the main source of uncertainty [64]. The comparison method was used in 6 papers, either comparison of input data or comparison of new inventories with the results from previous studies. Indispensable was the uncertainty analysis of emission models, based on the description of model uncertainty or with the use of Monte Carlo methods. The last approach was used in 6 studies. Study by Zhang et. al. [56], conducted in China area, used mathematical program tool AuvToolPro [55] to analyse uncertainty as part of validation process.

Figure 5: The validation process used in different studies.



The main goal of the collected studies was to develop validation of emission inventories. In 8 studies the results of emissions inventories were used in air quality models. Comparison of air quality model results with measurement network data still provide some discrepancy. For instance, vehicle emission factors for NOx emissions were typically underestimated, especially during the rush hours [65]. Moreover, emissions of PM can be underestimated due to the disregard of secondary emissions, resuspension and long-range emissions [20]. One of the disadvantage of this validation model is also, that dispersion models more preciously predict the average values of modelled pollution, meanwhile the maximum hourly or daily values are underestimated or overrated [19]. The main focus of five studies was to create different scenarios of fuel use, use of different technologies or changes in activity. In this way, the certain measures to improve local air quality were analysed.

DISCUSSION

Fine spatial resolution emission inventories are useful tools to briefly analyse different emission sources. They can also be used as an input to air quality models. Emission inventory enables to analyse different scenarios for different technologies used and activity changes. Consequently, it represents the effective tool to accept different measurements, which goal is to reach the most appropriate balance between human activities and quality of urban air.

This study found out, that the most covered areas with emission inventories are Europe and China, which could be result of diversity and availability of input data. The need for better spatial resolution, i.e. emission distribution on finer grid, based on the top-down method was shown [13]. The comparison of both methods, bottom-up and top-down, recognized the overrated emissions from top-down methods [66]. The detailed bottom-up emission model is achievable in cases of available detailed input activity and technology data, accessible only in countries or regions with transparent database centres, more common in developed countries [20].

The solution for lack of available activity input data from small combustion and transport on local scale offers the OLYMPUS model [27]. Model considers everyday citizen activities and defines their mobility needs around the city. Sum of each activity represents the common activity in city Paris. The spatial distribution of mobility is based on the proximity of service facilities or private buildings and use of different transport vehicles. The model also considers small combustion based on the energy use of buildings. The main model input data are population density, location of service facilities, road network, public transport and meteorological characteristics that have an impact on emissions [60].

Our study recognized that emission inventories need improvements of source identification and specification in the urban environment. Additionally, there is a need to broader knowledge about the formation of secondary emissions, emissions from resuspension and chemical-physical processes, which could be implemented in the inventory [20].

Furthermore, additional studies focused on discrepancies between bottom-up and top-down emissions on smaller area are needed. A tendency to make inventories with higher spatial resolution is evident [20], [67].

The requirement to acquire more precise emission factors for dominant technologies used in all SNAP sectors in a given area, was shown. More studies are needed with the focus on emission factors related to different conditions. Consequently, it is recommended to fund more studies, which purpose will be research emission factors obtain from different conditions [57], [34].

This study shown that almost all analysed inventories deal with anthropogenic emission sources. The natural emission sources can as well contribute to higher emissions, such as occurrence of desert dust.

Last but not least, the important step in emission inventory development is analysis of model uncertainties and sensitivities. In the most research papers included in our study, the uncertainty analysis and Monte Carlo method was used [13]. In the future, we suggest the improvement in comparison methodology to enable two inventories to be compared for the same area by different parts like sectors, activity use, emission factors, and population density [26]. Currently the Diamond graph is effective tool for comparisons of bottom – up and top – down emission inventories [26].

Above listed improvements will lead to the effective tools for assessment of measures targeting urban air quality.

CONSLUSION

Air quality can be assessed by measurement network composed of representative monitoring sites equipped with certain measurement equipment. On the other hand, air quality models represent reality with uncertainties. Their accuracy also heavily depends on the accuracy of input data. Emission inventories with fine spatial distribution and temporal emissions release are essential for defining effective air-pollution-control measures. They are help finding the compromise between human goods and health environment. Literature review showed there is still deficiency of available good quality input data to analyse sources. Furthermore, emission factors should be researched more, especially for new and widely used technologies. Currently the most covered states are China and Europe. Slovenia still has a lot of space to improve national Emission Inventory based on the bottom-up methods [68].

REFERENCES

[1] 71 World Health Assembly, “Health, environment and climate change: report by the Director-General,” World Heal. Organ., vol. 2016, no. SEVENTY-FIRSTWORLD HEALTH ASSEMBLY, pp. 1–7, 2018.
[2] I. Manisalidis, E. Stavropoulou, A. Stavropoulos, and E. Bezirtzoglou, “Environmental and Health Impacts of Air Pollution: A Review,” Front. Public Heal., vol. 8, no. February, pp. 1–13, 2020.
[3] P. D. United Nations, Department of Economic and Social Affairs, “The World ’s Cities in 2018,” World’s Cities 2018 - Data Bookl. (ST/ESA/ SER.A/417), p. 34, 2018.
[4] S. Gani et al., “Systematizing the approach to air quality measurement and analysis in low and middle income countries,” Environ. Res. Lett., vol. 17, no. 2, Feb. 2022.
[5] V. F. McNeill, “Addressing the Global Air Pollution Crisis: Chemistry’s Role,” Trends Chem., vol. 1, no. 1, pp. 5–8, 2019.
[6] K. Karroum et al., “A Review of Air Quality Modeling,” Mapan - J. Metrol. Soc. India, vol. 35, no. 2, pp. 287–300, 2020.
[7] S. López-Aparicio, M. Guevara, P. Thunis, K. Cuvelier, and L. Tarrasón, “Assessment of discrepancies between bottom-up and regional emission inventories in Norwegian urban areas,” Atmos. Environ., vol. 154, pp. 285–296, 2017.
[8] M. Li et al., “Special Topic: Air Pollution and Control Anthropogenic emission inventories in China: a review,” Natl. Sci. Rev., vol. 4, pp. 834–866, 2017.
[9] B. Xu et al., “The Study of Emission Inventory on Anthropogenic Air Pollutants and Source Apportionment of PM 2.5 in the Changzhutan Urban Agglomeration, China.”
[10] H. Q. Bang and V. H. N. Khue, Air Pollution: Monitoring, Quantification and Removal of Gases and Particles. IntechOpen, 2019.
[11] D. A. Vallero, Fundamentals of Air Pollution, Fifth. 2014.
[12] M. Satt, M. De Almeida, D. Agosto, F. Gonçalves, H. Beatriz, and B. Cybis, “The evolution of city-scale GHG emissions inventory methods : A systematic review,” Environ. Impact Assess. Rev., vol. 80, no. September 2019, p. 106316, 2020.
[13] M. Trombetti et al., “Spatial inter-comparison of Top-down emission inventories in European urban areas,” Atmos. Environ., vol. 173, no. May 2017, pp. 142–156, 2018.
[14] European Environment Agency, EMEP/EEA air pollutant emission inventory guidebook 2019, 13/2019. Luxembourg: European Environment Agency, 2019.
[15] et. al. Ole-Kenneth Nielsen, “EMEP/EEA air pollutant emission inventory guidebook 2019 Small combustion,” 2019.
[16] T. Kuokkanen, “The convention on long-range transboundary air pollution,” Mak. Treaties Work Hum. Rights, Environ. Arms Control, pp. 161–178, 2007.
[17] Eutat, “Definition SNAP Nomenclature,” Eustat official statistical information of the Basque Country, 2022. [Online]. Available: https://en.eustat.eus/documentos/elem_13173/definicion.html. [Accessed: 06-Jul-2022].
[18] L. Khazini, M. J. Kalajahi, Y. Rashidi, and S. M. M. M. Ghomi, “Real-world and bottom-up methodology for emission inventory development and scenario design in medium-sized cities,” J. Environ. Sci., no. xxxx, 2022.
[19] L. Sartini, M. Antonelli, E. Pisoni, and P. Thunis, “From emissions to source allocation: Synergies and trade-offs between top-down and bottom-up information,” Atmos. Environ. X, vol. 7, no. July, p. 100088, 2020.
[20] E. Terrenoire et al., “High-resolution air quality simulation over Europe with the chemistry transport model CHIMERE,” Geosci. Model Dev., vol. 8, no. 1, pp. 21–42, 2015.

REFERENCES

[21] K. M. Fameli and V. D. Assimakopoulos, "The new open Flexible Emission Inventory for Greece and the Greater Athens Area (FEI-GREGAA): Account of pollutant sources and their importance from 2006 to 2012," Atmos. Environ., vol. 137, pp. 17–37, 2016.
[22] L. Pallavidino, R. Prandi, A. Bertello, E. Bracco, and F. Pavone, "Compilation of a road transport emission inventory for the Province of Turin: Advantages and key factors of a bottom–up approach," Atmos. Pollut. Res., vol. 5, no. 4, pp. 648–655, 2014.
[23] H. A. C. Denier Van Der Gon et al., "Particulate emissions from residential wood combustion in Europe - revised estimates and an evaluation," Atmos. Chem. Phys., vol. 15, no. 11, pp. 6503–6519, 2015.
[24] J. J. P. Kuenen, A. J. H. Visschedijk, M. Jozwicka, and H. A. C. Denier Van Der Gon, "TNO-MACC-II emission inventory; A multi-year (2003-2009) consistent high-resolution European emission inventory for air quality modelling," Atmos. Chem. Phys., vol. 14, no. 20, pp. 10963–10976, 2014.
[25] P. Thunis et al., "Sensitivity of air quality modelling to different emission inventories: A case study over Europe," Atmos. Environ. X, vol. 10, no. October 2020, p. 100111, 2021.
[26] M. Guevara, S. Lopez-Aparicio, C. Cuvelier, L. Tarrason, A. Clappier, and P. Thunis, "A benchmarking tool to screen and compare bottom-up and top-down atmospheric emission inventories," Air Qual. Atmos. Heal., vol. 10, no. 5, pp. 627–642, 2017.
[27] A. Elessa Etuman, I. Coll, and V. Rivera Salas, "OLYMPUS: An emission model to connect urban form, individual practices and atmospheric pollutant release," Atmos. Environ., vol. 245, no. 118013, 2021.
[28] "Volatile chemical products emerging as largest petrochemical source of urban organic emissions," Atmos. Chem., vol. 764, no. February, pp. 760–764, 2018.
[29] S. Zhu, M. Mac Kinnon, B. P. Shaffer, and G. S. Samuelsen, "An uncertainty for clean air: Air quality modeling implications of underestimating VOC emissions in urban inventories," Atmos. Environ., vol. 211 pp. 256–267, 2019.
[30] Z. Zhou et al., "Compilation of emission inventory and source profile database for volatile organic compounds: A case study for Sichuan , China," Atmos. Pollut. Res., vol. 11, no. September, pp. 105–116, 2019.
[31] C. Gao, C. Gao, K. Song, Y. Xing, and W. Chen, "Vehicle emissions inventory in high spatial – temporal resolution and emission reduction strategy in Harbin-Changchun Megalopolis," Process Saf. Environ. Prot., vol. 138, pp. 236–245, 2020.
[32] I. Bouarar et al., "Influence of anthropogenic emission inventories on simulations of air quality in China during winter and summer 2010," Atmos. Environ., vol. 198, no. September 2018, pp. 236–256, 2019.
[33] H. Hua, S. Jiang, H. Sheng, Y. Zhang, X. Liu, and L. Zhang, "A high spatial-temporal resolution emission inventory of multi-type air pollutants for Wuxi city," J. Clean. Prod., vol. 229, pp. 278–288, 2019.
[34] P. Jiang, X. Chen, Q. Li, H. Mo, and L. Li, "High-resolution emission inventory of gaseous and particulate pollutants in Shandong Province, eastern China," J. Clean. Prod., vol. 259, p. 120806, 2020.
[35] A. K. Pathak, M. Sharma, and P. K. Nagar, "Chemosphere A framework for PM 2 . 5 constituents-based (including PAHs) emission inventory and source toxicity for priority controls: A case study of," Chemosphere, vol. 255, p. 126971, 2020.
[36] M. Zhu, L. Liu, S. Yin, J. Zhang, K. Wang, and R. Zhang, "County-level emission inventory for rural residential combustion and emission reduction potential by technology optimization: A case study of Henan, China," Atmos. Environ., vol. 228, p. 117436, 2020.
[37] Y. Kwon, H. Lim, Y. Lim, and H. Lee, "Implication of activity-based vessel emission to improve regional air inventory in a port area," Atmos. Environ., vol. 203, no. June 2018, pp. 262–270, 2019.

REFERENCES

[38] A. Azhari et al., “Highly spatially resolved emission inventory of selected air pollutants in Kuala Lumpur ' s urban environment,” Atmos. Pollut. Res., vol. In Press, 2020.
[39] A. Clappier and P. Thunis, “A probabilistic approach to screen and improve emission inventories,” Atmos. Environ., vol. 242, no. July, p. 117831, 2020.
[40] T. Coudon et al., “A national inventory of historical dioxin air emissions sources in France,” Atmos. Pollut. Res., vol. 10, no. 4, pp. 1211–1219, 2019.
[41] B. Das, P. V Bhave, S. P. Puppala, K. Shakya, B. Maharjan, and R. M. Byanju, “A model-ready emission inventory for crop residue open burning in the context of Nepal,” Environ. Pollut., vol. 266, p. 115069, 2020.
[42] E. Winijkul, F. Yan, Z. Lu, D. G. Streets, T. C. Bond, and Y. Zhao, “Size-resolved global emission inventory of primary particulate matter from energy-related combustion sources *,” vol. 107, pp. 137–147, 2015.
[43] A. De Sousa, L. Hoinaski, T. Barros, and R. Castelan, “A methodology for high resolution vehicular emissions inventories in metropolitan areas : Evaluating the effect of automotive technologies improvement,” Transp. Res. Part D, vol. 77, pp. 303–319, 2019.
[44] N. Huneeus et al., “Evaluation of anthropogenic air pollutant emission inventories for South America at national and city scale,” Atmos. Environ., vol. 235, p. 117606, 2020.
[45] D. Majumdar, P. Purohit, A. D. Bhanarkar, P. S. Rao, and P. Rafaj, “Managing future air quality in megacities: Emission inventory and scenario analysis for the Kolkata Metropolitan City, India1,” Atmos. Environ., vol. 222, p. 117135, 2020.
[46] S. Mentese et al., “A comprehensive assessment of ambient air quality in Çanakkale city : Emission inventory , air quality monitoring , source apportionment , and respiratory health indicators,” Atmos. Pollut. Res., vol. 11, pp. 2282–2296, 2020.
[47] H. Shahbazi, S. Taghvaee, V. Hosseini, and H. Afshin, “Urban Climate A GIS based emission inventory development for Tehran,” UCLIM, vol. 17, pp. 216–229, 2016.
[48] P. S. Enrique, B. Tomas, B. Lucas, and P. Romina, “High resolution inventory of atmospheric emissions from livestock production, agriculture, and biomass burning sectors of Argentina,” Atmos. Environ., vol. 223, p. 117248, 2020.
[49] O. Ghaffarpasand, M. R. Talaie, H. Ahmadikia, A. T. Khozani, and M. D. Shalamzari, “A high-resolution spatial and temporal on-road vehicle emission inventory in an Iranian metropolitan area, Isfahan, based on detailed hourly traffic data,” Atmos. Pollut. Res., vol. 11, pp. 1598–1609, 2020.
[50] Y. Shi, S. Zang, T. Matsunaga, and Y. Yamaguchi, “A multi-year and high-resolution inventory of biomass burning emissions in tropical continents from 2001–2017 based on satellite observations,” J. Clean. Prod., vol. 270, p. 122511, 2020.
[51] V. V. Paunu et al., “Spatial distribution of residential wood combustion emissions in the Nordic countries: How well national inventories represent local emissions?,” Atmos. Environ., vol. 264, no. October 2020, 2021.
[52] P. Jiang, X. Zhong, and L. Li, “On-road vehicle emission inventory and its spatio-temporal variations,” Environ. Pollut., vol. 267, p. 115639, 2020.
[53] Y. Zhao, Y. Xia, and Y. Zhou, “Assessment of a high-resolution NO X emission inventory using satellite observations : A case study of southern Jiangsu , China,” Atmos. Environ., vol. 190, no. X, pp. 135–145, 2018.
[54] M. Zhou, W. Jiang, W. Gao, B. Zhou, and X. Liao, “A high spatiotemporal resolution anthropogenic VOC emission inventory for Qingdao City in 2016 and its ozone formation potential analysis,” Process Saf. Environ. Prot., vol. 139, pp. 147–160, 2020.

REFERENCES

[55] H. C. Frey and J. Zheng, “Quantification of Variability and Uncertainty in Air Pollutant Emission Inventories: Method and Case Study for Utility NO x Emissions Quantification of Variability and Uncertainty in Air Pollutant Emission Inventories: Method and Case Study for Utility N,” J. Air Waste Manage. Assoc., no. 52, pp. 1083–1095, 2011.
[56] R. Zhang, “High-resolution ammonia emission inventories with comprehensive analysis and evaluation in Henan, China, 2006–2016,” Atmos. Environ., vol. 193, pp. 11–23, 2018.
[57] A. Leclerc, S. Sala, M. Secchi, and A. Laurent, “Building national emission inventories of toxic pollutants in Europe,” Environ. Int., vol. 130, no. March, p. 104785, 2019.
[58] Clarivate, “Journal Impact Factor,” Journal Citation Reports, Web of Science Group, 2021. [Online]. Available: https://clarivate.com/webofsciencegroup/solutions/journal-citation-reports/?gclid=CjwKCAjwtcCVBhA0EiwAT1fY7xpDAokCMFI1PD5UUTpJC3ZTXvEfYOtdSa0qZAOezhytcv2hWGbW1BoCLDkQAvD_BwE.
[59] K. Chen et al., “Summertime O 3 and related health risks in the north China plain: A modeling study using two anthropogenic emission inventories,” Atmos. Environ., no. October, p. 118087, 2020.
[60] A. Elessa Etuman and I. Coll, “OLYMPUS v1.0: Development of an integrated air pollutant and GHG urban emissions model-methodology and calibration over greater Paris,” Geosci. Model Dev., vol. 11, no. 12, pp. 5085–5111, 2018.
[61] T. L. Vaughn et al., “Temporal variability largely explains top-down/bottom-up difference in methane emission estimates from a natural gas production region,” Proc. Natl. Acad. Sci. U. S. A., vol. 115, no. 46, pp. 11712–11717, 2018.
[62] P. Thunis, B. Degraeuwe, K. Cuvelier, M. Guevara, L. Tarrason, and A. Clappier, “A novel approach to screen and compare emission inventories,” Air Qual. Atmos. Heal., no. March, pp. 325–333, 2016.
[63] JRC - Joint Research Centre, “FAIRMODE - Forum for Air quality Modeling.” [Online]. Available: https://fairmode.jrc.ec.europa.eu/home/index. [Accessed: 07-Jul-2022].
[64] D. G. Streets et al., “Emissions estimation from satellite retrievals: A review of current capability,” Atmos. Environ., vol. 77, pp. 1011–1042, Oct. 2013.
[65] O. E. Salmon et al., “Top-Down Estimates of NOxand CO Emissions FromWashington, D.C.-Baltimore During theWINTER Campaign,” J. Geophisical Res. Atmos., no. 10.1029/2018JD028539, pp. 7705–7724.
[66] M. Hoogwijk et al., “Sectoral Emission Mitigation Potentials: Comparing Bottom-Up and Top-Down Approaches,” Toshihiko Masui.
[67] P. Jiang, X. Chen, Q. Li, H. Mo, and L. Li, “High-resolution emission inventory of gaseous and particulate pollutants in Shandong Province, eastern China,” J. Clean. Prod., vol. 259, p. 120806, 2020.
[68] Slovenian Environment Agency, “Slovenian Informative Inventory Report 2020,” Ljubljana, 2020.

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[1] Bhatt Siddharta M. Energy audit case studies II – Air conditioning (cooling) systems. Appl Th Eng. 2000; 20: 297-307.

[2] American college of physicians. Clinical Ecology. An Int Med 1989; 111:168-78.

[3] Vivian VL, ed. Child abuse and neglect: a medical community response. Proceedings of the first AMA national conference on child abuse and neglect. 1984 Mar 30-31; Chicago. Chicago: American Medical Assotiation, 1985.

[4] Mansfieid LW. How the nurse learns which imbalance is present. V: Moidel HC, Sorensen GE, Giblin EC, Kaufman MA, eds. Nursing care of the patient with medical-surgical disorders. New York: Mc Grow-Hill, 1971: 153-60.

[5] Evaluation of the European Agency for Safety and Health at Work: http://osha.europa.eu/publications/other/20010315/index_1.htm (20. 12. 2006).

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