Geographical Information Management and Applications

Using Agent-based Modelling to evaluate the potential health impact of *E.coli* in fountain water

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Abstract

This study aims to assess how Agent-Based Modelling can be used to evaluate the health impact of faecal pathogens in fountain water. This study focusses on human exposure to *E.coli* in fountain water. A model was developed that simulates individual exposure for three different fountain locations in Amsterdam, the Netherlands. The model simulates the movement of people that visit the fountains. Visitors either sit on the benches that surround the fountain (indirect contact with water) or play in the fountain (direct contact with water). Elements such as the distance of the spray of the fountain, the angle of the spray of the fountain and the number of people visiting the fountain are incorporated in the experiments. At last, different water management strategies are tested to determine useful approaches that can limit the chances of exposure. The project shows that it is possible to evaluate factors contributing to *E.coli* exposure with the use of an Agent-Based Model. The experiments prove that exposure to *E.coli* mainly occurs due to direct contact with water. Secondly, this research shows that the number of visitors can strongly influence the infection of the fountain and therefore also determines the number of exposed visitors. At last, according to the model we see that increasing the frequency of cleaning proves to be the most successful management strategy. This approach lowers the chance of exposure and therefore limits the number of exposed visitors.

Acknowledgements

I am very happy to tell you that you are about to read my thesis. When I started this project back in September I never expected it to become what it is right now. During the process of reading literature, writing scripts and analysing the results I doubted myself a lot. I was afraid that I was not able to finish what I had started, let alone succeed well. However, eight months later the thesis came about and I find myself writing the acknowledgements. And even though I can be proud of myself, I do realise that I would not have been able to complete this project all alone. That is why, first of all, I would like to thank my mother, Thea à Nijeholt, who constantly supported me and always believed in me. You gave me confidence and made me feel like I could do it. Thank you once again!

Besides my mother, I want to thank my girlfriend Fieke Veringa. The fact that I was insecure about this project seemed so ridiculous to her that I often had to laugh about myself as well when I expressed my doubts to her. You certainly helped me to put things in perspective for the last eight months. You never complained and always told me that I should not worry. I guess you are right after all.

I also want to thank Bas Retsios, who helped me tremendously with writing the script for the model. Not only were you willing to help when I came to visit you in Enschede, you were also happy to assist me whenever I sent you questions per e-mail. Developing the model was one of the things I enjoyed the most during this thesis and you absolutely added to that experience.

At last, I want to express my profound gratitude to my supervisor Ellen-Wien Augustijn. You believed in me from the first day on and gave me wonderful advice. I can imagine that, because of my insecurities, our sessions would feel more like therapy or counselling at times to you. However, you remained full of confidence and helped me whenever I got stuck. I would have never been able to finish this project without your help. Thank you very much!

Table of content

1. Introduction

Nowadays, fountains are more often integrated into urban areas to make the living environment attractive and have a positive influence on people (de Man et al., 2009). Although recreational water can have positive consequences and can contribute to the well-being of citizens (Schets et al., 2017; de Man et al., 2009), the question arises whether these developments pose a risk to our public health. This because urban water in fountains can contain pathogens. An example of this is faecal pathogens. Exposure to faecal pathogens in water can lead to serious gastrointestinal complaints (de Man et al., 2009). Therefore this study will focus on the health impact of faecal pathogens in fountain water.

Despite the health risks, *E.coli* is sometimes still found in public waters in the Netherlands. A recent example is the Amsterdam City Swim in 2018. For this swimming competition, participants would swim through the canals of Amsterdam. However, due to the high concentration of *E.coli* that were measured in the canals, the competition had to be cancelled (Amsterdam City Swim, 2018; AD, 2018; Parool, 2018). This shows that the municipality is well aware of the fact that faecal pathogens in our water can present health risks. Therefore, the quality of drinking water and recreational water is strictly monitored. However, despite regulating and monitoring these water types, there are still no strict guidelines for faecal pathogens in urban waterbodies like fountains. Because of this, the quality of their waters can strongly vary. Fountain water can thus pose a serious threat to the health of many residents who come into contact with it. Since *E.coli* forms a good indicator of faecal pollution, this research focuses on the presence of *E.coli* in fountain water (de Man et al., 2009).

The danger of pathogenic microorganisms in urban water features has already been addressed in studies like the research by Schets et al. (2017). However, there is still much underexposed in these studies. For example, the emphasis of these researches usually has a strong microbiological focus (Schets et al., 2017), while other studies only address the possible presence of *E.coli* in urban waters (Flores et al., 2013; Burkowska-But et al., 2013). Meanwhile, the interaction between people and faecal pathogens and the possible exposure to these pathogens has not been researched extensively. This study will therefore elaborate on that. The potential exposure of pedestrians to *E.coli* in fountain water will be investigated with the use of Agent-Based Modelling (ABM). By simulating reality, Agent-Based Models offer the possibility to analyse the interaction of people with their environment, without actually exposing them to the pathogens. This enables us to study this phenomenon and allows us to experiment with agents and their given attributes. Agent-Based Modelling proves to be a very suitable method to do so, because it makes it possible to analyse and experiment with agents that operate in an environment created in a model (Abdou et al., 2012). Therefore, this research project can contribute to disease studies without facing the practical limitation of endangering someone's health. Theoretical and empirical findings will be tested in the simulation to generate results that reflect reality. Besides analysing the outcome of the model, we consider the process of building a robust model as another important element. Therefore this project aims to investigate how Agent-Based Modelling can add knowledge to social studies focussing on exposure to pathogens in urban waters.

1.1 Reading guide

First, chapter 2 will discuss the research objectives. After that, the theoretical framework is given in chapter 3. In chapter 4 the methodology is discussed. The conceptual design of the model is described in chapter 5 of this report. Chapter 6 will elaborate on the data processing that was required to develop the model. In chapter 7 the sensitivity analysis will be described. The final results are discussed in chapter 8. This report ends with the conclusion in chapter 9, followed by the discussion and recommendations provided in chapter 10. The codes of the Agent-Based Models can be found in the appendix of the report.

2. Objectives

2.1 Research objective

Although *E.coli* has been found in public water in Dutch cities like Amsterdam, it is unclear if *E.coli* exposure can result from visiting fountains. This research will assess fountain induced exposure using an Agent-Based Model. Therefore, the main research question states:

"How can Agent-Based Modelling (ABM) be used to evaluate possible pedestrian exposure to faecal pathogens in fountains?"

This research question results in two sub-objectives:

1. Model the individual exposure to *E.coli* via water in fountains.
2. Model *E.coli* fountain water infection levels.

The first sub-objective is analysed through the following research questions:

1.1 *"What role does the distance of the individual to the fountain play in the exposure process?"*
1.2 *"What is the role of the spatial environment in the exposure process?"*

The second research objective considers the infection of the fountain. No data is available of the actual infection levels of the fountains under study, but we can evaluate the impact of management strategies targeting the cleaning of the area and fountain water. This results in the following research question:

2.1 *"What is the impact of different water management strategies on the exposure to E. coli?"*

The possible ways of individual exposure should be considered first. Next, the urban environment and other characteristics of different locations can determine the number of exposures. However, when people are exposed to fountain water, it is important to consider the quality of the water of these fountains. This means that focussing on different management strategies can generate a better understanding of ways to limit the number of exposures to *E. coli*. By analysing how people are potentially exposed to *E.coli* via fountain water and modelling the quality of that water, this study can address and evaluate the potential health impact of fountain water.

2.2 Scope and limitations

This research will evaluate the factors that contribute to the health risks caused by fountains carrying faecal pathogens. This means that the study only considers urban water of fountains and only addresses the presence of *E.coli*. Health risks caused by water in rural areas or other urban features like canals are not part of this research. Also the effects of other non-faecal pathogens are not considered in this study. This means that not every factor contributing to pathogens in water are taken into account. The focus of this study is also on building an Agent-Based Model. This means that the process of how these concepts are modelled is considered to be one of the main tasks of this research. Delivering a useful and valid model is therefore a very important aspect. However, if the model proves to be useful, its findings will be used for further analysis. At last, it is important to understand that this study does not intent to create a quantitative or mathematical model in which each factor can be exactly calculated. The model will rather try to recreate human behaviour to provide an indication of a possible scenario of exposure to *E.coli* from fountain water.

2.3 Overview

For this study an Agent-Based Model will be developed to answer the research questions discussed in section 2.1. Below a schematic overview will elaborate on the process of designing the research and developing the model (figure 1).

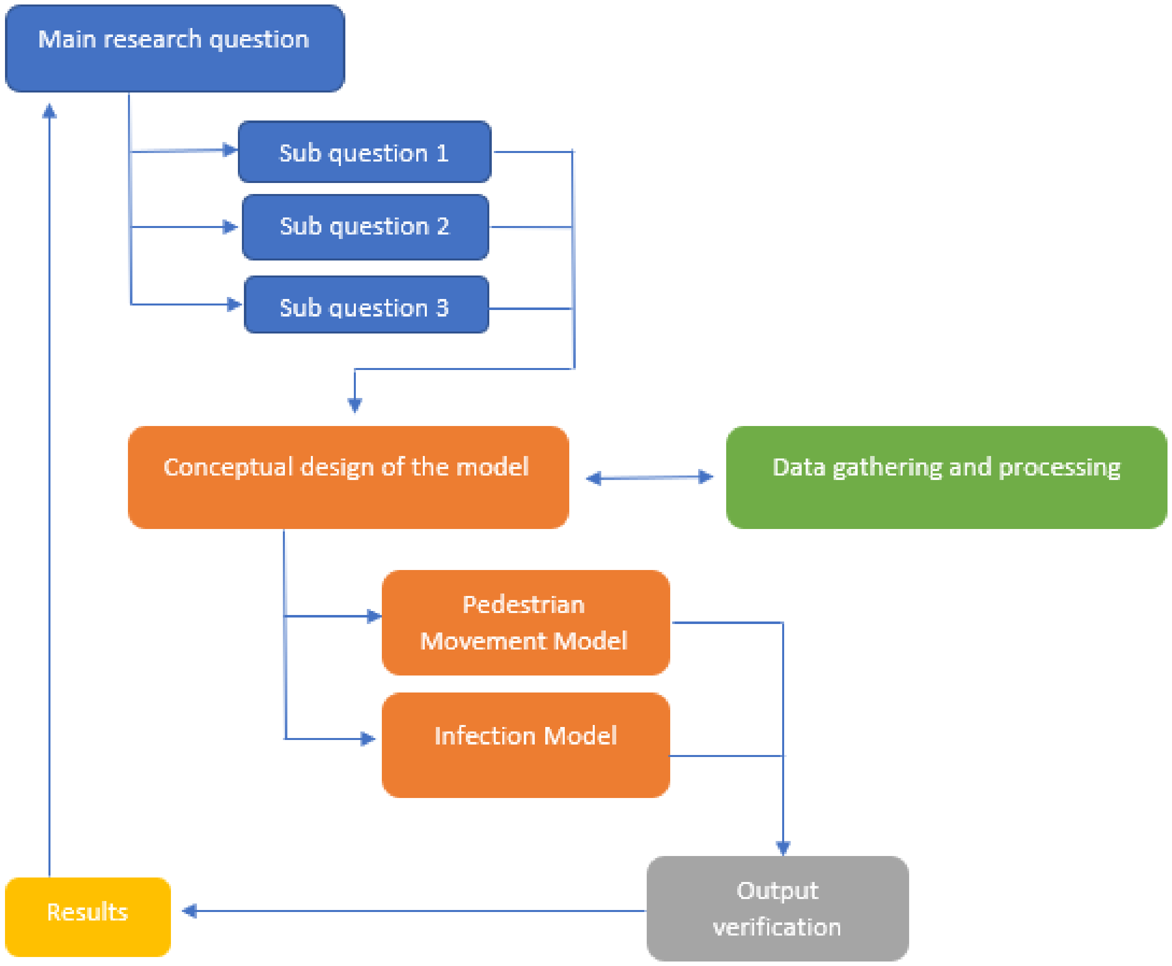


Figure 1 Schematic overview of model and research design

As the schematic overview shows, the study begins with the main research question. The main research for this study is *"How can Agent-Based Modelling (ABM) be used to evaluate possible pedestrian exposure to faecal pathogens in fountains?"* This research question is split up into three sub-questions. The sub-questions will be used to answer the main research question. To answer these sub-questions, an Agent-Based Model will be designed. Therefore the research questions lead to the conceptual design of the model. Gathering and processing data will help to define the conceptual design of the model. This eventually leads to the final development of the Agent-Based Model, which consists out of the Pedestrian Movement Model and the Infection Model. The output of the Agent-Based Model is then used in a verification analysis to determine if the model is capable of producing valid and robust results. After the verification, the outcome of the model will be analysed and incorporated in the final results. These final results will then be used to answer the main research question.

3. Theoretical framework

3.1. Spreading of E. Coli

This study considers the presence of *E.coli* bacteria in fountain water. *E.coli* is one of the biggest indicators to determine the degree of faecal pollution (de Man et al., 2009). *E. coli* itself is not extremely harmful, but the faecal pathogens are and can lead to serious gastrointestinal complaints (de Man et al., 2009). Despite this health risk, there are currently no guidelines on the amount of faecal pathogen that can be present in urban waters. However, standards for *E.coli* do exist for other water types like drinking and recreational water. The European guideline for recreational waters (2006/7/EC) is an example of this. This guideline states that a maximum of 100CFU of *E.coli* per 100ml water is allowed (de Man et al., 2009). The abbreviation CFU refers to colonial forming units. This is a unit used to determine the number of bacteria in a particular sample. When using these standards, the risk of getting gastrointestinal complaints are still around 11%. This means that even when the water meets the requirement, about 1 in 9 people still develop symptoms of illness after contact. Finding *E.coli* in fountain water is rare, but not uncommon. The study by Burkowska-But et al. (2013) for instance shows that some fountains exceed this level of CFU. Another study by Flores et al. (2013) also shows that there is obvious evidence of faecal contamination in some urban water bodies. For this study, it is therefore important to understand how this bacteria can end up in our fountains.

According to de Man et al. (2009), *E.coli* is spread by animals and can therefore enter fountains through them. Animals like birds, dogs and rats use fountains (Burkowska-But et al., 2013), and can carry *E.coli* and transfer the bacteria to fountain waters. There is a large variety of different animals that can carry and transfer *E.coli*. Out of those animals, rats are one of the largest contributors to disease spreads in cities (Himsworth et al., 2015). This is partly due to the fact that rat density in cities is high (Feng and Himsworth, 2014). Rats can cope well with urban challenges like climbing up buildings or creating nests out of waste materials (Feng and Himsworth, 2014). Therefore rats can easily thrive well in the built environment. Himsworth et al. (2015) state that there are three ways in which the pathogens are transmitted by rats to water. Namely through rat urine and faeces, saliva or fleas. However, rat faeces are the biggest source that can transfer *E.coli* to fountain water. To incorporate the transmittance of *E.coli* from rats, there are three important elements that need to be described:

1) How many rats carry *E.coli*?
2) How many rats are there in a city like Amsterdam?
3) How do rats move to transfer *E.coli*?

Many studies have addressed the first question. According to empirical studies by Himsworth et al. (2015) and Gakuya et al. (2001), approximately 60% of rat populations carry the *E.coli* bacteria. This indication can be useful for this study as well. In that case, 6 out of 10 rats will be considered to be carrying the *E.coli* bacteria. However, this also depends on the size of rat population. This brings us to the second question: how many rats are there in a city like Amsterdam?

Unfortunately, there is no unambiguous answer to this. This because there are no exact numbers on the number of rats in a city. The indication of Pimentel et al. (2005) is often used by the Public Health Service of Amsterdam (GGD) to determine the number of rats. In this approach, there is about one rat per citizen (Pimentel et al., 2005). This means that there should be around

800.000 rats in Amsterdam. However, estimations on the number of rats can also be calculated based on how often rats are reported. These calculations give a very different outcome.

At last, the third question has not been researched extensively. Therefore it is harder to determine rat behaviour to understand how they transfer *E.coli* to fountains. Feng and Himsworth (2014) describe in their study that areas with bad public cleaning services suffer from many rats. They believe that this is caused by the fact that waste in garbage bins is not being disposed of properly. These areas are then likely to provide food for rat populations (Feng and Himsworth, 2014). In addition to this, studies have proven that when waste is disposed of well, the number of rats decreased (Feng and Himsworth, 2014). Therefore waste is considered to be one of the greatest sources that attract rats and other animals. This problem is widely recognized. Navghane et al. (2016) published a paper concerning 'smart' bins. They state that garbage bins usually overflow, which then attracts rats. In an attempt to fight this, cities nowadays try to improve their garbage bins by making them 'smart' to prevent them from being too full when they tend to overflow. This should then prevent garbage bins from becoming sources of food for animals. That is why in this study, the movement or presence of vermin like rats is determined by their need for food. Their food is provided by the waste of people. More people lead to more waste. That is why for this study the number of visitors at a fountain will influence how fast an area can become infected with *E.coli*.

3.2 Agent-Based Modeling

Agent-Based Modelling (ABM) can best be described as a computational research of social agents in a system that operate and interact with each other autonomously (Janssen, 2005). This way ABM forms a useful instrument to investigate social systems from a complex adaptive system (CAS) perspective. This allows the researcher to study macro phenomena by looking at micro level interactions between heterogeneous actors (Holland, 1992 in Janssen, 2005). Using ABM models as computational laboratories enables researchers to study particular phenomena and allows them to test varying hypotheses that are connected to the given attributes of the agents in that model. This takes the predetermined behavioural rules into account, but also aspects like the kind of interactions are considered (Janssen, 2005). This allows researchers to generalize their findings in a broader context. Gilbert's (2008) description fits well to this by stating that: "*an agent-based model is a computer program that creates a world of autonomous, heterogeneous agents in which each agent interacts with other agents and with the environment*" (Elsenbroich & Gilbert, 2014, p.68). This method allows researchers to create, analyse and experiment with agents that operate in an environment created in a model (Abdou et al., 2012). Here, the model is a portrayal of a so called 'target' system which replicates the way the system works. Next, a computational method like Agent-Based Modelling entails the creation of models which are computer programs. This program (referred to as model) simulates and depicts particular processes or phenomena which are considered to exist in the 'real world' (Abdou et al., 2012). As a result, it allows the researcher to use this model to perform experiments and test hypotheses. For this research, that particular advantage is extremely useful. That is because it makes it possible to study the health issues related to water without using actual human beings. This makes studying such phenomena easier, more efficient and above all safer. ABM originates from three different research factions, namely game theory, complexity sciences and distributed artificial intelligence (Elsenbroich & Gilbert, 2014). The group of researchers that use modelling for complexity sciences often focus on processes of ecology, population dynamics, or human behaviour. The core believe of this approach is that there are many complex processes in the world and that we can use our knowledge of these phenomena to steer the analysis of the social world (Elsenbroich & Gilbert, 2014). Examples of early studies like this are the Cellular Automata models like the Game of Life (Berlekamp et al. 1982 in Elsenbroich & Gilbert, 2014), zero intelligence models (Mirowski 1999 in Elsenbroich & Gilbert, 2014) and Sugarscape (Epstein and Axtell 1996 in Elsenbroich & Gilbert, 2014). This research will use the same approach to analyse and understand how people are exposed to faecal pathogens in fountain water. Building and using an Agent-Based Model to capture this makes it possible to simulate and replicate human actions. This is because the study incorporates human behaviour in a closed environment. The results of that model can then be used to analyse potential scenarios related to the spread of diseases caused by faecal pathogens in fountains. This makes it possible for future research to study diseases caused by other water features elsewhere. The study will focus on the interaction between people and fountains. Therefore, people will be modelled as the agents for this simulation. When using this approach, the ABM can be used to estimate the extend of the health risks. This makes it possible to find patterns in the impact that faecal pathogens in urban water can have on human health. Because of this, ABM is a suitable method to perform a risk analysis that considers the exposure of individuals to *E. coli* in fountain water. The results of the study can be used to better understand the impact that urban water concepts have on our public health. This research can then provide insights in how many people are exposed to faecal pathogens in different locations. This allows us to understand how many people are exposed, but also provides insights in spatial patterns such as where the least people are exposed, or where most people are exposed. The creation of the model will be carried out in NetLogo.

3.3 Pedestrian behaviour models

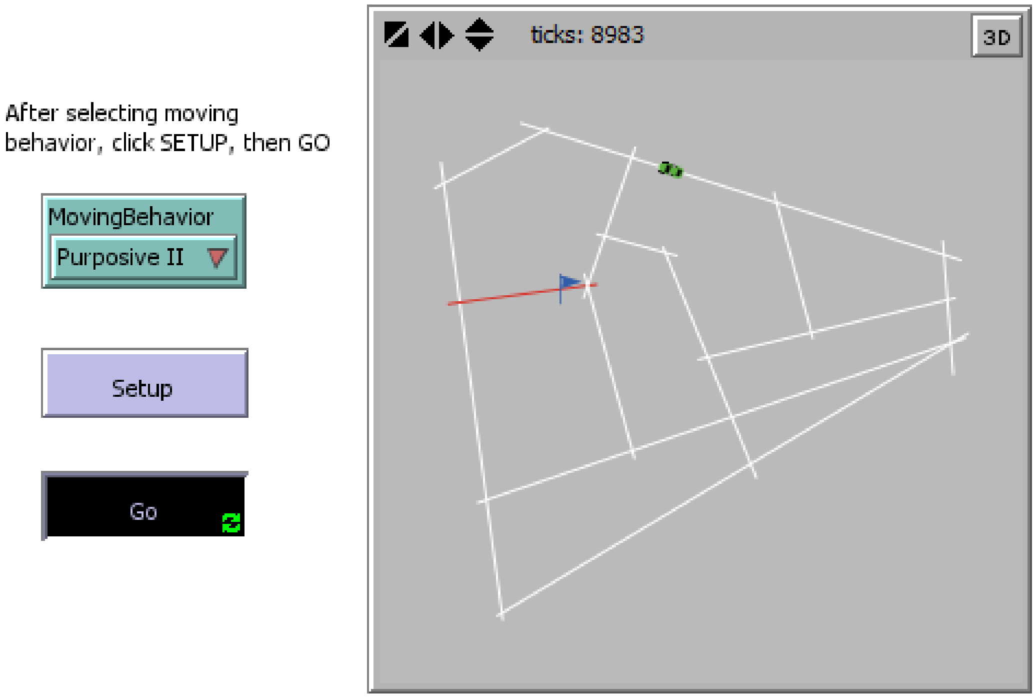
To model pedestrian movements in cities, it is essential to consider the built environment. This because it strongly determines the way people move and behave, and therefore has a significant effect on human spatial behaviour (Yan and Kalay, 2005). For this reason, various GIS studies have been modelling environmental and urban systems to better understand how people move in the built environment (Jiang, 2000). Jiang (2000) states that agent-based approaches, in particular, can offer a strong set of tools to research these phenomena. However, incorporating the built environments can be difficult. This is because it contains many different design elements, like walls, street, benches, fountains etc. Because of that, Yan and Kalay (2005) state that an agent should be able to perceive or understand its environment for it to behave naturally. This could be for instance standing by a fountain, sitting on a bench or walking on the sidewalk. That is why they believe that the semantic information of the environment should be structured in a manner that makes it perceivable for the agents. This way, the agents truly interact with the environment.

There are many different forms of human spatial behaviour. This study focusses on pedestrians in particular. Helbing et al. (2001) state that there are different possible approaches to model pedestrian movements. However in general, pedestrian movements are influenced by three aspects. The first aspect is obstacle avoidance by the agent. The second aspect is individuals planning like shopping or visiting a pub. The third aspect is the overall flows of masses of people between places. Because of that, the pedestrian activity becomes an outcome of two major components (Hakley et al., 2001). These are the same components used by Hakley et al. (2001) to generate their STREETS model, namely:

1) The configuration of the street network or urban space

2) The location of particular attractions (shops, restaurants, benches, etc) on that network.

The impact of the first can sometimes be considered to be the most important component. In this view, researchers argue that the street network mainly determines human movements. The influence of attractions is completely ignored in that case. The Agent-Based Model by Jiang et al. (2011) shown in figure 2 is an example of this.



After selecting moving behavior, click SETUP, then GO

MovingBehavior: Purposive II

Figure 2 Human movement shaped by underlying street structure (Jiang et al., 2011)

In this model, the movement is shaped by the underlying street pattern. This basic concept is then carried out in a much larger sense, shown in figure 3. Here the street pattern of the city completely determines the movement of the agents.

After selecting moving behavior, click SETUP, then GO

MovingBehavior Random

simulatio... 0.06 pixel/s

car-number 100

ticks: 1155

Figure 3 Human movement shaped by underlying street structure (Jiang et al., 2011)

Jiang et al. (2011) state that the model is generated to show that the underlying street pattern mostly shapes human movement. They believe that human moving behaviour therefore has almost no effect in the model.

Other researchers strongly disagree with this. They state that this view does not consider the effects of attractors. Hakley et al. (2001) mention that the idea of attractors influencing human movement has already been recognised long ago. They quote: *"Vehicles do not move about the roads for mysterious reasons of their own. They move only because people want them to move in connection with activities which they (the people) are engaged in."* (Ministry of Transport, 1961 in Hakley et al., 2001, p. 345). Human movement should therefore be considered as a product of activities influenced by attractions. Hakley et al., (2001) then say that this statement applies to pedestrian traffic in the same way. A merely strong focus on the street pattern is not suitable for this study. This because fountains are often located on squares. Movement over squares or larger open areas without roads is different from movements that only happen over the street pattern. The approach by Jiang et al. (2011) is therefore not very suitable for this study, because only addressing the street network to determine pedestrian behaviour is not enough. To tackle this, models create a raster layer to indicate a 'walkable area' for pedestrians. Examples of this way of modelling are described below.

3.3.1 Configuration of the street network

Modelling the street network of a city has already been done by other researchers. This is for example done in the STREETS model by Hakley et al. (2001) or the PEDFLOW model by Kerridge et al. (2001). Here, the street network is represented by GIS data. To recreate this, the sources of required information are:

- *Vector data of building outlines*. This data contains land-use categories to differentiate between buildings or type of buildings.

- *Raster data*. This is used to determine the so called 'walkability' of an area. In the STREETS model (Hakley et al., 2001), pavements are considered very walkable, but other areas like roads are much less walkable. Buildings are not walkable at all and are therefore obstacles that should be avoided. This approach was used by Hakley et al. (2001) to ensure that agents would walk on the sidewalk. It shapes the way pedestrians move on the street. The raster resolution should be decided on carefully since it determines how many agents are able to walk on a particular cell. The grid size of the cells depends on the scenario that is modelled. According to Kerridge et al. (2001), a conventional urban situation requires a grid size of 750 mm. They state that a common flow rate is 27 persons per 0.3 meters width per minute at a concentration of about 1.4 persons per square meter. These are the resolutions used by Kerridge et al. (2001) to develop their PEDFLOW model. In their model, a pedestrian can move into eight different directions and cannot walk backwards. This results in a situation portrayed in figure 4.

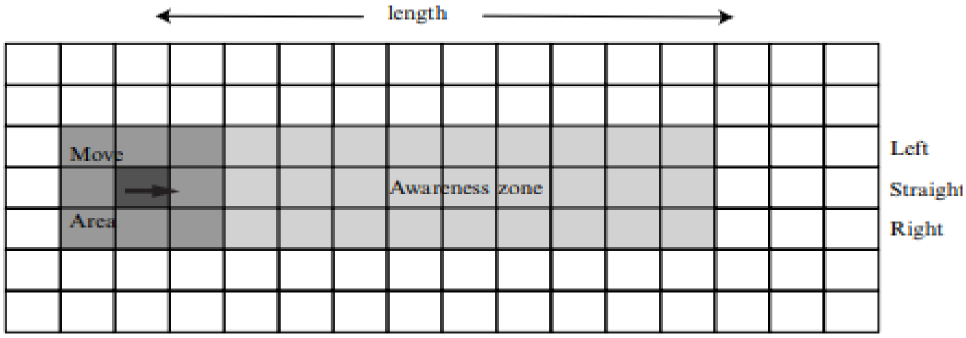


Figure 4 Single point of view (Kerridge et al., 2001)

Here we see that an agent can move in eight directions. The direction of the agent is determined by the values of its neighbouring raster cells.

3.3.2 Attractions

As mentioned earlier, attractions play an important role too. Attractions are the objects that form the target for agents to move towards. Using attractions as a target for agents is not uncommon, as the STREETS model by Hakley (2001) shows. The behaviour of agents is influenced by these attractions and therefore determines the direction of the agents. This study considers fountains to be an attraction. The fountain attracts agents and makes them move towards them. They become the target or objective for an agent to move to. However, agents are constrained by the street network when they want to reach the target. Hakley et al. (2001) developed the STREETS model that recreates these types of pedestrian movements in a model. Their model leads to a situation shown in figure 5.

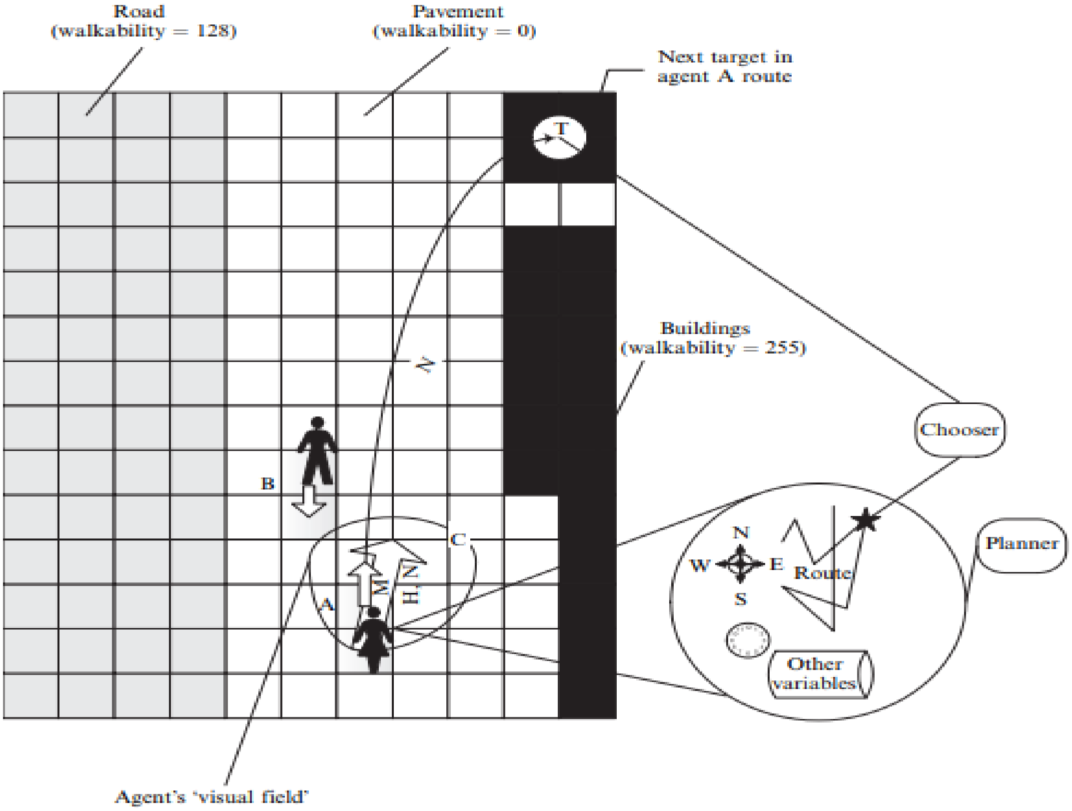


Figure 5 Influence of street pattern and attractions on pedestrian behaviour (Hakley et al., 2001)

Here we see that a raster grid defines the street pattern. Each cell in the raster has a unique value that corresponds with its walkability. Here the agents choose the path of least resistance to move towards their goal. In this case, the buildings have a very high value which means that agents will not walk on it. The pavement has a very low value and therefore agents will choose these cells in the raster to walk on.

Yan and Kalay (2005) state that simulating human spatial behaviour can be extremely advantageous. This because once city planners and designers can better predict behavioural patterns, they will be able to structure an urban landscape that is more suitable for and compliant with its citizens. That is why this study can contribute to a cleaner and safer environment for people.

4. Study areas and data collection

To answer the main research question, the individual exposure will be analysed first. The distance that a person has to the fountain will be mainly analysed here. This bring us the first research question: *"What role does the distance of the individual to the fountain play in the exposure process?"*.

Secondly, to identify the impact of different spatial environments (sub-objective 2) three case study areas will be used. This will facilitate the comparison of different urban situations. These case study areas are introduced in section 4.1.

As these case study areas are located in different parts of the city, the number of people that visit the areas varies. To recreate a realistic scenario, different locations should be compared with each other. This brings us to the second research question: *"What is the role of the spatial environment in the exposure process?"*. To answer that question this study will firstly consider the characteristics of the location of the fountain. These are the position of the buildings around the fountain, the presence of benches and the different number of visitors. That information can help to understand the number of people passing by a fountain, but also which type of people will pass the fountain. A location with for instance many benches and cafés can attract more pedestrians than areas that do not have these features. By taking the role of the urban environment into account, the individual exposure will be addressed more realistically for each location. Therefore all that information will be used in an Agent-Based Model to recreate and analyse a scenario that is close to reality. Once the individual exposure to fountains is properly described and modelled and the outcome at the different locations are compared, it is important to address the water quality of the fountains. This brings us to the third research question *"What is the impact of different water management strategies on the exposure to E. coli?"*

The answer to this question allows us to better understand to what degree each fountain can cause health risks to individuals that are exposed to it. Therefore samples of the fountains are taken. This could provide information that can be integrated in the Agent-Based Model. However, taking samples to analyse the concentration of *E.coli* requires certain technical skills that are beyond the scope of this research. Therefore, samples of other studies will mainly be used to determine how much *E.coli* can be present in a fountain. Studies by Burkowska-But et al. (2013), Flores et al. (2013) and de Man et al. (2009) provide results of sample findings of *E.coli* bacteria in fountains which can be used for this study as well. This way, information from literature can be integrated in the Agent-Based Model to recreate a situation that is close to reality. Once the exposure to the water fountains can be determined and the water quality is also modelled, the potential consequences can be analysed by combining the two. However it should be clear that the model merely gives an indication of a possible outcome of potential ways of exposure to pathogens. The indication should be as precise as possible and the model must therefore be as realistic as possible, but the findings are simply a prognosis. By doing so, this study can provide insights in the potential health risks of fountains that carrying *E.coli*.

4.1 Study areas

The study considers three locations in Amsterdam: Frederiksplein, Haarlemmerplein and the area in front of the Americain hotel. On each location a fountain is situated that will be studied for this research. ArcGIS software is used to generate raster files of these sites. The raster files are used to incorporate the study areas in the Agent-Based Model. In this model each location is characterized by a fountain, the surrounding buildings and benches that are located close to the fountain. The number of visitors for each location is estimated based on the findings by de

Man et al. (2009) and empirical research. The findings by de Man et al. (2009) are used to determine how many people visit a fountain, the empirical research is used to determine the difference in number of visitors between weekdays and weekend days. Therefore the number of visitors on weekdays and during the weekend was counted at Frederiksplein. By combining these two sources of information, we are able to estimate the number of visitors for each location, with a variance between the weekdays and weekends.

The first study area is Frederiksplein. The area is situated in the city centre. The square is located close to the Utrechtstestraat, Weteringschans and the Sarphatistraat. A map of this study area is shown in figure 6.

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6 Location of fountain Frederiksplein

The map shows the buildings surrounding the square. The blue circle in the middle of the area is where the fountain is located. To have a better view of this fountain, a detailed image of the square and its fountain is given in figure 7

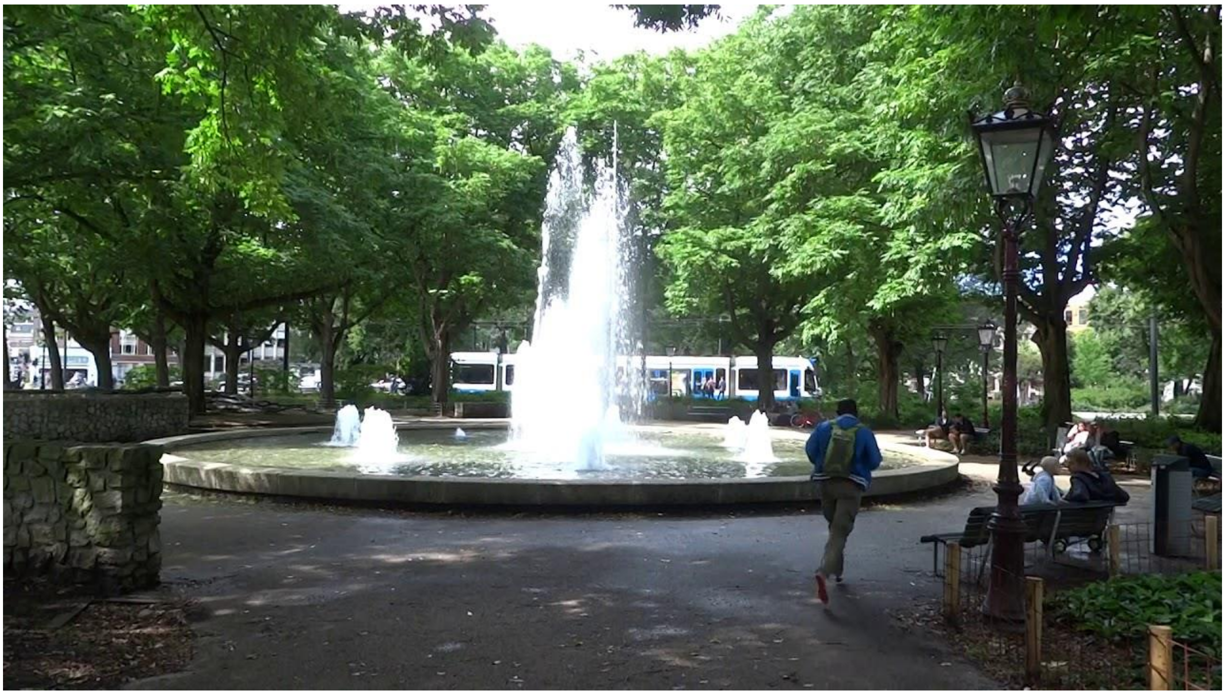


Figure 7 Image of Frederiksplein and fountain

This image shows that the benches are located around the fountain. There is about 3 meters space between the fountain and the benches. We can also see that the spray of the fountain can reach up to several meters.

The second study area is Haarlemmerplein. Figure 8 below shows the map of this study area.

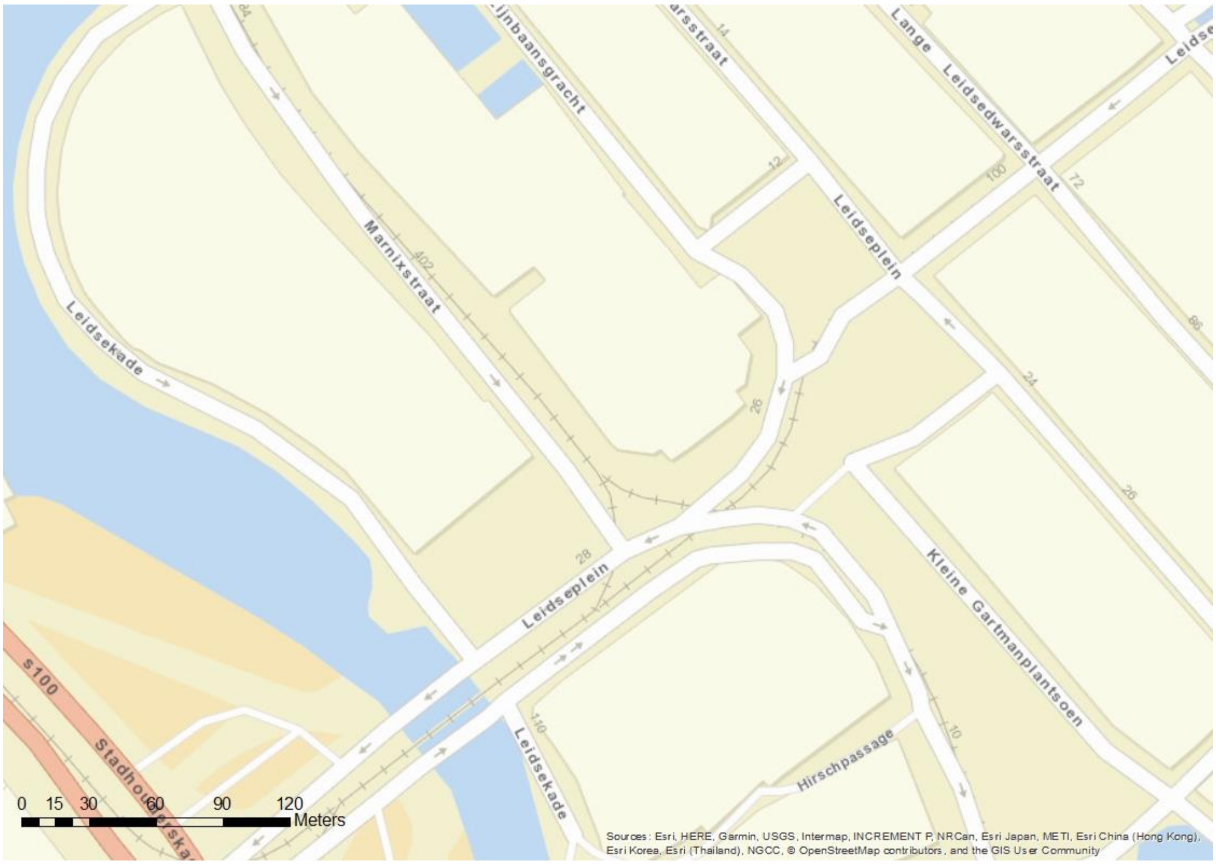
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 8 Location of fountain Haarlemmerplein

Haarlemmeplein is located at the western part of the city centre. The square connects the Marnixstraat, with the Planciusstraat and is adjacent to the Haarlemmerdijk. The square and its fountain are located relatively close to the central station. This, in combination with the proximity to the Westerpark, can make the Haarlemmerplein an attractive area for tourists. Figure 9 below provides a detailed image of this square and the fountain.

Figure 9 Image of Haarlemmerplein and fountain

Again there are benches located close to the fountain. The distance between the fountain and the benches is approximately 1 meter. Where the fountain of Frederiksplein has a basin, this fountain is of the type "bedriegertjes" and walking into the fountain area is very easy. The lack of a basis influences the depth of the water which can influence the spray of the fountain. The height of this fountain is much less than the fountain at Frederiksplain. It can be estimated at approximately 2 meters. The third area of interest is the square in front of the Americain hotel. That area is shown in the map given in figure 10 below.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 10 Location of fountain Americain

This fountain is located near Leidseplein. Leidseplein also attract many tourist and therefore this fountain can also be visited by many people. An image of the fountain is given in figure 11 below.

Figure 11 Image of fountain at Americain

The benches are located about 2 meters away from the fountain. This fountain has a large basin which means that most of the water from the spray may fall in it. As we can see in the image, there are people sitting on the benches but there are also people that stand close to the fountain. This means that there are many people that interact with this fountain.

4.2 Datasets and field work

This study combines three sources of data: empirical data retrieved from the study sites, theoretical information to support the development and findings of the model and geographical data containing the spatial information. The theoretical findings are already discussed in chapter 2, and will also be elaborated on in chapter 7. This section will describe how the empirical data was retrieved and will also address the geographical datasets that were used. The geographical data will be described first. After that, we will discuss how the empirical data was collected during the field work.

Below, table 1 provides an overview of the GIS datasets that are used. The table also gives information of the content of the dataset, its source and what it was used for.

Table 1 Overview of GI datasets

Dataset	**Content**	**Source**	**Used for**
"Zomerse plekken"	Location of the fountains	Municipality of Amsterdam https://maps.amsterdam.nl/open_geodata/	- Maps to show location of fountains - Generate cost distance layer to create attraction point for agents in model to walk to
"22 Gebieden"	Shapefile of the 22 neighbourhoods of Amsterdam	Municipality of Amsterdam https://maps.amsterdam.nl/open_geodata/	- Maps to show position of fountain
"Klimatologie daggegevens"	Daily windspeeds and wind directions measured at three locations	The Royal Netherlands Meteorological Institute (KNMI) http://projects.knmi.nl/klimatologie/daggegevens/selectie.cgi	- To determine the daily wind direction and wind speed in model. This influences the daily direction and distance of the water spray
"World Street Map"	Highways, roads, parks and buildings	Esri, ArcMap 10.5.1 https://www.arcgis.com/home/item.html?id=3b93337983e9436f8db950e38a8629af	- Drawing buildings from this base map to generate the walkability raster

The datasets mentioned in table 1 were primarily used to incorporate spatial elements in the model. This allowed the creation of a 'walkability raster'. In addition, climatic data was used to determine the daily wind speed and wind direction. Geographical data was also used to make the maps for this report.

However, besides using GIS data, fieldwork was conducted to gather empirical data. The fieldwork started with visiting the three study areas. Once arrived, the following steps were carried out:

1) At each location the total number of visitors were counted. This was done to better understand how many people should be modelled at each location.

2) Secondly, we looked at how many people would sit on a bench and how many would go into the fountain. This was done at one study site: Frederiksplein. At that location, the number of people that sat down on a bench were recorded and also the number of people that would go into the fountain were recorded. This was registered for every hour. The counting started at 8 o'clock in morning and ended at 2 o'clock in the afternoon. To determine if there are variations between weekdays and weekend day, the counts were done on multiple days. This meant both during the week and weekend.

3) At last, samples were taken from the fountain and tested for *E.coli*. Unfortunately it was not possible to determine the concentration of *E. coli* in these samples, but the presence of *E. coli* could sometimes be determined. Therefore, these findings were not incorporated in the final model. First of all, more information was needed about the concentration of *E. coli* and secondly, the measurements were not always very accurate. As a result, we have primarily made use of the findings of other studies to develop the model.

5. Conceptual design

The purpose of this model is to investigate the exposure of pedestrians to the *E.coli* bacteria in fountains in Amsterdam. The state variable of the model is, therefore, the exposure of pedestrians. The model contains one type of agents: pedestrians. The model is geographically explicit (models a real environment). It contains a range of environments including, moveable space, the location of the fountains, the location of benches. The spatial resolution of the model is 2 meters. The model will run for a duration of 1 month, yet there are no restrictions to the temporal extent.

This model consists of two sub-models:

- Pedestrian Movement Model (PMM)

- Infection Model (IM)

The Pedestrian Movement Model will be explained in section 5.1. The model generates pedestrians for the area around the fountains and steers the movement of these pedestrians until they exit the study area.

The Infection Model (IM) is responsible for the exposure to the *E.coli* bacteria. Pedestrians can become exposed when they are in the vicinity of an infected fountain and inhale water droplets that contain the bacteria. A fountain can become infected depending on the number of pedestrians. More pedestrians lead to more food available for animals that can infect the fountain.

5.1 Pedestrian Movement Model

In this model, pedestrians move towards a fountain and spend time in or around this fountain. Depending on whether the fountain is infected, the position of the pedestrian (either in the fountain or around the fountain) and the amount of time the pedestrian spends in that position, the pedestrian will be exposed to the *E.coli* bacteria or not. The goal of the sub-model is to monitor how many people are exposed to *E.coli*. Pedestrians are represented by agents in this model. The variables of the pedestrians are described in table 2.

Table 2 Variables of pedestrians

Variables	**Explanation**
Exposed	Shows if the agent is exposed to *E.coli* or not. This is determined by the location of the agent and how long the agent has been in that position. Visitors can only become exposed when the fountain is infected with *E.coli*.
Spraytime	A counter used to determine if the agent really spent time in the spray of the fountain or only quickly walked through it on its way out. Only those that spent time in the spray can become exposed. Agents that briefly walk through it cannot become exposed.
Phase	This determines the goal that the agent walks towards to. There are two phases. Agents start with the 'walking to fountain' phase and after they spent time in or around the

	fountain, their phase turns to ‘walking to exit’. When their phase is on ‘walking to fountain’, the agent moves towards the fountain. When the agent’s phase turns to ‘walking to exit’, the agents move away towards the exit. When the phase turns from ‘walking to fountain’ to ‘walking to exit’ is determined by how long the agent will stay in or around the fountain and therefore varies per agent.
Initial-time	This determines the duration of stay of an agent. Every agent has a unique initial-time and because of that, every agent has a unique duration of stay.
Time	The maximum amount of time an agent can possibly spent in or around the fountain. This is 90 minutes.
Exit point	The exit point that the agent will move towards to. An agent will move towards a random exit point after it has been in or around the fountain.

Pedestrians are created at fixed locations, which are the entry point of the area. The Pedestrian Movement Model uses of the following key elements:

1) Agents should move from their starting point towards the fountain.

2) When an agent reaches the fountain, it should spend some time there. The amount of time an agent spends in or around a fountain should vary between agents. In other words, each agent has its own unique duration of stay.

3) Some agents spend time in the fountain; these are people that puddle in the water or play in it. Others move to a designated spot close to the fountain; these are people that sit on benches or other resting places like terraces close to the fountain.

4) An agent can be exposed to *E.coli*, depending on where they are during their stay and how long they stay there.

5) After their stay, agents should be assigned one exit point where they move to. When reaching the exit, the agents will leave the simulation.

Based on the steps above we can determine that agents are in either of three states when they are in the simulation: *Walking towards the fountain*, *staying at or around the fountain*, or *leaving the area*. These phases will be explained in more detail in sections 5.1.1 – 5.1.3

Pedestrians cannot walk through buildings, so the agents are not allowed to do this either. That is why they should avoid buildings when moving. Before the model can run, the environments are loaded. The GIS extension in NetLogo is used for this.

The environment consists out of following components:

1. Raster layer of the buildings

2. Raster layer with the distance from the fountain

3. Raster layer with the distance to the exit points

4. Raster layer with resting spots surrounding the area (benches)

These components together make up the environments in which the agents can move around, interact with the fountain and become exposed to the bacteria and possibly infected. Once the environments are loaded in NetLogo, the agents will be generated. This will be explained in further detail below.

5.1.1 Generating agents and moving pedestrians towards the fountain

The first step is creating the agents. This model has fixed entrance points and exit points that match the real area. The number of visitors that are generated in the model is based on findings in literature and fieldwork. How many people the model generates will be discussed in the verification chapter 7.1. The findings of the literature and field work are also discussed in that chapter. When an agent is created, it will start at one of these entry points and the model will continuously create new agents at these points. Agents have a list of properties with a corresponding value or state that can change. They have several properties, but the most important ones are their 'Exposure state', 'Walking phase' and 'Duration of stay'. At first, their exposure state is 'false', implying that the agent has not been exposed to *E. coli*. Their walking phase is set to 'walking towards fountain'. At last, the duration of stay differs per agent and is randomly determined, with a maximum duration of 90 minutes. To illustrate the environment, figure 12 shows the initial phase of the model.

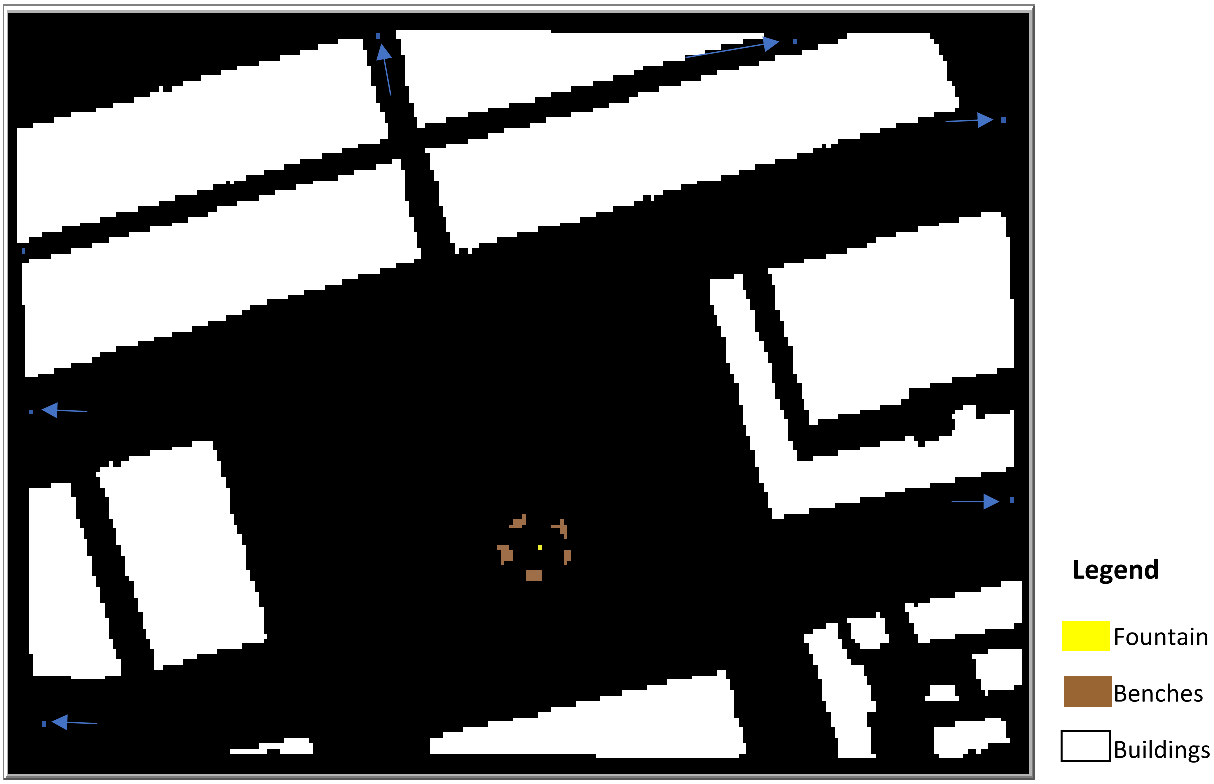


Figure 12 Main environment, with brown representing benches, yellow point is fountain, blue marks are the entrances.

The little blue dots that are pointed out by the blue arrows in figure 12 represent the entrance points of the area, which are also the exit points. This is where the agents enter the model and eventually leave the model as well. The white patches are the buildings and the black patches represent the pedestrian area. Brown patches represent the places to stay, which are in this case benches. The yellow dot is the fountain. At this moment, the environment is loaded, but the model is not running. Therefore there are no agents yet.

The agents start with the walking phase ‘walking to fountain’. This means that their goal is to move towards the fountain. The agents are able to do this because of an underlying walkability raster in the model. This raster is a cost distance raster calculated from the fountain. Here, the fountain has the lowest value, namely 0. To illustrate this, figure 13 shows this cost distance raster.

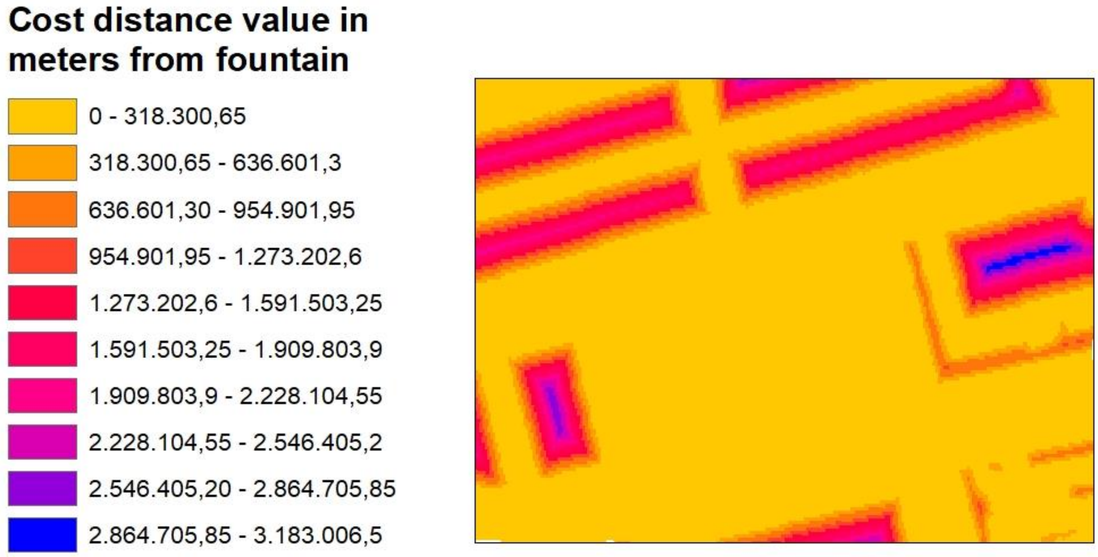


Figure 13 Cost distance raster, with the yellow colour representing low values and the red and blue represents high values

The further away from the fountain, the higher the value of the raster cells are. A weighting factor is added to this cost distance raster. In this case, the location of the buildings is used as a weighting factor. As a result, the raster cells that are situated on the location of the buildings have a higher value. We see that the higher the cost distance, the darker the raster cells become. The buildings are assigned extremely high values. As a result, these cells have a very high value in the cost distance raster. The agents move along the cost distance raster of the fountain and are instructed to consider their neighbouring cells and move towards the cell with the lowest value. This causes them to constantly move towards the lowest value, eventually reaching the lowest possible value of 0. This is where the fountain is located. Because buildings were assigned very high values, agents will avoid these cells.

5.1.2 Staying in or around the fountain

The second phase of the agents is the phase in which pedestrians stay in the area around the fountain. Once the agents reach the fountain, they will stay there for some time. The time that they will spend there is determined by their property ‘*Duration of stay*’. The duration of stay is randomly assigned to the agent, with a maximum stay of 90 minutes. This is based on the findings of field work. Besides their duration of stay, there is also a distinction in the type of stay. An agent can either reside in the areas close to a fountain, like for instance sitting on benches, or spend time in the fountain. The latter represents people puddling or playing in the water. Most of the agents will stay in the areas close to the fountain, depicted as the brown patches in figure 12. Where an agent will stay is based on their duration of stay. Agents that have a very short stay will move into the fountain, whereas agents with an average or long stay will move to the areas close to the fountain. When their duration time has passed, the agent will move towards a randomly decided exit point. Figure 14 provides an image of different agents that stay in and around the fountain.

Figure 14 Agents in and around the fountain

As the image shows, one agent is staying around the fountain; the other is spending its time in the fountain. This replicates a scenario of one person sitting on a bench and another puddling or playing in the water.

5.1.3 Moving towards the exit

After their time of staying in or around the fountain has passed, the agent will move on and go towards an exit point. The agent chooses a random exit to move to. Agents move towards their exit by following another underlying cost distance raster that corresponds with the exit points. The agents will again consider their neighbouring cells and move towards the cell with the lowest value. Buildings have high values, making the agents avoid them again. This way, the agents will eventually reach the raster cell with the lowest value, which is evidently the exit point they should be at. Once they reach their exit, they will 'die' and disappears from the model.

When we consider these steps, we can summarize the sub-model as follows. There is now a model where agents will appear and start moving towards the fountain. This makes the fountain the first target for every agent. When the agents reach the fountain, they will either go into the fountain or stay close to it. Depending on where they stay and how long they stay there, the agents can be exposed to *E.coli* or not. If the agent is exposed, its exposure state will turn from 'false' into 'true'. When their duration of stay has passed, the agent will choose a random exit point and move towards it. After reaching the exit, the agent 'dies' and disappears from the simulation.

5.2 Infection Model

The way agents move towards fountains is described in the PPM, but how they become exposed and how fountains become infected will be explained here. In the Infection Model (IM), pedestrians can be exposed by interacting with the fountain. Fountains can be infected with *E.coli*, but it is also possible that a fountain is not infected. Pedestrians can only be exposed when fountains are infected with *E.coli*. How the process of exposure to *E.coli* and infection of pedestrians is worked out in this model will be explained in sections 5.2.1.

The infection of fountains is related to the number of pedestrians. This because fountains are infected by animals that carry the *E.coli* bacteria (Himsworth et al., 2015). Animals are attracted by waste of pedestrians (Feng and Himsworth, 2014). As a result, when there are more pedestrians there are also more animals that can infect the fountain. Therefore more people lead to a bigger chance of infection. How this works will be explained into more detail in section 5.2.2.

5.2.1 Pedestrian exposure

Once the agent reaches the fountain, it can be exposed to the *E.coli* bacteria, if the bacteria is present in the water of the fountain. Whether an agent is exposed depends on three aspects:

- The location of the agent

- The amount of time that the agent stays there

- Whether the fountain is infected or not

Agents that go into the fountain are obviously more exposed to the water of the fountain than people that are staying on the benches close to the fountain. Agents that stay in the fountain therefore need to spend less time to become exposed to the *E.coli* bacteria than the agents that are close by.

According to the study by de Man et al. (2009) about 1 in 9 people that are exposed will show actual symptoms of illness. That is why about 1 in 9 (11%) of the exposed agents will be classified as ‘infected’. De Man et al. (2009), also explain the link between exposure and the duration of stay and the amounts of water consumed (See table 3 below).

Table 3 Forms of contact and estimated exposure (de Man et al., 2009: p.23)

Type of contact	**Estimated duration**	**Estimated amount of water consumed**
Breathing close to fountain		
→ Cyclist	10 seconds	0.1 ml
→ Cyclist waiting for traffic light	45 seconds	0.45 ml
→ Person on terrace/tea-garden	20 minutes	1.2 ml
Child playing in the water of a fountain	10 minutes	1-50 ml
Adults paddling in water of a fountain	10 minutes	1-10 ml

5.2.1.1 Agents in the fountain

Agents that go into the fountain will be exposed to *E.coli* after spending more than 8 minutes in the water. This is based on the study by de Man et al. (2009). Their study shows that a person spending 10 minutes in a fountain ingests about 1 – 50 ml of water (Table 3). Therefore our study estimates that an average person going into a fountain ingests 25 ml of water after 10 minutes. De Man et al. (2009) then state that ingesting about 20 ml of infected water is sufficient to be exposed to the *E.coli* bacteria and potentially become ill. If an average person in the fountain consumes 25 ml in 10 minutes, we can assume that a person has ingested 20 ml of water after 8 minutes (20/25 = 0.8) That is why if an agent stays in the water for longer than 8 minutes it is considered to be exposed to the *E.coli* bacteria in this model.

5.2.1.2 Agents close by

Agents that stay close by the fountain (but not in the fountain), are exposed after 33 minutes. De Man et al. (2009) explain that a person standing close to a fountain inhales up to 0,6ml of water per minute. We can therefore assume that someone inhales about 6ml of water after 10 minutes. Since we know that a person becomes exposed after inhaling 20ml of polluted water, we can estimate that someone needs to spend at least 33 minutes on a bench to become exposed. Because of that, agents that spend more than 33 minutes close to the fountain is considered to be exposed to *E.coli* if the fountain is infected.

However, only staying close by will not lead to direct exposure. The area around the fountain is characterized by a so called ‘exposure zone’. This exposure zone is the area where the water spray of the fountain lands (see figure 15). The direction of the water spray is determined by the wind direction of that day. The distance of the water spray is determined by the windspeed of that day. As a result, the position of the exposure zone constantly changes according to the wind direction of the day and the windspeed. Only the agents that stand in the exposure zone (against the wind and not too far) are exposed to the water droplets from the fountain.

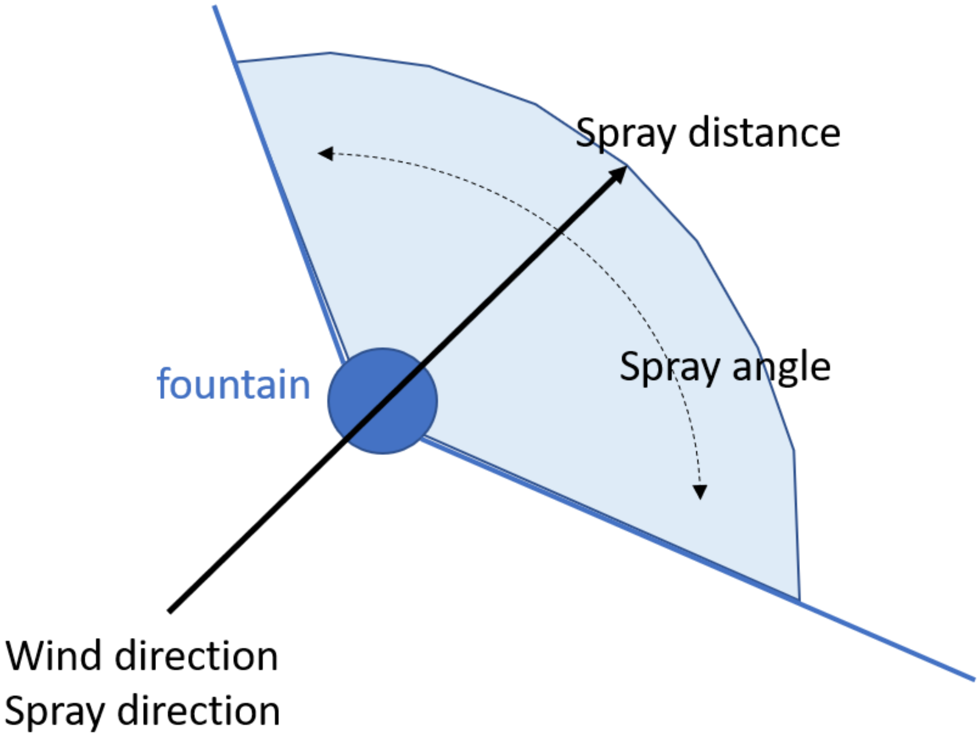


Figure 15 Fountain with spray angle and stray direction

Those that stay in the exposure zone for more than 33 minutes are exposed to the bacteria. Agents that do not stay in the exposure zone are not exposed and can, therefore, stand close to the fountain without being at risk. When the agent is exposed, its exposure state changes from ‘false into ‘true’. Table 4 provides an overview of the amount of time an agent needs to spend to be exposed

Table 4 Time required to become infected if fountain is infected

Location	Maximum	ml/minute ingested	Time needed to be exposed
In the fountain	20 ml	2.5ml/minute	8 minutes
Close to the fountain	20ml	0.6ml/minute	33 minutes

5.2.1.3 Number of visitors

The number of visitors is also based on statements of de Man et al. (2009). They monitored fountains and the study shows that between April and September, about 5400 people went into the fountain. This means that per day on average about 30 people go into the fountain during the summer months. However, there are also people that visit the fountain without going into the water. This number is likely to be much greater. To get a better understanding of this, fieldwork has been conducted. The findings vary strongly for each location, so the number of visitors depends on the location. However, on average, every day about 60 people sit close to a fountain but do not go into the water. This brings us to a total of around 90 visitors per day.

5.2.2 Infection of fountains

Whether the fountain is infected with *E.coli* depends on the number of pedestrians that visit the fountain. Fountains are infected with *E.coli* by animals. Feng and Himsworth (2014) mention that areas with bad public cleaning services suffer more from rats than areas with good cleaning services. Feng and Himsworth (2014) believe that this is caused by the fact that the waste is likely to provide food for animals like rats or other rodents. Waste attracts animals and because of that when there is more waste there are also more animals that can infect a fountain. In this model, waste is produced by pedestrians. The more pedestrians, the more waste there is. When there is more waste, there are more animals and the chance of a fountain becoming infected increases. This means that when there are more people visiting an area, there is more waste which then attracts more animals. Therefore, the number of pedestrians determines if a fountain will become infected or not. In this model, the fountain will become infected after 300 people visited the fountain.

Once a fountain is infected, it remains infected unless the municipality cleans the fountain. Despite the fact that the municipality of Amsterdam is very committed to keeping the city clean (Municipality of Amsterdam, 2017), their main focus is particularly on waste sorting and providing ways for the inhabitants to throw their waste away. Their policies concerning waste (Municipality of Amsterdam, 2017) or water (Municipality of Amsterdam, 2016) do not focus on cleaning fountain water. That is why this study assumes that the municipality of Amsterdam currently does not clean fountains or fountain water on a regular basis. Therefore, it is not clear how often the fountain is cleaned. In this model we will simulate a scenario where the fountains are cleaned once a week. By cleaning the fountain water, the municipality could potentially get fewer pedestrians exposed to *E.coli*.

6. Data processing

To generate the model described above, several inputs were used. The following raster layers are used to create the environment:

1. Raster of the buildings
2. Raster of the distance from the fountain
3. Raster of the distance to the exits
4. Raster of the benches surrounding the area

6.1 Building raster

The first generated dataset is the raster of the buildings. Generating this dataset requires several intermediate steps. To generate the building layer, WorldStreetMap was used as a base map. The ‘Editing’ tool is used to digitize the buildings, resulting in a Shapefile with the features of the buildings. This Shapefile is then converted from feature to raster by using the ‘Feature to raster’ tool in ArcGIS. Once the buildings are generated in a raster file, the file is converted to an ASCII file. This is done because NetLogo 6.0.2 can only read this file in an ASCII format. At last, the commas in this file are replaced by a period mark so that NetLogo can read the file properly. Figure 16 shows the steps that are taken to generate the ASCII file for the buildings.

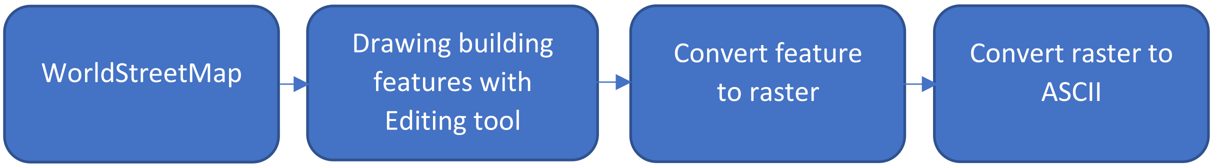


Figure 16 Steps of generating the buildings ASCII file

6.2 Cost distance to fountain raster

The second dataset is a raster with the distance from a given location to the fountain. There are different ways to calculate the distance from a source. For this analysis, a cost distance layer was produced. This technique makes it possible to not only calculate the distance from the source feature but also assigns a weighting factor. These weighting factors will increase the value of the particular cells of interest. In this case, the buildings are used as a weighting factor. The buildings were assigned high values at first. As a result, the cells where buildings are located have a higher value in the cost distance raster. When agents move along the values of the cost distance raster to find the lowest value, they will avoid the high values which are in this case buildings. This allows us to make the agents avoid the buildings. The cost distance layer is generated in ArcMap. Figure 17 below shows the steps that were taken to generate a cost distance layer for NetLogo.

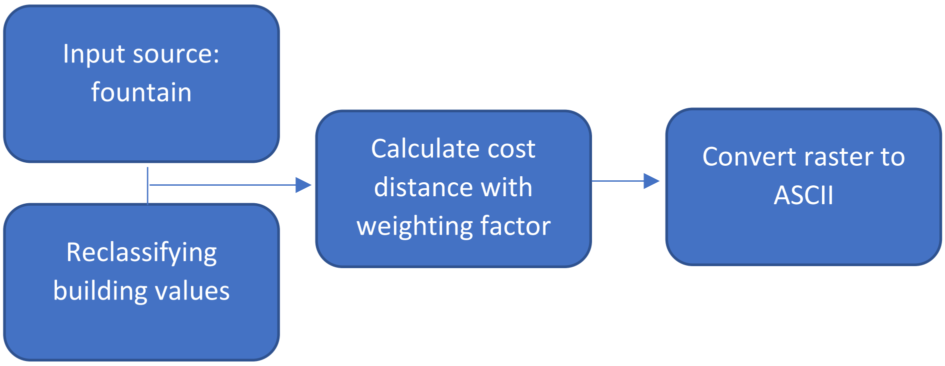


Figure 17 Steps of generating the cost distance ASCII file from the

First, the fountain is used as the input source. Secondly, the raster file that was created to show the buildings is used as the cost factor. The values representing buildings are reclassified. This way the buildings were given an extremely high value (100.000) compared to grid cells where the buildings are not located. This results in a cost distance raster layer shown in figure 18 below.

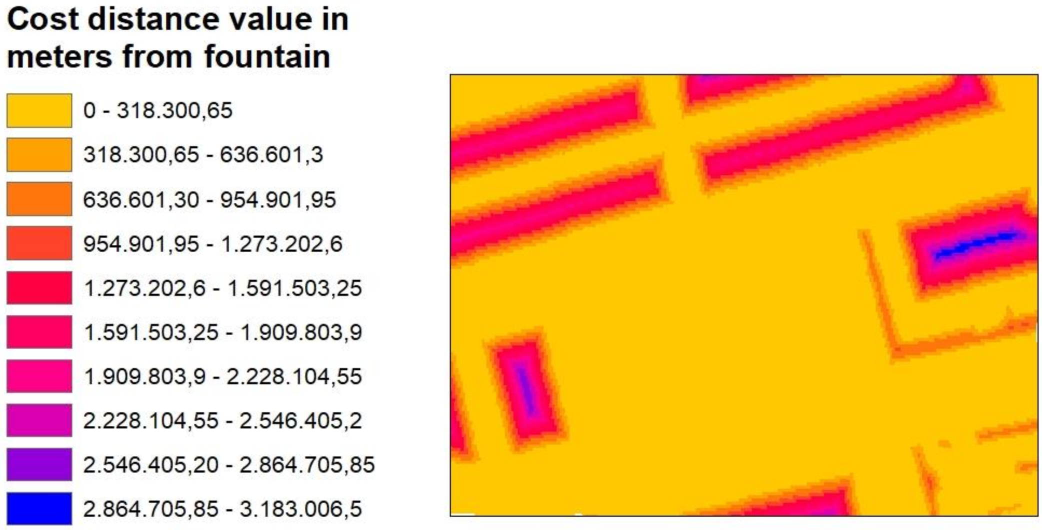


Figure 18 Cost distance layer

Since NetLogo can only read this file when it is an ASCII file, the cost distance layer is also converted to an ASCII file.

6.3 Cost distance to exit raster

As explained above, agents move towards the lowest value of their neighbouring grid cell. This way the agents move towards their target. An example of this is already given in the cost distance raster of the fountain. The same principle can be applied to make the agents move towards an exit. In this scenario, not the fountain, but the exit point is the input source from which the distance is calculated. Figure 19 shows the steps that are taken to create them.

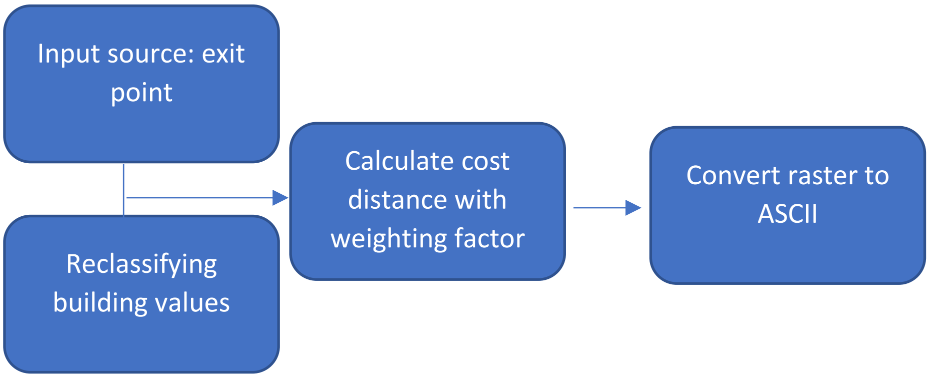


Figure 19 Steps to generate the cost distance ASCII file for exit points

Again the building values are used as a weighting factor. When agents move to the grid cell with the lowest value, they will not step on those values. This will again ensure that the agents do not step on buildings or through buildings. The cost distance raster is generated for each exit points. The exit point that is used as input source to calculate the distance from is drawn in ArcMap by using the ‘Editing tool’.

6.4 Benches raster

As described above, the agents can stay in the fountain, but also stay at a ‘resting place’. In the figures 12 and 14 these resting places are benches. The benches are represented by brown patches. The resting places are generated in ArcMap with the ‘Editing tool’. First, the benches are drawn in. Next, these features are reclassified to make a distinction between the benches and the rest of the environment. The features are converted to raster. The raster is then converted to an ASCII file.

6.5 Wind data

As explained earlier, the area around the fountain is characterized by a so called ‘exposure zone’. This exposure zone is the area where the water spray of the fountain lands. Wind data is used to determine where the droplets can land and how far the droplets can travel through air. This is done for each day. By the use of an Inverse Distance Weighted (IDW) interpolation in ArcMap, it was made possible to estimate the wind direction and windspeed for the study area. For this analysis we used wind data from July 2018.

The data is retrieved from The Royal Netherlands Meteorological Institute (KNMI): http://projects.knmi.nl/klimatologie/daggegevens/selectie.cgi and measurements from three locations are used: Schiphol, Houtribdijk and IJmuiden. The wind analysis in ArcMap resulted in a wind direction with corresponding windspeed for each day. These results are stored in a CSV file and then loaded in NetLogo.

7. Verification

Verification analysis is used to determine whether the model is capable of producing valid and robust results (Berger et al. 2001). It provides information to identify how well the model approaches the real world and also if it meets the main objectives of the model. It is a process that will test the logic of the model for its acceptability and validity. This means that the model is basically checked to see if it acts like it is supposed to. Crooks (2006) describes this as testing the *"inner validity"* or *"inner workings"* of the model. Verification is often done by using examining processes in order to compare the outputs with the expected outcome of the model.

7.1 Generating visitors

First, the number of visitors that are generated in the model will be verified. The number of visitors that are generated in the model is based on findings in literature and fieldwork. The study by de Man et al. (2009) shows that between April and September, about 5400 people went into the fountain they observed. This means that on average per day about 30 people went into the fountain during the summer months. Fieldwork was carried out to determine the number of visitors on benches for the study area. These results are shown in figure 20 below.

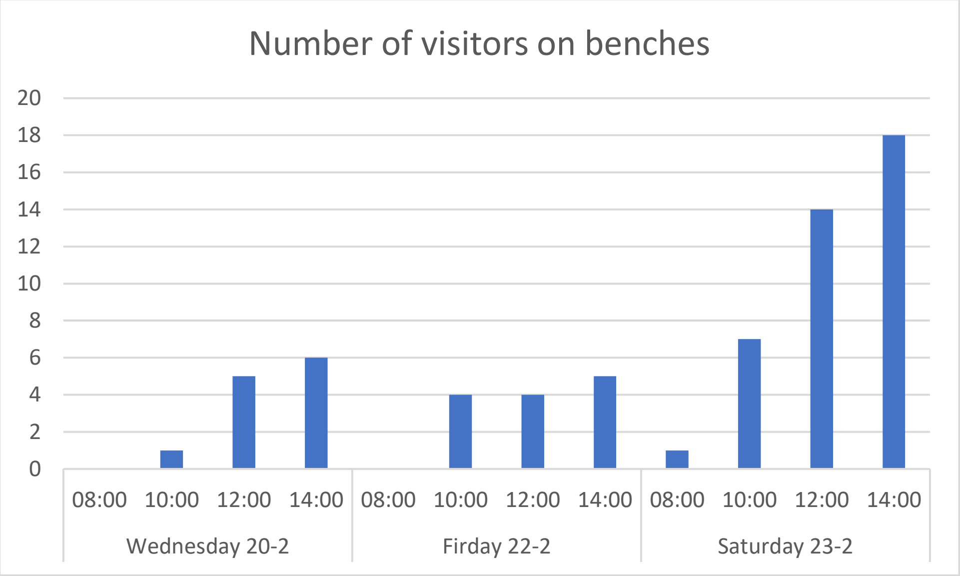


Figure 20 Number of visitors counted during fieldwork on weekdays and weekend

This graph shows two patterns. First of all, we can see that there are far fewer visitors that sit on the benches during the weekdays than during the weekend. Secondly, the number of visitors increases during the day, starting off with very few to none visitors early in the morning. On average, about three visitors reside on the benches per hour during the weekdays. Some visitors stayed on the benches for a couple of minutes, others stayed there longer. The maximum duration of stay was about 90 minutes. During the weekend, this average goes up to 10 visitors per hour that reside on a bench. If we exclude the night, we can assume that in total about 48 people sit on the benches on a weekday and about 160 people sit on the benches during a day in the weekend. Since about 30 people go into the fountain per day, we can assume that on weekdays about 78 people visit the fountain and on a Saturday or Sunday about 190 people visit the fountain. In 2018, July had 9 weekend days and 22 weekdays. Keeping the results of the field work and the findings from de Man et al. (2009) into account, we can estimate that about 3426 people have visited the fountain during July. This will, however, remain a rough estimation, since the field work was conducted in February. The number of visitors in July are therefore probably higher than this number, but it is not possible to verify this. We therefore assume that 3426 people have visited the fountain during one month.

This means that the model should also generate this number of visitors in a single run, with an average of 4 to 5 visitors per hour during the weekdays and 11 to 12 visitors per hour during the weekend. Since the nights are excluded, one day consists of 16 hours. There are 31 days, meaning that there are 496 hours simulated in a single run. After simulating 496 hours, the model generated 3416 visitors in total.

This confirms that almost the exact number of visitors that have been estimated are generated during the simulation. However, the number of visitors varies between weekdays and weekend days. This variance is also implemented in the model. Figure 21 provides a graph showing the number of visitors that are present during a particular moment in time.

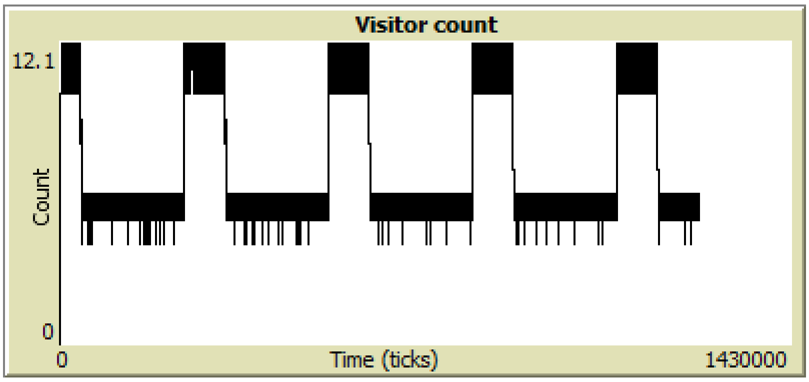


Figure 21 Visitor count

The graph shows clear peaks and dips. During the peaks, the number of visitors is around 11 or 12 persons. The peaks occur with regular intervals. These are the weekend days. The dips in this graph represent the weekdays, where there are less visitors present. Variations between weekdays were not detected during the field work and therefore this model only makes a distinction between weekdays and weekend days.

As mentioned, in total 3416 visitors were simulated in a single run. The last graph also shows that the number of visitors increase during the weekends and decrease during the weekdays. To conclude, the following graph (figure 22) shows the total number of visitors that were generated during the simulation.

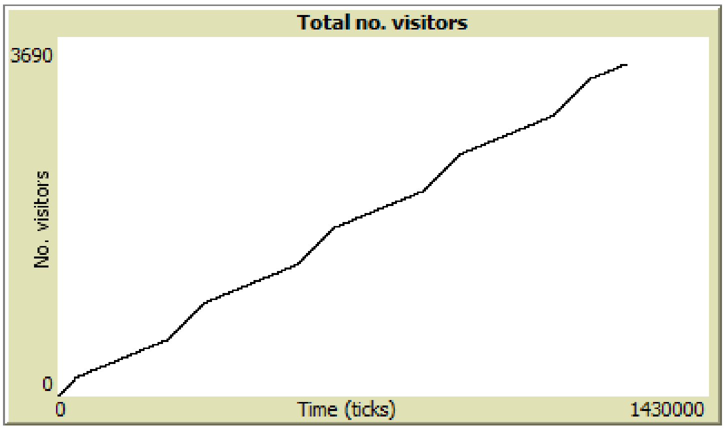


Figure 22 Total number of visitors during a single run

The graph shows that the total number of people that are generated steadily increases. In this graph we can detect five steeper angles. These are the weekends, where there are much more visitors generated in a shorter amount of time. The graph starts with a steep angle, because the first day of the simulation represents a Sunday.

7.2 Exposure zone: a vision cone

As been described, the model makes use of an ‘exposure zone’. This exposure zone is the area where the water spray of the fountain lands. The wind direction of that day determines the direction of the water spray. The wind speed determines the distance of the water spray. The exposure zone is integrated into the model with the use of a vision cone. Figure 23 below shows this vision cone.

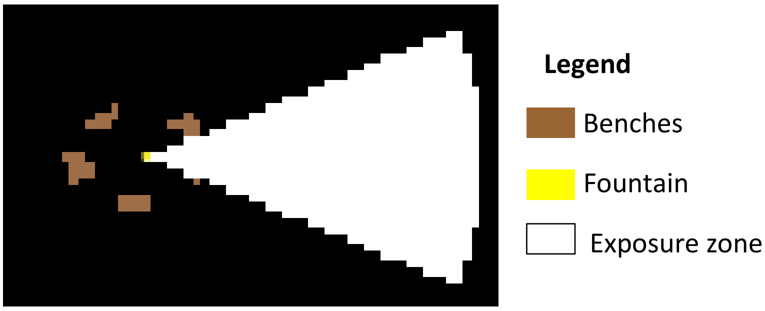


Figure 23 Vision cone used as exposure zone

Here, the cone is represented by the white patches around the fountain. When an agent stays in this ‘field of vision’ long enough, it will become exposed. This makes that the vision cone replicates the workings of an exposure zone.

The vision cone is directed towards the east. This corresponds with the winddirection of that day, which was 91° degrees (360° being north, 90° being east, 180° being south and 270° being west). Figure 24 shows that the heading of the wind is set to 91 degrees.

who 0
color 45
heading 91

Figure 24 Wind direction

Obviously the wind constantly changes. When we consider the third day for instance, the wind has a direction of 36°. This results in a new exposure zone. Figure 25 shows the exposure zone of the third day.

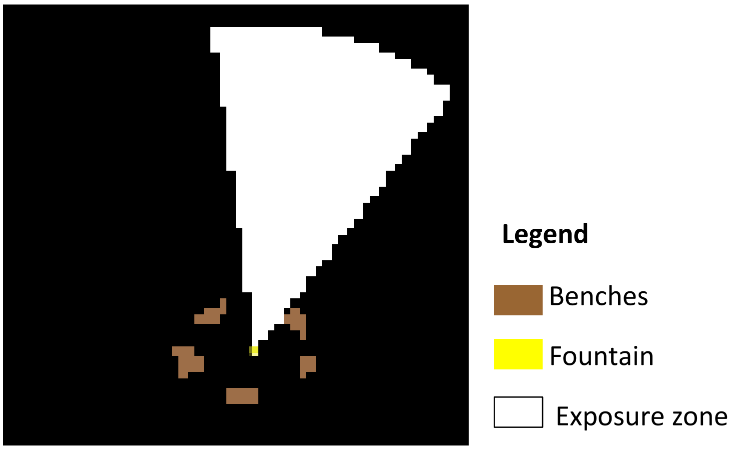


Figure 25 Vision cone used as exposure zone

Now the exposure zone is pointed more towards the northeast, meaning it covers a different area now.

7.3 Duration of stay

Every visitor has a unique duration of stay. The duration of stay depends on two variables: “time” and “initial-time”. The first variable is simply a timer that starts counting from the moment the visitor reaches its position in or around the fountain and stops after 3776 ticks. This is equivalent to 90 minutes in real time. Once that is reached, the visitor will move away from the fountain. “Initial-time” is a unique value assigned to every visitor. This is a value between 0 and 3776. The duration of stay takes the “time” variable and subtracts it from the unique “initial-time” variable, which means:

$$Duration\ of\ stay = Time - Intial\ time \qquad \text{Eq. 1}$$

The duration of stay determines how long an agent has stayed in its position in or around the fountain. As a result, this can be used to determine if a visitor has stayed in or around the fountain long enough to become exposed. For visitors inside the fountain, a duration of stay of 8 minutes is enough to be exposed. This is equal to 336 ticks. This means that only those who stay in the fountain for 336 ticks or more while the fountain is infected will become exposed. This means that if time – initial-time > 336 while the fountain is infected, the agent in the fountain becomes exposed.

Figure 26 below shows a scenario where an agent goes into the fountain while the fountain is infected.

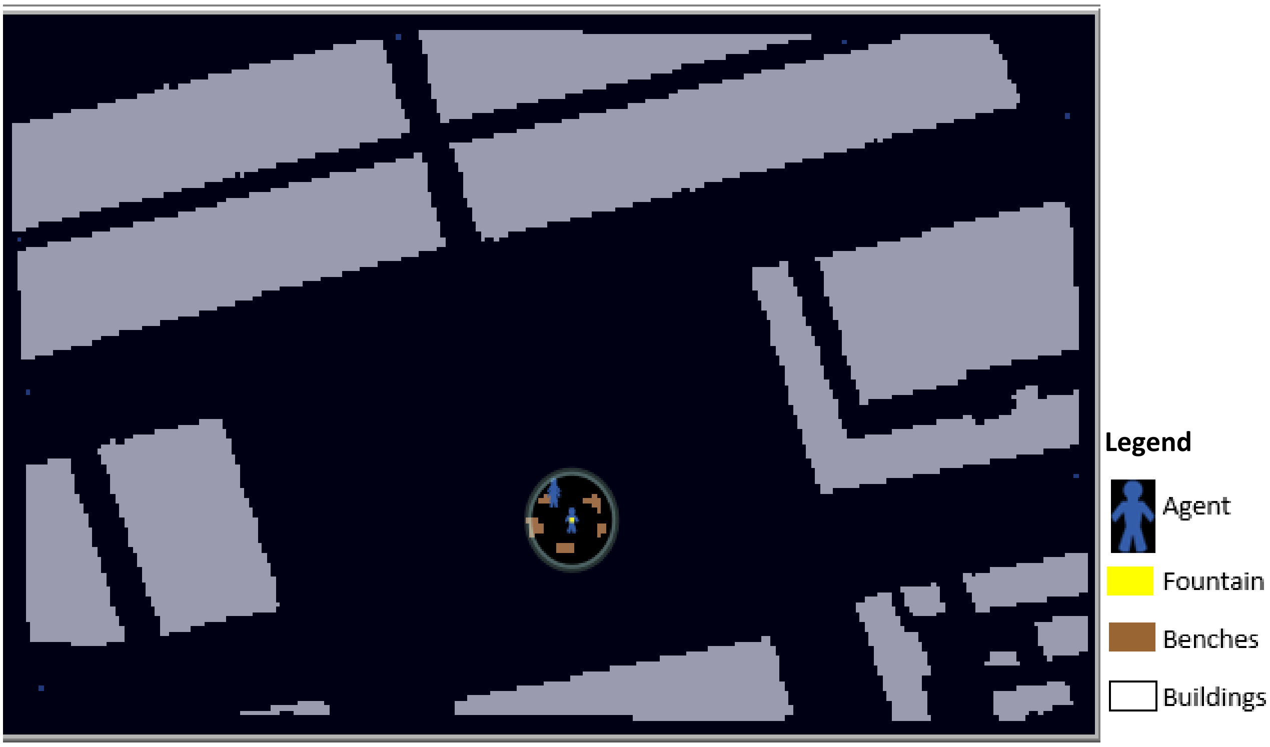
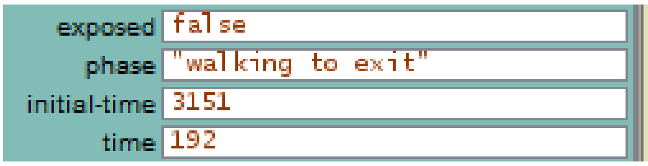


Figure 26 Agent staying in the fountain while it is infected.

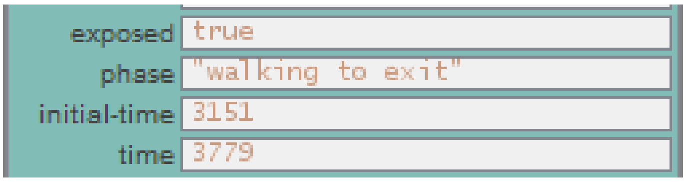
Here we see that the pedestrian stays inside the fountain. As mentioned, the fountain is currently infected. The following figures (27 and 28) shows the values of this agents variables.



exposed	false
phase	"walking to exit"
initial-time	3151
time	192

Figure 27 Variables of pedestrian 341 before it leaves the environment of the model

As we can see, the agent is not exposed. Its "*Initial-time"* is set to 3151 and *"Time"* shows that the agent has been there for 192 ticks. As the simulation continues, the duration of stay will be 3779 – 3151 = 625. This means the agent should become exposed.



exposed	true
phase	"walking to exit"
initial-time	3151
time	3779

Figure 28 Variables of pedestrian 341 after it leaves the environment of the model

Here we see the variables of the agent after it was removed from the simulation. The timer stopped counting after 3779 ticks. The model has calculated the duration of stay: 3779 - 3151 = 628. This means the agent has been in the fountain for more than 336 ticks. We can conclude that the agent now should be exposed. As the figure shows, 'exposed' has indeed changed from being 'false' to 'true', meaning that the agent was exposed to *E.coli* during its stay because of its duration of stay.

7.4 Exposure in the fountain and on the benches

We assume that during July, about 30 visitors go into the fountain every day. This means that the model should simulate about 930 agents going into the fountain. After one run, the model has generated the following number of visitors per location (see table 5).

Table 5 *Number of visitor in the fountain vs on the benches*

Hours	Total number of visitors	Number of visitors on benches	Number of visitors in the fountain
496	3416	2494	922

After a single run, the model generated 922 agents that went into the fountain. This is about 29 to 30 visitors a day. This means the model meets the goal to produce around 30 visitors per day that go into the fountain.

8. Results

This chapter provides the results for each research question. Before discussing the results we will check the robustness of the model (8.1) by determining the number of repetitive runs needed for each experiment. In the second part of this chapter (8.2) a sensitivity analysis is conducted. The results presented are generated using the model. After the sensitivity analysis, every section in this chapter (8.3, 8.4 and 8.5) is related to a single research questions.

8.1 Robustness check

To analyse the individual exposure to *E.coli*, we ran the model for the fountain located on Frederiksplein. For this experiment, we assume that 3416 people will visit the fountain, with an average of 78 visitors during the weekdays and 190 visitors during the weekends (see section 7.1). The angle of water spray is 45° and the constant value used to determine how far the spray reaches is set to 0.9. The constant will be described into more detail in equation 2 in section 8.2.2. The fountain will become infected after 300 people visited the fountain and the fountain is cleaned once a week. Setting a threshold of 300 people before the fountain becomes infected is based on the idea that people will produce garbage. The garbage will then attract animals that feed on this. These animals will then be interacting with the (area surrounding the) fountain and will use the water for bathing and drinking. This will then contribute to the infection of the fountain. The results after each run over the course of 100 runs are shown in figure 29 below.

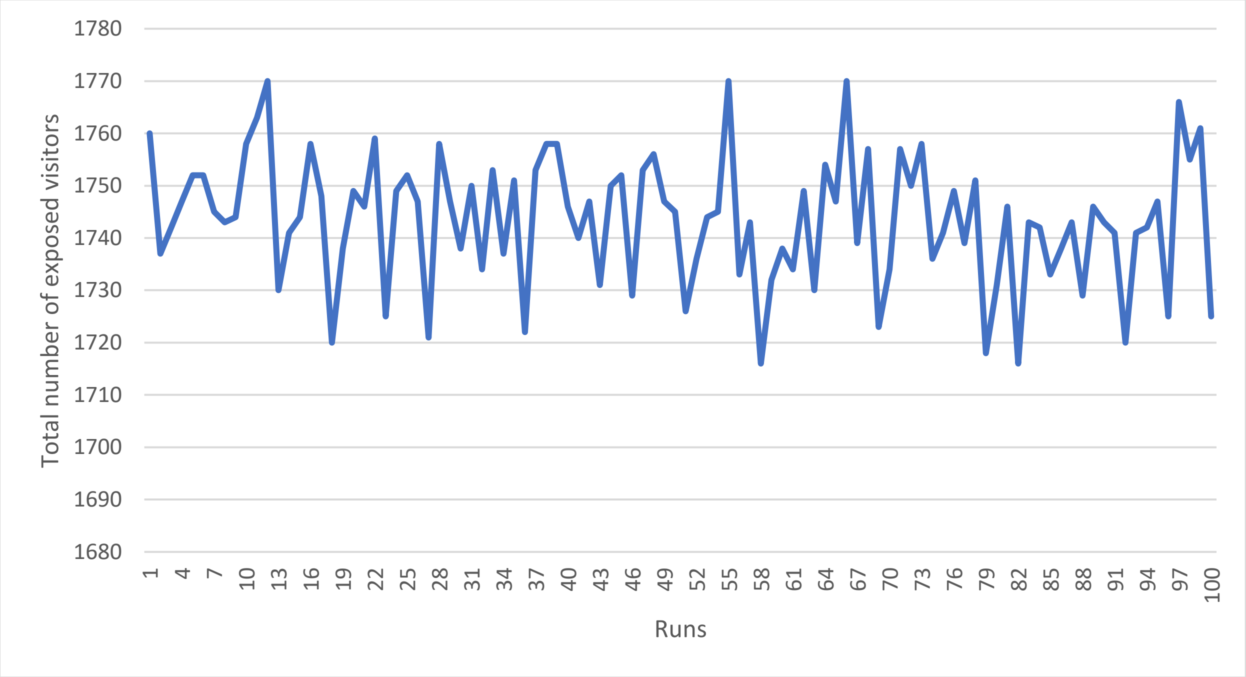


Figure 29 Total number of exposed visitors at Frederiksplein after 100 runs

Here we see the distribution of the total number of exposed visitors after each runs. The graph shows that the number of exposed visitors varies between the runs, with a minimum of 1716 exposed visitors and a maximum of 1770 exposed visitors. Figure 29 shows the fluctuations between the outcomes of each run. However, it is also important to consider the average number of exposed visitors. To gain a better understanding of this, the following graph in figure 30 shows the robustness of the model.

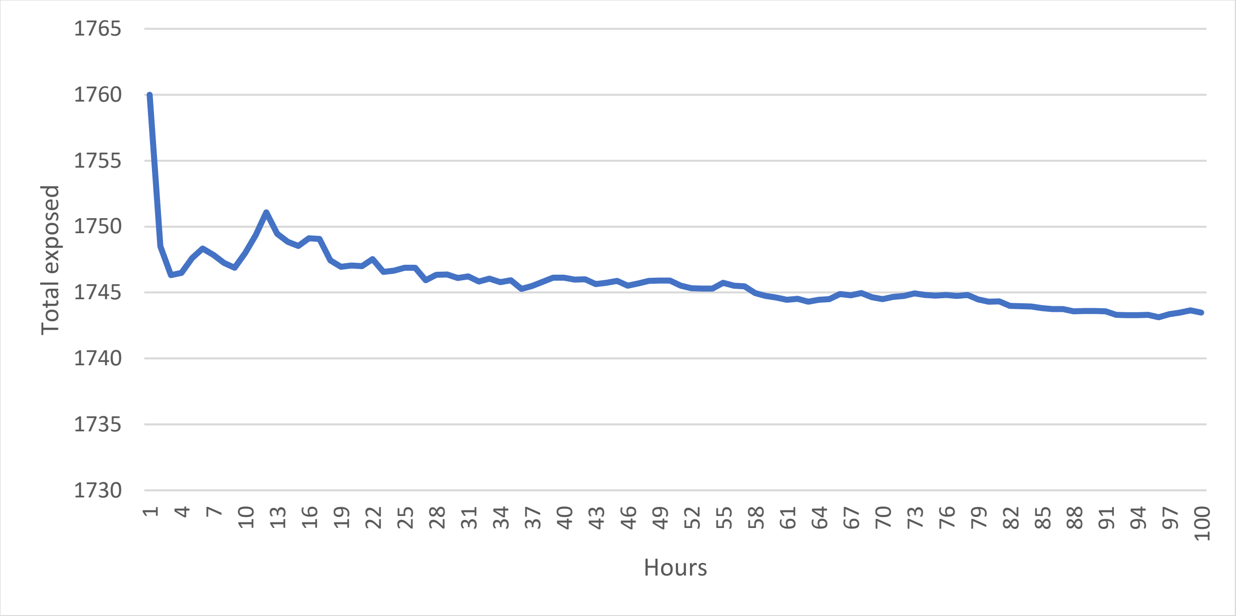


Figure 30 Robustness of the model

This graph shows the average of the total number of exposures agents over the course of multiple runs. First the average is calculated after the first run, then the average is calculated over the first and the second run, then over the first, second and third run etc. This is done for every run. We see that the average varies a lot at first. However after about 30 runs the average number of exposed visitors remains close to 1745 people. This shows that the model stabilizes after about 30 runs.

8.2 Sensitivity analysis

In the sensitivity analysis, we examine the impact of different parameters on the model's output (Berger et al., 2001). This process helps to determine to what extent the parameters influence the final results. Happe (2005) explains that a common way of testing this is by changing one of the parameters, without altering the other parameters. There are a number of input parameters that will be tested in this sensitivity analysis. These include the *number of visitors, the spray distance* and the *spray angle*. This analysis aims to check if additional research has to be conducted to calibrate the value of these parameters. The experiments in the model will be conducted on the fountain located on Frederiksplein. The effect of the variation of parameter values will be evaluated using the average number of total infections.

8.2.1 Number of visitors

The first parameter that we will discuss is the number of visitors. This number has a significant impact on the total number of exposed visitors. This has two reasons. First of all, whether the fountain is infected or not is determined by the number of visitors. This means that when more visitors are simulated, the fountain will become infected earlier. Secondly, more visitors lead to more agents that will come in contact with the fountain. As a result, more visitors can become exposed. To examine this, we will run the model multiple times. First, the model will generate 3416 visitors. Every run the model will generate about 150 more visitors. In the final run, 6807 visitors will be generated. This is about double the number of visitors that were generated during the first run. While increasing the number of visitors, the week and weekend patterns remain the same. After each run we look at the total number of exposed visitors. Figure 31 provides a graph with an overview of the generated number of visitors and the corresponding number of exposed visitors.

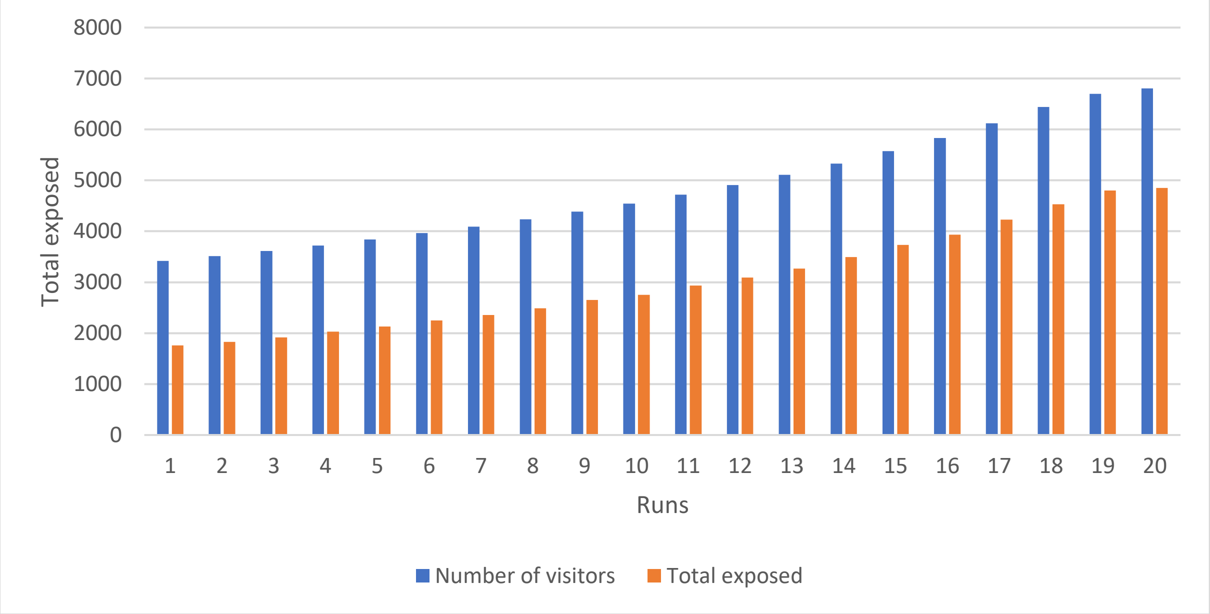


Figure 31 Total number of exposed visitors after two runs

The first pattern we see here is that as the number of visitors increases, the number of exposed visitors also increases. As the figure shows, after the first run 1759 visitors became exposed. This is equal to 51% of the total number of visitors that were generated. After the last run, 6807 visitors were generated. In total 4850 visitors were exposed. This is equal to about 66% of the total number of visitors. This shows that by only increasing the number of visitors, the total number of exposed visitors increases. However, also relatively more visitors became exposed after more visitors were generated. This shows that the number of visitors is a parameter that strongly influences the number of exposed visitors. The relative increase is caused by the fact that the fountain becomes infected much quicker. Therefore, the fountain is more often infected leading to more visitors being exposed.

8.2.2 Spray distance

The distance of the spray is the second parameter that will be analysed. The spray distances determines how far the exposure zone reaches. As described earlier, the spray distance is influenced by the windspeed of the day. To determine the spray distance the following equation is used:

$$\text{spray distance} = V * 0.9 \qquad \text{Eq. 2}$$

Where V is the windspeed.

This means that besides the windspeed, the spray distance is also a product of a constant, which is in this case 0.9. However, this constant is determined based on the height of the fountain and the size of the water particles. When the water particles are smaller, the droplets can travel further through the air, resulting in a larger spray distance. This means that if water particles are smaller, the constant should be greater than 0.9. To compare different scenarios, table 6 provides an overview of the number of exposed visitors after one day (16 hours) with varying constants.

Table 6 Comparing results after different constant values

Hours	Constant	Total exposed on benches	Total exposed in fountain	Total exposed
16	0.9	0	0	0
16	1.2	0	0	0
16	1.6	0	0	0

The table shows that the number of visitors that became exposed while sitting on a bench is constantly 0. This would imply that the spray distance does not reach far enough in all three scenarios. However, this turns out not to be true. Figure 32 below shows how far the spray reaches when we use the highest constant value of 1.6.

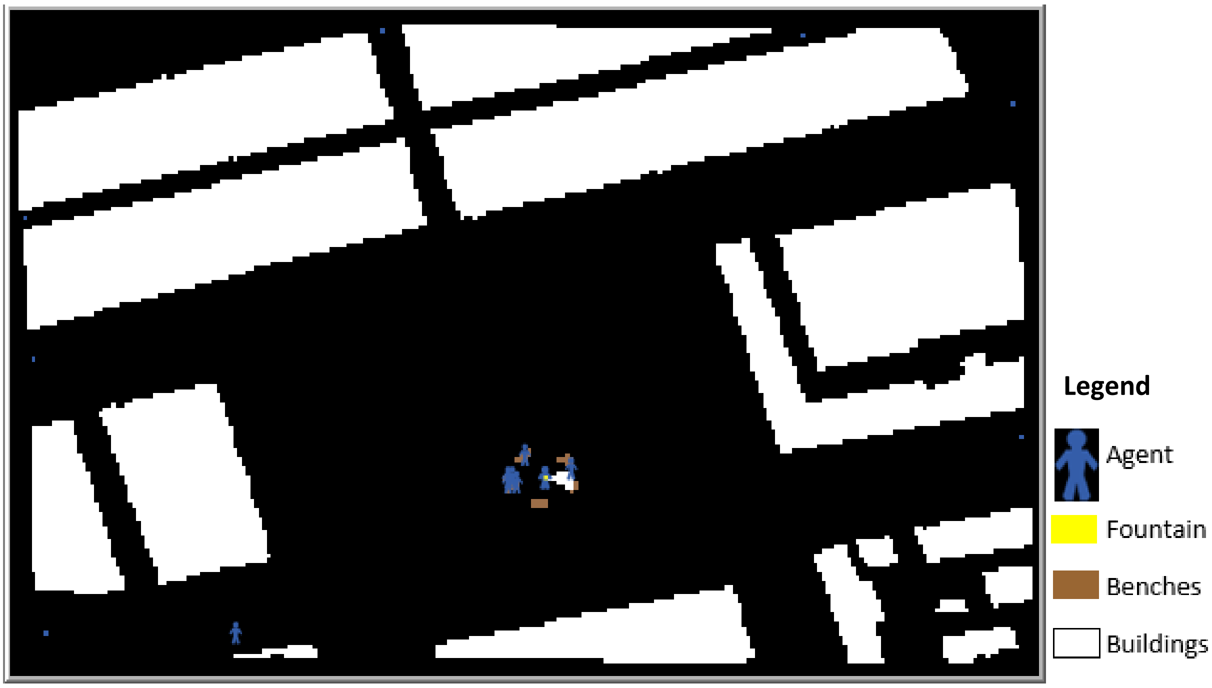


Figure 32 reach of water spray on the first day

As the image shows, when using a constant of 1.6 the exposure zone can reach the benches on the first day of the simulation. This indicates that the agents could become exposed. However, when running the model we see the following results for the first three days (table 7).

Table 7 Results after first three days

Hours	Total number of visitors	Total number exposed	Total number exposed in fountain	Total number exposed on bench
16	189	0	0	0
32	266	0	0	0
48	344	0	0	0

None of the visitors became exposed, and therefore, obviously none of the visitors that sat on the benches became exposed. This might come as a surprise since figure 32 shows that the water spray reaches the bench. The fact that none of the agents became exposed during these days can be explained by the fact that the fountain was not infected during these days. If the spray reaches the benches while the fountain is not infected, none of the visitors will become exposed. This means that when the fountain is not infected, the exposure zone does not affect the visitors. However, if we assume that the fountain actually is infected on those days, we should see a completely different outcome. Therefore we compare the results with an alternative scenario where we assume that the fountain is already infected on the first day. The results of this alternative scenario are presented in table 8 below.

Table 8 Water spray reaching benches while fountain is infected on the first three days

Hours	Total number of visitors	Total number exposed	Total number exposed in fountain	Total number exposed on bench
16	189	164	156	8
32	266	243	235	8
48	344	317	308	9

Now we see that after the first 16 hours, 189 people have visited the fountain. In total 164 visitors became exposed on that day. Out of the 164 visitors that became exposed, 8 were people that sat on the benches. When we compare the results of table 7 and table 8 we can see that visitors become exposed when the fountain was infected. But perhaps more importantly, we see that the visitors that stayed on the benches also became exposed during these days. This shows that only when the fountain is infected visitors can become exposed. These results show that when the exposure zone reaches the benches while the fountain is infected, people can become exposed when they sit on a bench. However, table 7 shows that if the spray distance is large enough but the fountain is not infected, the visitors will not become exposed.

The state of infection of the fountain is not the only parameter that determines whether a visitor on the bench can become exposed or not. The distance of the spray also plays an important role in this. This because the spray can only affect agents that sit on benches inside of the exposure zone. If the spray cannot reach the benches, the people that sit on the benches will not become exposed even when the fountain is infected. As described in equation 2, the spray distance is determined by the wind speed of the day. Figure 33 gives an overview of the daily windspeeds in July 2018.

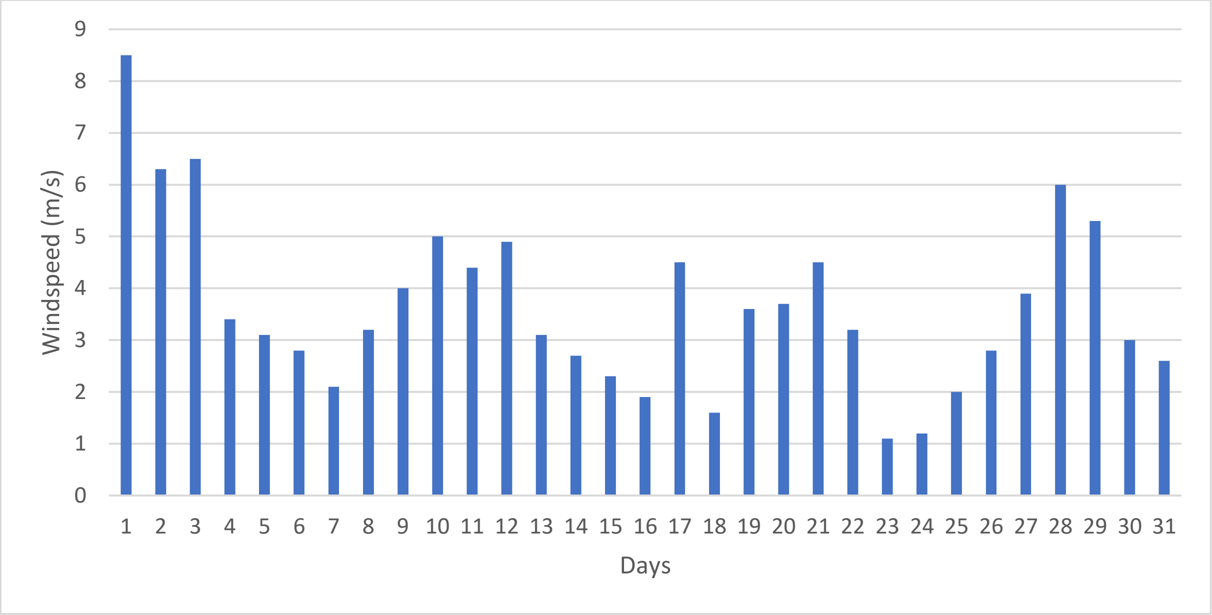
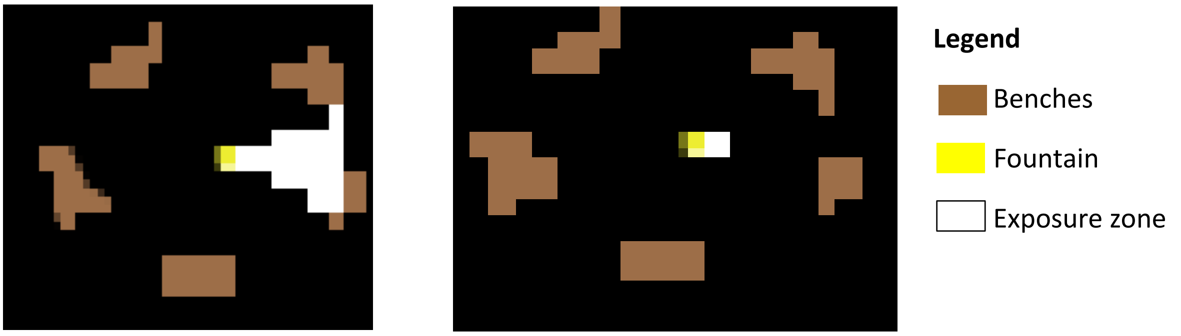


Figure 33 Daily windspeed (m/s)

Here we see that on the first day there was a windspeed of 8.5 m/s. Figure 32 already showed that such a windspeed can blow the water particles onto the benches if we use a constant of 1.6. Since we use different windspeeds for every day, the distance of the spray and the reach of the exposure zone should also change accordingly. That is why we compare the distance of the spray with varying windspeeds. For example, on day 1 a windspeed of 8.5 m/s was recorded, while on day 7, a windspeed of 2.1 m/s was recorded. This means that the danger zone should reach much further on day 1 (8.5 m/s) compared to day 7 (2.1 m/s). Figure 34 shows a comparison of the water spray distance when we use a windspeed of 8.5 m/s and windspeed of 2.1 m/s.



Distance with 8.5 m/s *Distance with 2.1 m/s*

Figure 34 Comparison of water spray distance with different windspeeds

We can clearly see that if nothing else but the windspeed changes, the distance of the spray also changes. When we use a windspeed of 8.5 m/s, the water spray can reach the benches, but if we use a windspeed of 2.1 m/s, the water spray cannot reach the benches at all.

This has a strong impact on the number of visitors that become exposed when sitting on a bench. We can illustrate this by comparing two runs with different windspeeds for the same day while assuming that the fountain is infected. Table 9 shows the number of exposed visitors after one day with a windspeed of 8.5 m/s, and the number of exposed visitors when we use a windspeed of 2.1 m/s. For both cases we assume that the fountain was infected to ensure that the agents can become exposed.

Table 9 Number of exposed visitors on after different windspeeds

Windspeed	Hours	Total number of visitors	Total number of visitors exposed on benches
8.5 m/s	16	189	12
2.1 m/s	16	189	0

Here we see that with a windspeed of 8.5 m/s, 12 of the visitors that sat on a bench became exposed. With a windspeed of 2.1 m/s, none of the visitors that sat on the benches became exposed. This is due to the fact that the spray could not reach the fountain with a windspeed of 2.1 m/s (figure 34). This shows that the speed of the wind has a big impact on the number of exposed visitors that stay on benches. If the wind is not strong enough the visitors can sit on the benches without being at risk, even if the fountain is infected.

The analysis so far shows that the infection rate of the fountain and the spray distance determine how many visitors can become exposed when sitting on a bench. These two are also interrelated. If the fountain is not infected, the water spray cannot affect the agents even if it reaches the benches. On the other hand, if the fountain is infected but the water spray cannot reach the benches, the people that sit on the benches will not become exposed. Whether the spray can reach the benches depends on the constant that is used in the equation and the windspeed of the day.

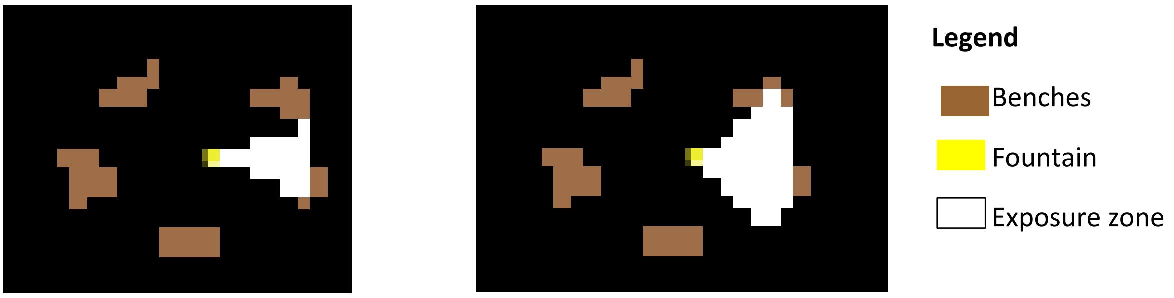
8.2.3 Exposure zone angle

The last parameter that will be analysed is the angle of the exposure zone. This angle determines the width of the exposure zone. The exposure zone uses a standard angle of 45°. A larger angle will create a larger width for the exposure zone, leading to a bigger sized exposure zone. When the exposure zone is bigger, there is a greater chance that someone will be sitting in it. This means that a larger angle can increase the number of people that become exposed while sitting on a bench. Using a smaller angle obviously has the opposite effect. To compare the impact of different exposure angles, we look at the number of visitors that have been exposed on the benches after a single run but with varying angles. Here we compare the results after running the model with an angle of 45° and an angle of 90°. In both cases, we assume that the fountain is infected and we use a constant of 1.6. Also, we assume that there is a windspeed of 8.5 m/s on that day. Table 10 below shows the results after 16 hours.

Table 10 Number of exposed visitors on benches using different angles

Angle	Windspeed	Hours	Total number of visitors	Total number of visitors exposed on benches
45°	8.5 m/s	16	189	6
90°	8.5 m/s	16	189	13

Here we see that the number of visitors that became exposed on a bench has more than doubled after using a wider angle. It indicates that the angle of the exposure zone highly influences the number of agents that can become exposed after sitting on a bench. Again, it is important to note that visitors could only become exposed because the fountain was infected and the wind was strong enough. As the different outcomes of table 7 and table 8 already made clear in section 8.2.2, agents will not become exposed if the fountain is not infected. Table 9 illustrated that the windspeed must also be strong enough to reach the benches before visitors can become exposed. The increase in exposed visitors on benches shown in table 10 is caused by the fact that the exposure zone is much smaller when using a 45° angle in comparison with a 90° angle. To visualize this, figure 35 compares both exposure zones.



Exposure zone with 45° angle *Exposure zone with 90° angle*

Figure 35 Different exposure zones due to varying angles

The image shows that the exposure zone covers a much larger area when we run the model with a 90° angle. This shows that the angle of the exposure determines the size of the exposure zone and therefore can influence the number of visitors that become exposed while sitting on a bench. However, as section 8.2.2. already made clear, the distance of the water spray plays a crucial role. If the spray cannot reach the benches, the angle of the spray does not affect the number of exposed visitors. Under normal circumstances, the water droplets do not always reach the benches. Because of this, the model is not very sensitive to the spray angle value. Therefore the default angle of the spray in the model is set at 45°.

8.2.4 Parameters under normal circumstances

In the following sections of the results chapter, three research questions will be answered. To answer these research questions, we will compare three fountain locations in Amsterdam: Frederiksplein, the Americain hotel and lastly Haarlemmerplein. To compare these locations properly, all the circumstances are made equal. This means that for all three locations we assume that the fountain becomes infected after 300 visitors, the angle of the water spray is 45° and the constant value used to determine the distance of the spray is set at 0.9. The number of visitors will vary per fountain. The number of visitors is determined based on the field work and literature. As described in sub-section 7.1, Frederiksplein has 3416 visitors. Based on the same methods, the number of visitors at Americain is set at 7667 visitors. For Haarlemmerplein the same number of visitors was counted during fieldwork. This location therefore also has 7667 visitors. An overview of the parameters is given in table 11. Each experiment will be evaluated based on 100 model runs.

Table 11 Parameters under normal circumstances

	Frederiksplein	Americain	Haarlemmerplein
Total number of visitors	3416	7667	7667
Angle of the water spray	45°	45	45
Constant value for water distance	0.9	0.9	0.9
Infection rate	300 visitors	300 visitors	300 visitors
Water cleaning	Once a week	Once a week	Once a week

8.3 Individual exposure

First, the research question *"What role does the distance of the individual to the fountain play in the exposure process?"* will be answered. Technically speaking, exposure to *E. coli* via fountain water can occur in three ways: while playing in the fountain, when sitting/standing near a fountain, or while passing this fountain as a pedestrian or cyclist. As the duration time for people passing the fountain is short, this study will focus on visitors that get exposed to *E.coli* while going into the fountain, or when staying close to the fountain by sitting on a bench nearby. As described earlier, people can only become exposed when two requirements are met: the fountain should be infected and the exposure time should exceed a threshold value. The fountain becomes infected when more than 300 people have visited the fountain. Secondly, the visitor should spend enough time in or around the fountain while it is infected. As described in section 5.2.1.1 and 5.2.1.2 those that go into the fountain for more than eight minutes will become exposed, while visitors that stay around the fountain need to spend more than thirty-three minutes on a bench to become exposed. However, visitors that stay on benches also need to sit in the area where water droplets from the fountain can land (exposure zone). If a visitor spends time near the fountain but the spray does not reach the bench that the visitor is sitting on, the person cannot become exposed. At last, it is important to note that the water of the fountain is cleaned every week.

After 100 runs, the average number of exposed visitors is 1743 people. This tells us that in this scenario, on average 1743 people were exposed to *E.coli* from the fountain located at Frederiksplein. The results of this scenario are given in table 12 below.

Table 12 Number of exposed visitors on benches using different angles

Total number of visitors	3416
Angle of the water spray	45°
Constant value for water distance	0.9
Infection rate	300 visitors
Total number exposed	1743

Table 12 shows that if we assume that there were 3416 visitors at Frederiksplein during July, 1743 visitors were exposed to *E.coli* from the fountain. In this scenario the angle of the water spray was set at 45° and the fountain becomes infected after 300 visitors. However to better understand the individual exposure to *E.coli*, we should also consider where these individuals were exposed. To analyse this, we will run the model a hundred times. We then look at the number of visitors that became exposed in the fountain and at the number of visitors that became exposed from sitting on a bench near the fountain. How this is distributed is shown table 13 below.

Table 13 Number of exposed visitors on benches using different angles

Location	***Visitors***	***Exposed on bench***		***Exposed in fountain***		***Exposed total***	
		Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)
Frederiksplein	3416	0	0	1743	51%	1743	51%
Americain	7667	2	0,03%	7665	99,07 %	3198	41%
Haarlemmerplein	7667	0	0	1407	18%	1407	18%

This table clearly shows that almost none of the visitors that sat on a bench became exposed in this scenario. It reveals that under these circumstances visitors will mainly become exposed when they go into the fountain. This could mean that the benches are located far enough from the fountain to prevent visitors from becoming exposed.

Also, we will compare the locations based on their difference in number of visitors. The number of visitors is determined based on the field work and literature. As described in sub-section 7.1, Frederiksplein has 3416 visitors. Based on the same methods, the number of visitors at Americain is set at 7667 visitors. For Haarlemmerplein, the same number of visitors was counted during fieldwork. This location therefore also has 7667 visitors. The ratio between the number of visitors on weekdays and weekend days are the same for each location. After running the model for this scenario, we see the following results when comparing Frederiksplein to Americain (figure 36).

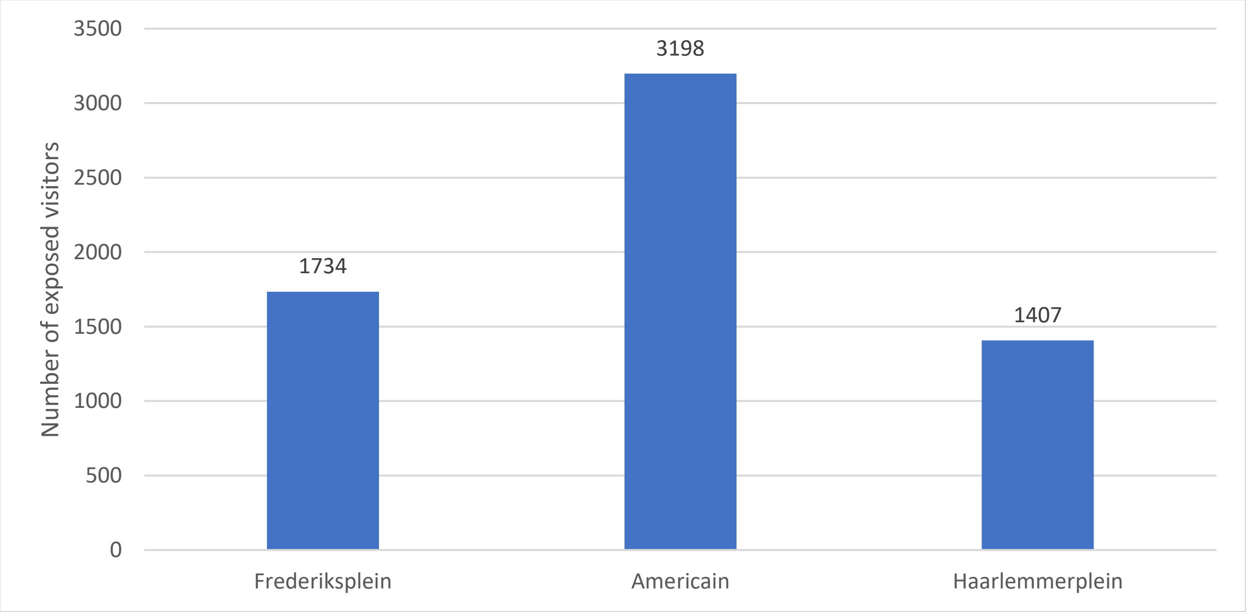


Figure 36 Difference between Frederiksplein, Americain and Haarlemmerplein

The graph shows that Frederiksplein, has 1743 (51%) exposed visitors. None of them were visitors that sat on a bench. Americain has 3198 (41%) exposed visitors, two of them were people that sat on a bench. At Haarlemmerplein only 18% (1407 people) became exposed. On average not even one of them were people that sat on a bench (0.5). We see that, by only changing number of visitors, the results for these locations strongly vary. The graph tells us that the total number of exposed visitors at Americain is much higher than at Frederiksplein. Americain has 3198 exposed visitors opposed to 1743 at Frederiksplein. This could indicate that when a fountain is visited by more people, there are more exposures at that fountain. Since the number of visitors influences the infection of the fountain, more visitors can lead to a quicker infected fountain. As a result the visitors at Americain will then interact more often with an infected fountain than the visitors at Frederiksplein do. Secondly, more visitors at Americain can also lead to more people interacting with the fountain. Americain has therefore more visitors that come in contact with the fountain, while the fountain is also infected more often. To analyse this assumption, we should also to look at the infection time of the fountains at both locations (Frederiksplein and Americain). The infection time of the fountain can show us how fast a fountain becomes infected and for how long the fountain is infected. Figure 37 provides a graph that shows the infection time of the fountains at Frederiksplein and Americain.

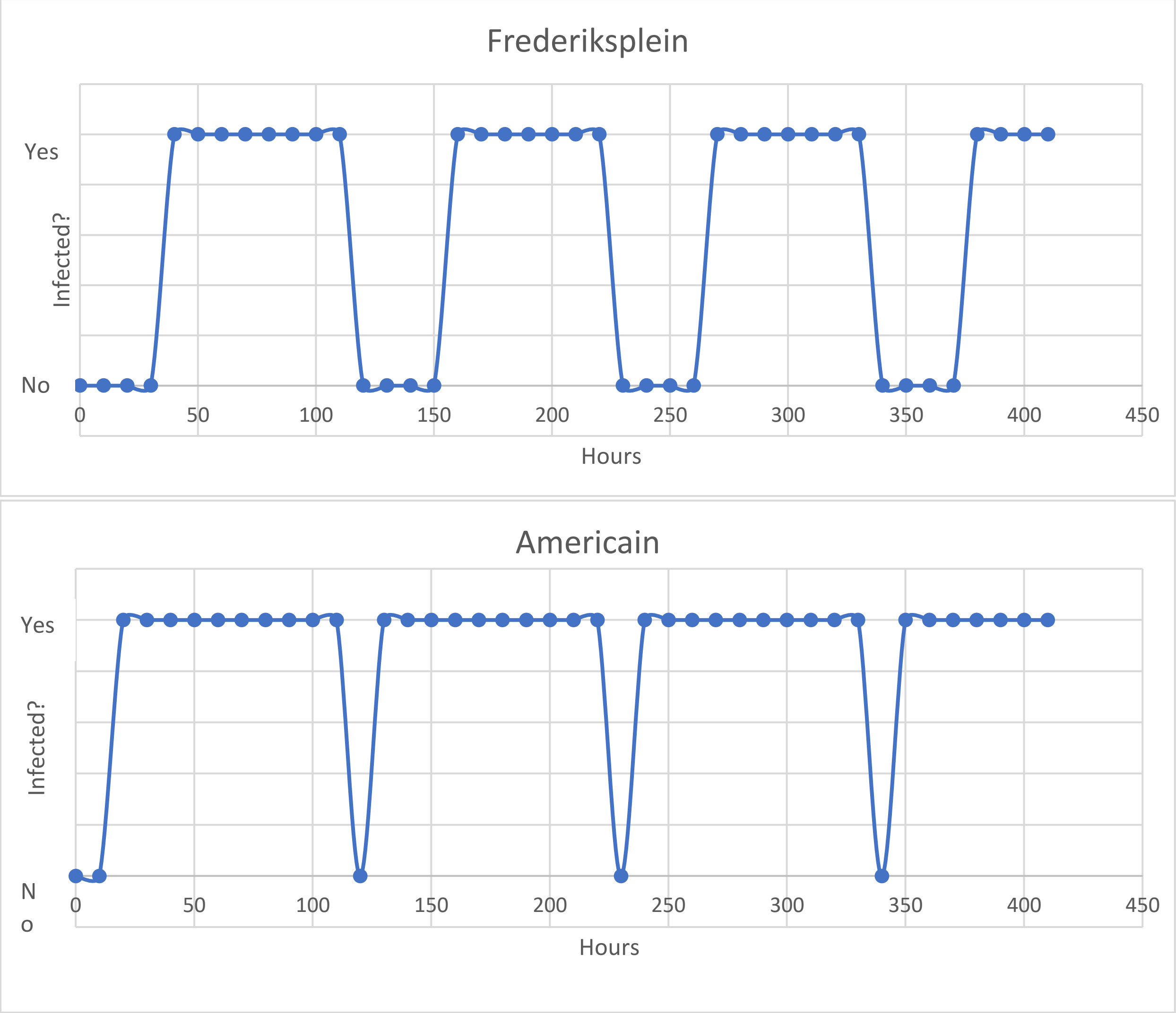


Figure 37 Infection time of the fountain Frederiksplein and Americain

The graphs in figure 37 show that the fountain at Americain is indeed infected much faster than the fountain at Frederiksplein. The graphs also show that the duration of the infection at

Americain is much longer compared to Frederiksplein. This means that the fountain does become infected much quicker since there are more visitors. This explains why Americain has more exposed visitors than Frederiksplein. Not only is the fountain infected much faster, but there are also more visitors that can interact with the infected fountain. However, when the number of exposed visitors are expressed as percentages of the total number of visitors, we see that Frederiksplein has relatively more exposures (51%) compared to Americain (41%). We can conclude from this that by looking at the total number of exposures, Americain has by far the most exposed visitors. However, when comparing that number to their to the total number of visitors, Frederiksplein has the most exposures. This can be caused by the fact that Americain has over twice as many visitors as Frederiksplein. At the same time, the fountain at Americain is not infected twice as often and twice as long. Therefore, this most likely explains why Frederiksplein has a higher exposure ratio.

Another interesting finding from these experiments is that almost every visitor became exposed from going into the fountain rather than sitting on a bench. As described earlier, none of the visitors that sat on a bench at Frederiksplein was exposed. However, at Americain and Haarlemmerplein we did see some exposures from visitors that sat on a bench. To analyse this, we will look at the number of exposures on benches for these two locations. Figure 38 shows the number of exposures on benches for Americain over the course of the 100 runs.

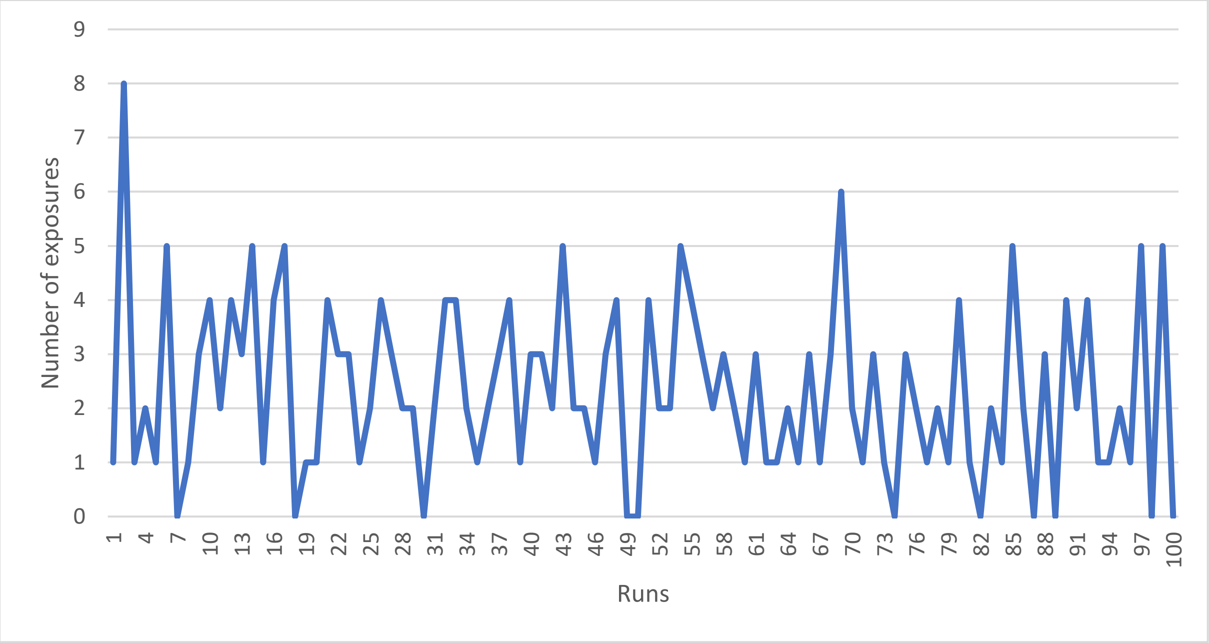


Figure 38 Distribution of exposure on benches at Americain hotel

The graph shows that the number of exposures on benches fluctuates a little. The total number of exposures on the benches remain very low, with a maximum of 8 exposures and a minimum of 0 exposures. On average, around 2 visitors became exposed after sitting on a bench. This number is still very low compared to the total number of exposed visitors (3198), but it does show that the benches are located close enough to the fountain for visitors to become exposed. This means that under these circumstances, sitting on a bench close to the fountain of the Americain hotel can lead to exposure to *E.coli*. However, this does not happen often. We see that exposures are mainly caused by going into the fountain.

The same scenario is tested for Haarlemmerplein. There are less exposures on benches there, but when we look at the distribution we also see a fluctuating trend. The results are given in Figure 39.

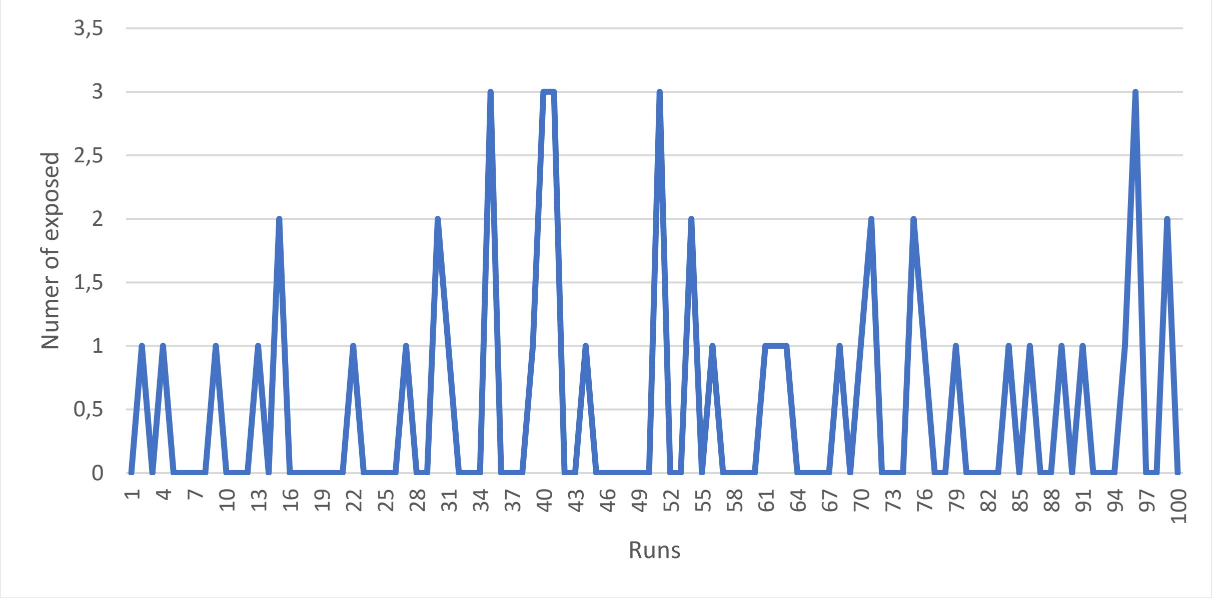


Figure 39 Distribution of exposure on benches at Haarlemmerplein

The graph shows that the total number of exposures on benches is also very low. On average, not even 1 person became exposed after sitting on a bench (0,49), but the values do vary sometimes. The maximum number of exposures on benches at Haarlemmerplein is 3, but this does not occur very often. When looking at the results shown in figure 38 and figure 39, we do see that more visitors became exposed on the bench in comparison with Frederiksplein, where none of the bench-sitters became exposed. This means that the location of the benches plays a role but still does not influence the total number of exposures much. Because some visitors became exposed after sitting on a bench at Haarlemmerplein and Americain, we know that the spray of the fountain can reach the benches while the fountain is infected at these locations. We can, therefore, assume that under these circumstances, the benches at Americain and Haarlemmerplein are located close enough to the fountains to form a threat for visitors. However, chances of exposure are very small since not many visitors become exposed under these circumstances. In some cases, the spray of the fountain does not even go past the basin of the fountain. Going into the fountain can therefore be considered to be the main reason for visitors to become exposed to *E.coli* at all three locations.

8.3.3 Using different angles

Because we know that the water spray can reach the benches at Haarlemmerplein and Americain, we can also consider the impact of the angle of the water spray at these locations. This because it could influence the number of exposures on benches. Frederiksplein will not be taken into account here, since the benches are already located far enough there. Figure 40 shows the distribution of exposure on a bench for Americain with a spray that has a 90° angle compared to a 45° angle.

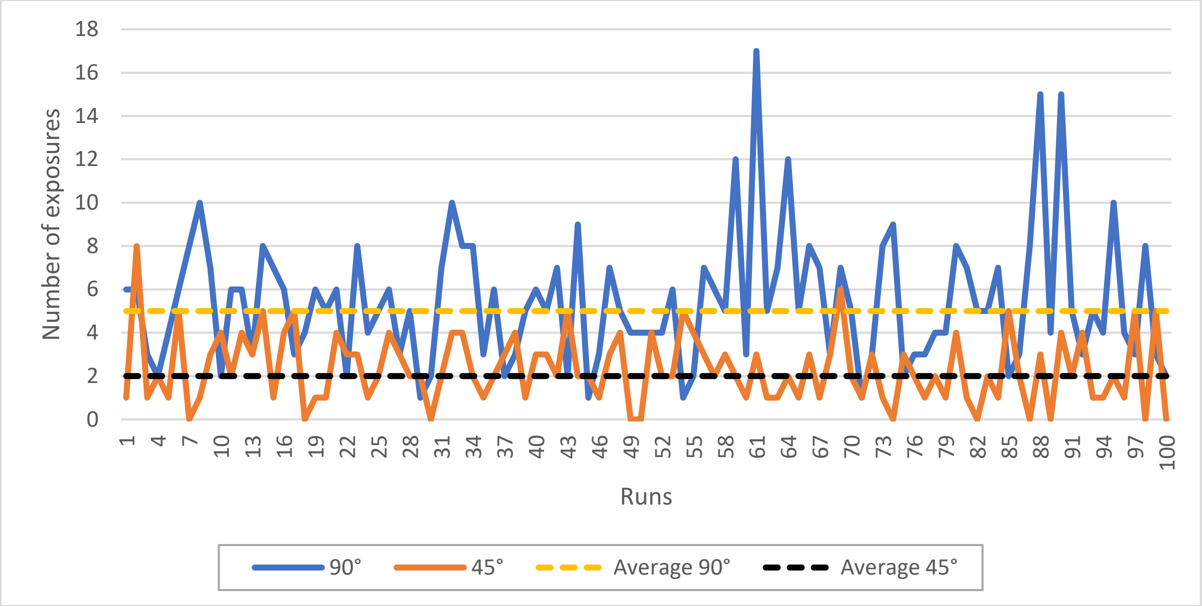


Figure 40 Comparison of bench exposures at Americain with different angles

The graph shows different results for different angles. First of all, the graph shows that with a 45° angle, the number of exposures on benches often remains 0. However, with a 90° angle every run shows at least 1 visitor that became exposed after sitting on a bench. The maximum number of exposures on benches has increased as well. With a 90° angle, the results show a maximum of 17 visitors that became exposed after sitting on a bench. This is much higher than compared to a water spray with a 45° angle.

We also see a difference in the average number of people that became exposed after sitting on a bench. With a 90° angle we see an average of more than 5 exposures on the bench. For a 45° angle, this average is 2. We can therefore assume that the angle of the water spray does affect the total number of exposures on benches at Americain. By increasing the angle, the width of the exposure zone increases as well. This because the spray can then cover a much larger area, resulting in more exposures on benches at this location. However, the number of exposed visitors that sat on a bench is still very low compared to the total number of exposed visitors. Therefore, we can conclude that the angle does not have a big impact on the total number of exposed visitors at Americain.

To compare both locations, the experiment is carried out again, but this time for Haarlemmerplein. The results are shown in figure 41.

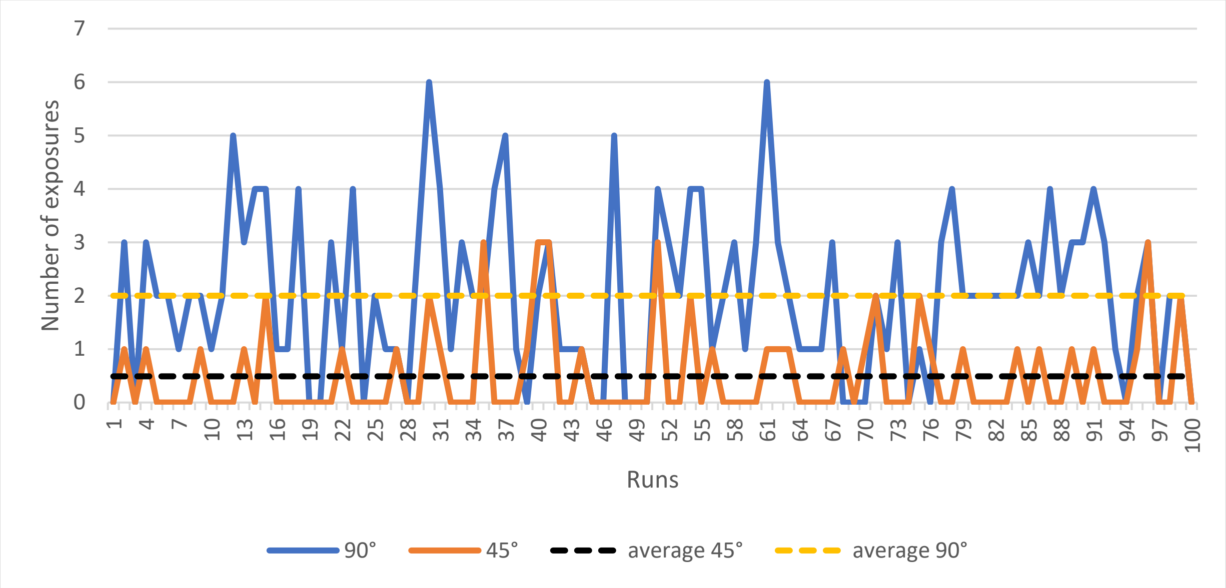


Figure 41 Comparison of bench exposures at Haarlemmerplein with different angles

This graph shows a similar pattern: a wider angle again results in more exposures on benches. It shows that the angle of the spray affects the number of exposed visitors at this location as well. When the angle increases, the number of exposures on benches increases too. Again, the number of people that became exposed after sitting on the bench is not high. This means that the angle of the spray also does not have a big impact on the number of exposed visitors at Haarlemmerplein. However, by comparing Americain with Haarlemmerplein we do notice a difference between the two locations. This is shown in figure 42 below.

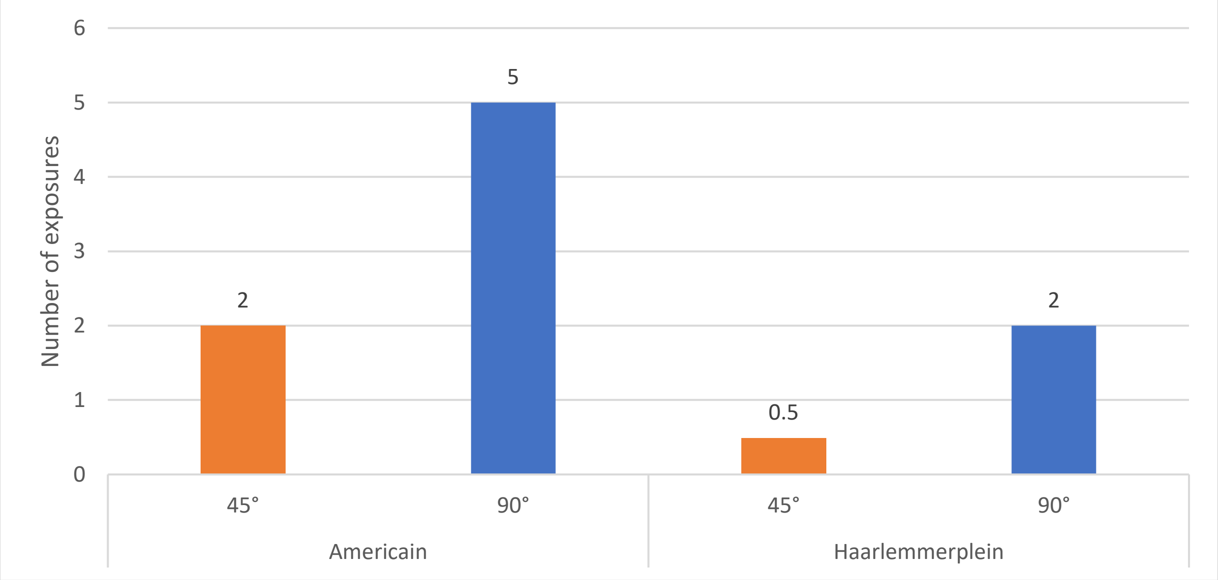


Figure 42 Comparison after different angles at Americain and Haarlemmerplein

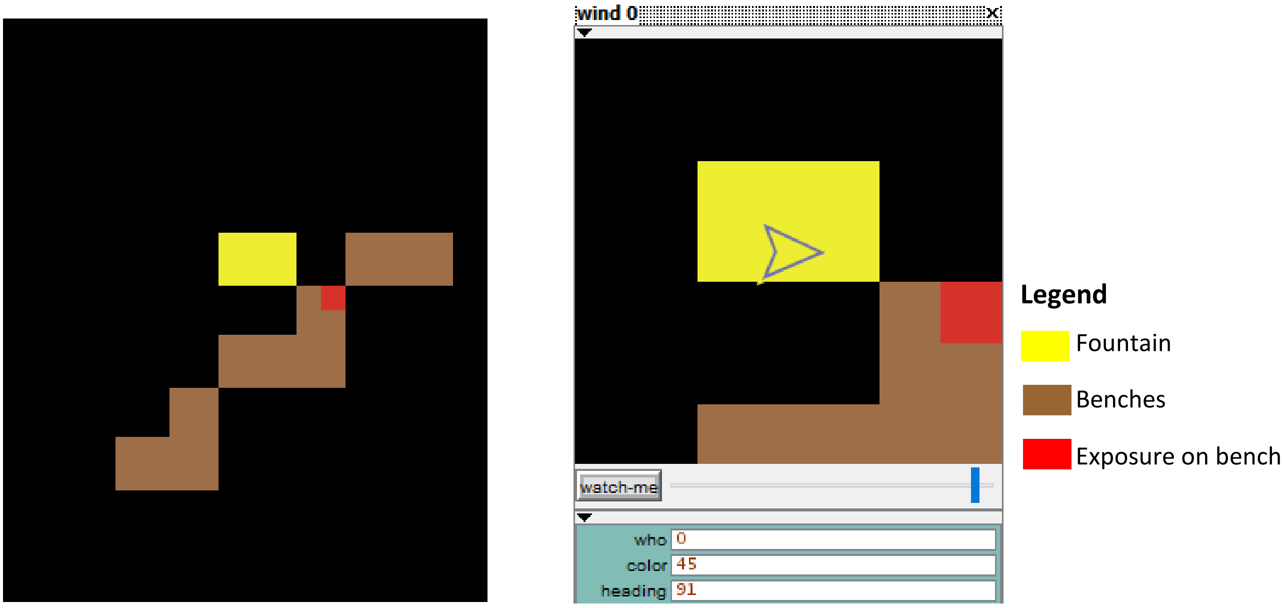
The graph gives the rounded results for both locations. It clearly shows that a wider angle leads to more exposures for both locations, but on average Americain has more exposures on benches than Haarlemmerplein. This is caused by the position of the benches in relation with the fountain.

8.4 Urban environment: exposure on benches

This section will discuss the second research question: *"What is the role of the spatial environment in the exposure process?".* This question is relevant because the urban environment can play an important role in the number of exposed visitors.

The urban environment could play a role in the windspeed and wind direction as tall buildings can block the wind, or influence the wind direction. This will however, not be evaluated in this section. This section will focus on the benches where people became exposed, and will identify if the position of the bench in relation to the fountain (north, east, south, west) influences the number of exposures. When certain benches are more exposed to water spray, these benches could be repositioned or removed.

In order to investigate this we will look at the where people became exposed when they sat on a bench. In other words: we will determine on which benches people became exposed. Section 8.3 already showed us that people rarely became exposed after sitting on a bench. On average we only recorded 2 exposures on a bench at Americain under normal circumstances. We also recorded exposures at Haarlemmerplein, but on average there was not even 1 person that became exposed after sitting on a bench. Therefore we will only consider the positioning of the benches at Americain. To understand where the agents where sitting when they became exposed, figure 43 provides an image of the model, showing the direction of the spray and the position of the benches at Americain when visitors became exposed there. This means that the image shows where the agents where sitting when they became exposed and also shows the direction of the spray during that time.



who 0
color 45
heading 91

Exposure on bench *Direction of the spray*

Figure 43 Exposure on the bench and direction of the spray

The images in figure 43 show that, the very few individuals that became exposed all sat on the part of the bench that is represented by a red patch. As the image shows, this a part of a bench that is situated on the eastern side of the fountain. We can see that the heading of the spray had a direction of 91° during that time. Therefore the spray of the fountain was also directed towards the east during the time that the agents became exposed when sitting on the bench. This means that people can become exposed to *E.coli* when they sit on the part of the bench at Americain situated on the eastern side of the fountain. Because only spending time on this part of the bench can lead to exposure, we can assume that the other parts of the benches are not located in the areas where the wind would be blowing. They can also be situated far enough from the fountain so that the spray could not reach them. As we know, only 2 visitors became exposed here. However, we could perhaps bring this number down to zero visitors by placing the benches further away from the fountain. This because that part of the bench would then be placed out of the exposure zone. In that case we would record zero visitors that became exposed on the benches at Americain. We can assume that if the benches are located far enough from the fountain, the benches are outside of the exposure zone and as a result the spray cannot reach the visitors.

8.5 Water management strategies

Lastly, we will consider the research question *"What is the impact of different management strategies on the exposure to E. coli?"*. To gain a better understanding of different water management strategies, we should first look at the factors that influence the quality of the water. In this model, the water quality of the fountain is determined by three elements. First of all the infection rate. This influences when the fountain can become infected. During the last experiments, the infection rate was set at 300 visitors, meaning that the fountain becomes infected after 300 people have visited the fountain. This threshold is "artificial". The underlying logic is that visitors produce garbage. Garbage attracts animals that feed on these leftovers. When animals (birds, rats etc) are attracted to the fountain area, they will also use the fountain water for bathing and drinking and can contribute to the infection of the water.

The second element that determines water quality is the number of visitors. If there are more visitors, the limit that is set by the infection rate is reached faster. Therefore when more people visit the fountain, the water will become infected much quicker. Section 8.2.1 and 8.3 already showed that when the number of visitors changes, the number of exposed visitors also changes.

Thirdly, how often the fountain is cleaned determines the water quality. During the last experiments the fountain was cleaned once a week. However, if the fountain is cleaned more frequently, the water of the fountain becomes clean again more often. This should result in less exposures.

This means that cleaning the fountain more often could be a useful management strategy. Therefore this is be the first water management strategy that will be analysed. To do this, two scenarios are compared. In the first scenario, the fountain is cleaned once a week. In the second scenario, the fountain is cleaned twice a week. To compare the results, the total number of exposed visitors are plotted over time for both scenarios. This graph is given in figure 44 below.

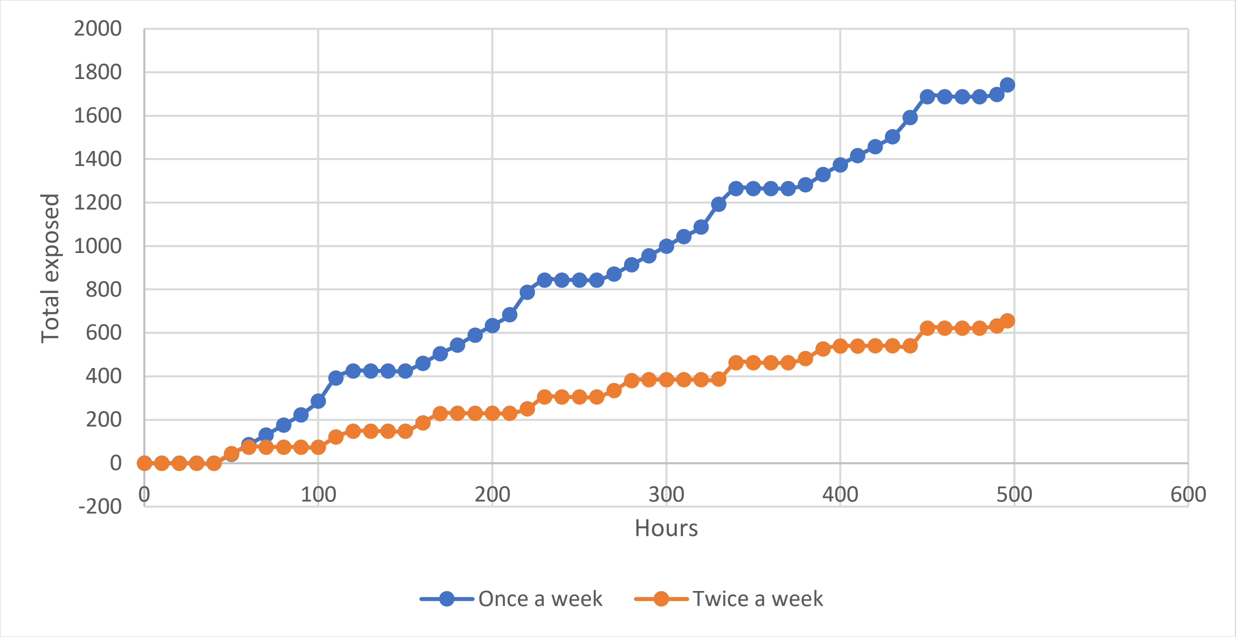


Figure 44 Total exposed at Frederiksplein with different cleaning frequencies

This graph provides the number of exposed visitors over time for both scenarios. It shows that when the fountain is cleaned more often, the total number of exposures decrease. When the fountain is cleaned once a week, there are 1743 exposed visitors after 496 hours. This is 51% of the total number of visitors. When the fountain is cleaned twice as many times (two times a week) there are only 663 (19%) exposed visitors after 496 hours. This means that by only cleaning the fountain twice as often, the total number of exposed visitors decreases with 62%. This shows that cleaning the fountain more often has a big impact on the total number of exposures.

However, in this model, the water quality is not only determined by how often the fountain is cleaned. Besides the cleaning frequency, the infection rate strongly determines the water quality. We will, therefore, compare the impact of different infection rates. We should expect that when we change the infection rate from 300 visitors to 600 visitors, the total number of exposed visitors will decline. Figure 45 shows a comparison between these two scenarios for Frederiksplein.

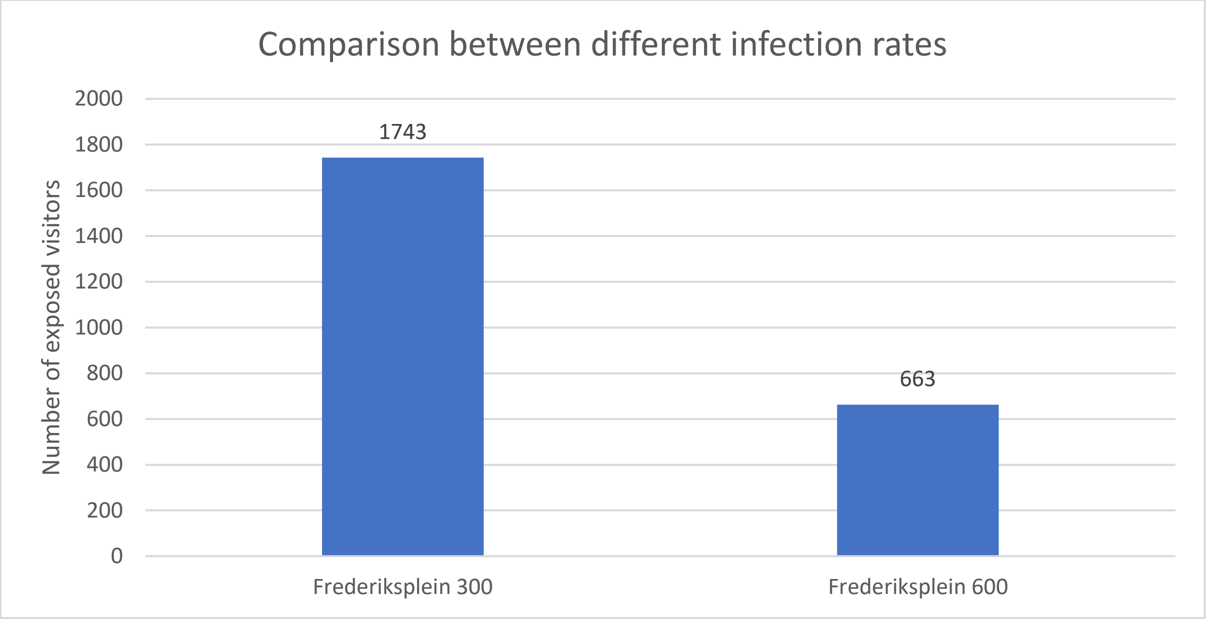


Figure 45 Comparison between different infection rates

The graph shows that when the infection rate is set at 300 visitors, there are 1743 (51%) exposed visitors. If the infection rate is set at 600 visitors, the total number of exposures decreases to 663 (19%) exposures. This means there is a clear decrease in exposures. A decline from 1743 to 663 (62%) means that we measure more than half the number of exposures. This also becomes clear when we plot these number of exposers over time and express the exposure as a percentage of the total number of visitors (figure 46).

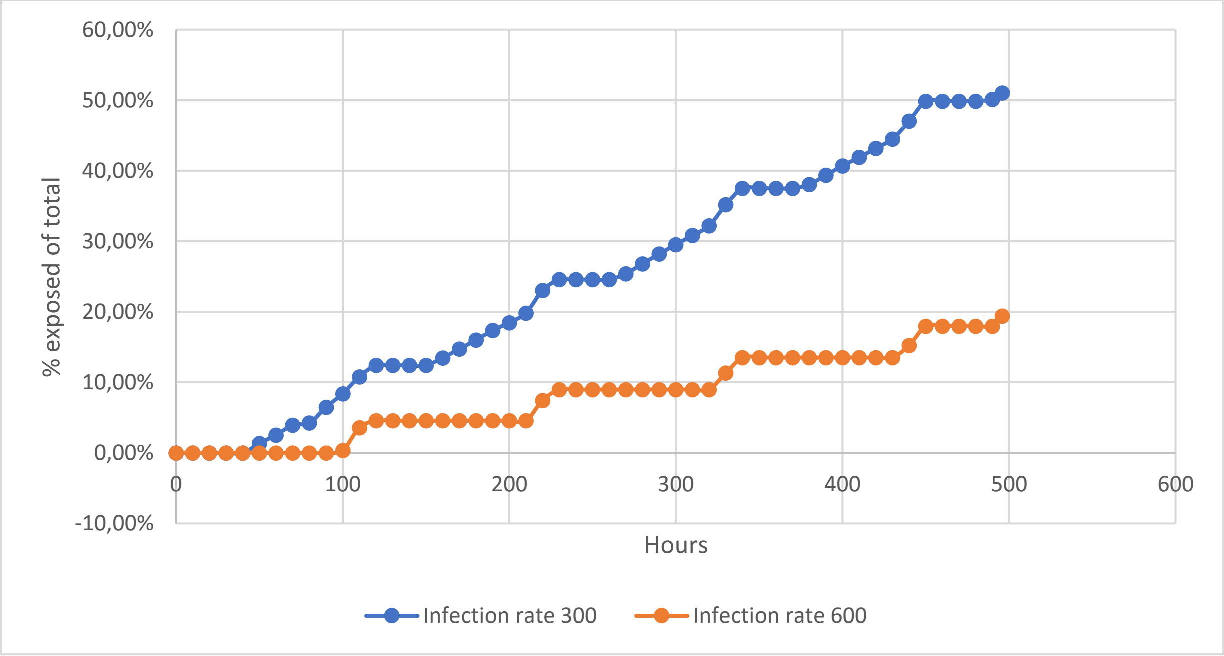


Figure 46 Accumulative infection rate over time expressed in % of total

Now we see that a similar pattern emerges as we have seen in the graph in figure 44. The difference in the number of exposures in this graph is caused by the fact that it will take longer for the water to become infected. Therefore the water of the fountain is relatively less often infected under these circumstances. If we compare figure 44 with figure 46, we see that doubling the infection rate from 300 to 600 generates a comparable result as cleaning twice as often. This means that a higher infection rate leads to fewer exposures, but cleaning the fountain more often has the same effect.

This indicates that influencing the infection rate could also be a useful water management strategy. However, manipulating this threshold, in reality, can be very difficult. First of all because the infection rate is an artificial threshold and merely provides a rough estimation based on assumptions. Secondly, changing this infection rate can be hard if not impossible in reality, since this would require different garbage or pest control policies. However, cleaning the fountain more often can be done much easier. The model shows that cleaning the fountain more often has a big impact on the number of exposures. Ensuring a better water quality can, therefore, lead to a sharp decrease in the number of exposed visitors. It could, therefore, be very useful to clean the fountain more frequently.

At last, as section 8.3 pointed out, limiting the number of visitors also leads to lesser exposures. The graph in figure 37, for instance, showed that the infection time is strongly influenced by the number of visitors. We also know that fewer visitors leads to fewer people that can interact with the fountain. Despite the fact that limiting the number of visitors can be a useful water management strategy the approach is not very realistic. Influencing the number of visitors means that the area should not always be accessible. This means that an area should be gated, or strictly monitored. Also, this approach goes beyond the goal of ensuring better water quality. By denying visitors access, the quality of the water is great but nobody will be able to enjoy it.

Sections 8.1 – 8.3 show that according to the model, visitors can become exposed to *E. coli* via fountain water. The model reveals that most exposures occur due to direct contact with fountain water. Even though very few visitors became exposed after sitting on a bench, the results shows that this is still is possible at Americain and Haarlemmerplein. However, these numbers are extremely low. Exposure is determined by a combination of multiple elements such as location of the benches, distance and angle of the water spray and the number of visitors. After comparing different locations we see that the position of the benches is therefore not the most important factor that influences the number of exposures. Since most visitors became exposed after direct contact it is more important to limit the number of visitors that go into a fountain or clean the fountain more often. If 1 in 9 exposures lead to illness (de Man et al., 2009), we can assume that 174 (5%) people became ill after visiting the fountain at Frederiksplein, 352 (4,6%) people became ill at Americain and 155 (2%) people became ill at Haarlemmerplein. However, this remains a rough estimation and is simply an indication provided by this model. By improving the water quality of the fountain, this model shows that we can limit the number of exposures. Cleaning the fountain more often could be a great measurement to ensure good water quality. This will then result in less illnesses, which could potentially improve the general public health of a city.

9. Conclusion

In this research, an Agent-Based Model was designed and implemented to test the possible exposure of visitors of fountains to the *E.coli* bacteria. The model includes two elements that are important in *E.coli* exposure:

1) The infection of the fountain water and

2) The exposure of the visitors

The model assumes that the infection level of the fountain is influenced by the number of visitors (via littering and garbage disposal) and the management strategies of the municipality (refreshing of the fountain water). In this model, several factors including wind speed and wind direction, the number of visitors and the spatial environment were taken into account. The model was tested using three fountain locations in Amsterdam: Frederiksplein, the Americain hotel and Haarlemmerplein. As no information was available on actual *E.coli* infections due to fountain visits, and of the water quality of the fountains, the research focusses on the possibility of exposure, rather than infection.

Before the actual experiments were conducted, a sensitivity analysis was performed. This sensitivity analyses revealed that the angle of spray of the water could influence the number of exposures, but the impact is very small. Therefore we can conclude that the angle of the spray does not determine the number of exposures to a great extent. On the contrary, the outcomes of the model were strongly influenced by the number of visitors. This because the model assumes that when more people visit the fountain, the fountain becomes infected quicker. As a result, more people interact with a fountain that is infected and this interaction occurs more often. This leads to more exposed visitors. The distance of the spray also proves to be an important parameter. The distance of the spray is determined by the daily windspeed. The model showed that under normal circumstances the spray can reach the benches. However, the number of exposed visitors on benches remain low.

The main objective of the research *"How can Agent-Based Modelling (ABM) be used to evaluate the health impact of faecal pathogens in fountains?"* was tested via three experiments (linked to the three research questions):

1. *"What role does the distance of the individual to the fountain play in the exposure process?"*

2. *"What is the role of the spatial environment in the exposure process?"*

3. *"What is the impact of different water management strategies on the exposure to E. coli?"*

Reflecting on the first experiment and research question, we see that visitors mainly become exposed by going into the fountain. People that sat on the benches rarely became exposed. In the first experiment we saw that 51% of the visitors at Frederiksplein became exposed to *E.coli* (1743 people). All of them had direct contact with the fountain and none of the exposed visitors became exposed while sitting on the bench.

For the second experiment, we compared the results of Frederiksplein, Americain and Haarlemmerplein. We did find exposure on benches at Americain and Haarlemmerplein, but this rarely occurred. At Americain, on average, 2 people (0,03%) per run became exposed after sitting on a bench. When this was tested with a wider angle (90°), there was an average of 5 people (0,065%) that became exposed after sitting on a bench. At Haarlemmerplein these averages were respectively 0.5 people and 2. This means that on average the number of exposures on benches was very low at all three locations. The number of visitors did influence the number of exposed visitors. More visitors leads to more exposures.

Results of the urban environment, related to research question 2, showed that people only became exposed on the part of the bench at Americain situated on the eastern part of the fountain. Exposure to *E.coli* was possible there because of the wind direction and the distance that the spray could covering. Placing these benches further away from the fountain could ensure that none of the visitors can became exposed here, because then the bench would not be situated in the exposure zone.

At last, we looked at different water management strategies. This model showed that improving water quality will lead to a lot less exposed visitors. Less exposed visitors leads to fewer illnesses. This means that improving the water quality can be an important instrument to limit the number of exposures to *E.coli* and can therefore potentially improve public health. There are different ways to improve water quality. The experiments showed that cleaning the fountain more often can be a very effective approach to do so. This strategy can be particularly useful because it can be implemented relatively easy in reality.

There are currently not many studies that focus on the health impact of faecal pathogens in fountain water. Because of this, there is still a lot of uncertainty about how *E.coli* in fountain water can affect our health. These uncertainties are also caused by the fact there are many different interrelated factors that can play a role in the way that people can be affected by *E.coli* in fountain water. However, this study does show that Agent-Based Modelling can be a very useful technique to analyse and evaluate the potential health impact of *E.coli* in fountain water. The research makes clear that Agent-Based Modelling can be used to incorporate multiple interconnected factors and combine them in one model to generate an outcome for different possible scenarios. By making use of the spatial environment, wind directions, windspeeds, positions of benches, numbers of visitors and human behaviour (going into the fountain or sitting next to it) this model demonstrates that we can evaluate the health impact of faecal pathogens in fountain water with ABM. These outcomes can be used to estimate the number of exposed visitors and the possibilities of becoming exposed to *E.coli* in different scenarios. The prognosis can be very useful to gain better insights into the potential health impact that *E.coli* in water can have. However, the outcome of the model remains a rough estimation based on several assumptions. Evaluating the potential health impact of faecal pathogens in fountain water with the use of this model can therefore always be improved.

10. Discussion and recommendations

One of the main limitations of the research was the lack of available data. To empirically ground this model, data will be needed on:

a. *E.coli* infections due to fountains. This could make it possible to compare the number of infections with the outcome of the model. However, there is much uncertainty about how *E.coli* affects people. This because empirical studies find it hard to determine if someone fell ill due to *E.coli* or something else. Also, the number of people that go to the doctor when ill might not be the same as the number of people that actually become ill. Symptoms are often not severe, so people might not always mention it.
b. *E.coli* in fountain water. Comparing the results with other studies regarding pathogens in fountain water can be helpful to better calibrate the model and verify the results of this study. Particularly more information on the concentration of *E.coli* could improve the model.
c. Number of visitors. Monitoring this more intensely or having empirical data on this helps to have a better idea of the real situation.
d. The angle of the spray. Therefore it is made possible to change the angle in the model with a slider. However, we are not certain of the real angle of the spray and how this may vary. The angle may also very well depend on a subset of other factors that were not taken into account.
e. Data on the management actions taken by the municipality.

A second limitation of the research was lack of information on the role that animals play in the (re) infection of fountains. For this model, the assumption was made that infection of fountains is due to animals. However, no real proof of this is provided.

Although the model has been carefully designed and implemented, there are some limitations to the model that need to be considered as well. First of all, in this research the height of the fountains was not explicitly modelled. The height of the fountain determines the distance of the spray. Incorporating the height of the fountain could therefore improve the model. Secondly, the effects of a microclimate are not taken into account in this study. This could have a strong impact on the way wind flows or where people might walk. The position of the fountain in relation to buildings will influence the speed and direction of the wind. When creating a three-dimensional model these factors would have been implemented.

This brings us to the recommendations. By improving this model on the limitations mentioned above, the ABM can be a useful tool for municipalities or other organizations to perform a health risk analysis of urban water bodies. Where this study mainly addresses the possibility of generating a model that can evaluate the health impact of *E.coli* in fountain water, future studies can elaborate more on this. Such studies could focus on different ways to prevent exposure, but could also go deeper on actual infection of people. The latter can be done more accurately when more empirical data is available.

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Appendix

Appendix A: Model Frederiksplein

```
extensions [ gis csv]

breed [pedestrians pedestrian]
breed [winds wind]

globals [windd windsp totalgrey totalexposed counting2 counting rest_location
distance_nearest_fountain pedestrian_speed exit_location exit_location2
exit_location3 exit_location4 exit_location5 exit_location6 exit_location7
last_sprout_tick]
patches-own [Fountain-infected1 rest-value distance-value exit-value exit-value2
exit-value3 exit-value4 exit-value5 exit-value6 exit-value7]
pedestrians-own [spraytime turtlecounter exposed phase initial-time time exitpoint]

to load
  ca
  file-close-all
  file-open "JulyDirectionSpeed.csv"
  reset-ticks

  set distance_nearest_fountain gis:load-dataset "CostDistanceRob.asc"
;Costdistance file of the fountain
  gis:set-world-envelope-ds gis:envelope-of distance_nearest_fountain ;Make the
environment fit the cost distance file
  gis:apply-raster distance_nearest_fountain distance-value ;distance-value is
distance to fontian (fountain has a value of 0)
  ask patches with [distance-value = 0]
  [set pcolor yellow]
  ask patches with [distance-value > 1000]
  [set pcolor white]

  set exit_location gis:load-dataset "CDExit1.asc" ;cost-distance file exit 1
  gis:set-world-envelope-ds gis:envelope-of exit_location
  gis:apply-raster exit_location exit-value
  ask patches with [exit-value = 0]
  [set pcolor blue] ;exit1 has exit-value 0 is blue

  set exit_location2 gis:load-dataset "CDExit2.asc" ; same as cost-distance exit 1
  gis:set-world-envelope-ds gis:envelope-of exit_location2
  gis:apply-raster exit_location2 exit-value2
  ask patches with [exit-value2 = 0]
  [set pcolor blue]

  set exit_location3 gis:load-dataset "CDExit3.asc"
  gis:set-world-envelope-ds gis:envelope-of exit_location3
  gis:apply-raster exit_location3 exit-value3
  ask patches with [exit-value3 = 0]
  [set pcolor blue]

  set exit_location4 gis:load-dataset "CDExit4.asc"
  gis:apply-raster exit_location4 exit-value4
  ask patches with [exit-value4 = 0]
  [set pcolor blue]

  set exit_location5 gis:load-dataset "CDExit5.asc"
  gis:apply-raster exit_location5 exit-value5
  ask patches with [exit-value5 = 0]
  [set pcolor blue]

  set exit_location6 gis:load-dataset "CDExit6.asc"
  gis:apply-raster exit_location6 exit-value6
  ask patches with [exit-value6 = 0]
  [set pcolor blue]
```

```
  set exit_location7 gis:load-dataset "CDExit7.asc"
  gis:apply-raster exit_location7 exit-value7
  ask patches with [exit-value7 = 0]
  [set pcolor blue]

  set rest_location gis:load-dataset "Restlocation6.asc" ;Loading rest location
raster
  gis:set-world-envelope-ds gis:envelope-of rest_location
  gis:apply-raster rest_location rest-value
  ask patches with [rest-value = 1]
  [set pcolor brown]

  set last_sprout_tick 0
  set counting 0
  set counting2 0
  set totalexposed 0
  set totalgrey 0


  create-winds 1
  [set color yellow
   setxy 127 43]

end
;-----------------------------------Sprouting pedestrians-------------------------
-----------------------

to go

  ask (patch-set patch 5 75 patch 8 10 patch 240 55 patch 238 134 patch 188 151
patch 88 152 patch 3 107)
  [
    ifelse ticks > 0 and ticks < 40279
    or ticks > 241674 and ticks < 322232
    or ticks > 523627 and ticks < 604185
    or ticks > 805580 and ticks < 886138
    or ticks > 1087533 and ticks < 1168091

  [if ticks > last_sprout_tick + 212; Makes the model keep on sprouting
pedestrians. I want around 4 agents per hour, so 4 agents every 2517 ticks. 2517/4
= 630. Otherwise constant groups of 4 every hour
    [sprout-pedestrians 1
   [
        set last_sprout_tick ticks
        set exposed false ; nobody is exposed yet
        set phase "walking to fountain"
        set initial-time random 3776 ; waiting time of the agent. Maximum of 3376
ticks = 90 minutes
        set size 5
        set shape "person"
        set color blue
        fd 1 ; to prevent agents from dying when they are sprouted ---> exit [die]
        set pedestrian_speed 1 ;pedestrian speed = 1,4 meter per tick. Cell size is
2 meters,so agent moves 2 meter per tick, which makes 1 tick 1.43 seconds.
        set counting counting + 1
        set counting2 counting2 + 1
        set turtlecounter counting ;turtlecounter keeps track of total amount of
sprouted turtles
        set spraytime 0
  ]]]
    [if ticks > last_sprout_tick + 516; Makes the model keep on sprouting
pedestrians. I want around 4 agents per hour, so 4 agents every 2517 ticks. 2517/4
= 630. Otherwise constant groups of 4 every hour
    [sprout-pedestrians 1
   [
        set last_sprout_tick ticks
        set exposed false ; nobody is exposed yet
        set phase "walking to fountain"
```

```
        set initial-time random 3776 ; waiting time of the agent. Maximum of 3376
ticks = 90 minutes
        set size 5
        set shape "person"
        set color blue
        fd 1 ; to prevent agents from dying when they are sprouted ---> exit [die]
        set pedestrian_speed 1 ;pedestrian speed = 1,4 meter per tick. Cell size is
2 meters,so agent moves 2 meter per tick, which makes 1 tick 1.43 seconds.
        set counting counting + 1
        set counting2 counting2 + 1
        set turtlecounter counting ;turtlecounter keeps track of total amount of
sprouted turtles
        set spraytime 0
  ]]]]



;----------------------------------Pedestrian directions---------------------------
-------------------------
     ask pedestrians [
    let d min-one-of neighbors [distance-value] ;d is patch with lowest distance-
value
    let u min-one-of neighbors [exit-value] ;u is patch with lowest exit-value
(this is exit 1)
    let u2 min-one-of neighbors [exit-value2] ;u2 is patch with lowest exit-value2
(this is exit 2)
    let u3 min-one-of neighbors [exit-value3] ;""
    let u4 min-one-of neighbors [exit-value4] ;""
    let u5 min-one-of neighbors [exit-value5] ;""
    let u6 min-one-of neighbors [exit-value6] ;""
    let u7 min-one-of neighbors [exit-value7] ;""

;-----------------------------------Fountain infection-----------------------------
----------------------------
    if ticks mod 281955 = 0
    [set counting 0]

  ifelse turtlecounter > infection_rate ;if there have been more than 300 visitors,
fountain becomes infected
  [set Fountain-infected1 "yes"]
  [set Fountain-infected1 "no"]


;----------------------------------Pedestrian infection----------------------------
--------------------------------

    if phase = "walking to fountain"
    [face d fd pedestrian_speed] ;when phase = walking to fountain agent moves to d
to reach fountain

    if distance-value = 0
    [set phase "walking to exit" ;after reaching fountain phase turns to walking to
exit
     if initial-time < 2518 ; This is about 2/3 of the agents. The group with
avarage/longer waiting time. They will move to the benches
      [move-to one-of patches with [rest-value = 1]]]

    if distance-value = 0
    [set time time + 1 ;agents with a shorter waiting time 1/3 do not move to
benches.
      if time > 3776 ;after 3776 the agent moves away. This is '90 minutes', but
agent already has intial time. Time - initial time = time agent has to wait before
it moves.
      [set exitpoint one-of (range 1 8)] ;select exit point
      if time < 3776
      [set time time + 1]] ;agent stays put until they reach the waiting time limit
      if time - initial-time > 336 and Fountain-infected1 = "yes"; Calculates the
time they spent in the fountain. If this exceeds 336 (8 min) AND fountain is
```

```
infected, agent becomes exposed
   [set exposed true]

    if rest-value = 1 ; this is for agents that wait on the benches
      [set time time + 1
      if time > 3776
      [set exitpoint one-of (range 1 8)] ; agent selects exitpoint
     if time < 3776 ;time - initial time is the time that agent waits. Time starts
counting from initial time.
        [set time time + 1]] ;agent stays put until they reach the waiting time
limit.
    if time - initial-time > 1384 and Fountain-infected1 = "yes" and color = grey;
calculates the time they spent on the benches. If this exceeds 1384 (33min) AND
fountain is infected, agent becomes exposed.
      [set exposed true]

    if exposed = true and [pcolor] of patch-ahead 1 = blue
    [set totalexposed totalexposed + 1]

    if color = grey and exposed = true and [pcolor] of patch-ahead 1 = blue
    [set totalgrey totalgrey + 1]

    if exitpoint = 1 and time > 3776
    [face u fd pedestrian_speed] ;if agent chose exitpoint 1, follow costdistance
raster of exitpoint 1
    if exitpoint = 2 and time > 3776
    [face u2 fd pedestrian_speed] ;if agent chose exitpoint 2, follow costdistance
raster of exitpoint 2 etc.
    if exitpoint = 3 and time > 3776
    [face u3 fd pedestrian_speed] ;""
    if exitpoint = 4 and time > 3776
    [face u4 fd pedestrian_speed] ;""
    if exitpoint = 5 and time > 3776
    [face u5 fd pedestrian_speed] ;""
    if exitpoint = 6 and time > 3776
    [face u6 fd pedestrian_speed] ;""
    if exitpoint = 7 and time > 3776
    [face u7 fd pedestrian_speed] ;""

    if pcolor = blue
    [die]
    if spraytime > 50
    [set color grey]]


;--------Winddata-----------
  file-open "JulyDirectionSpeed.csv"
  if ticks = 1248649 [stop]
  if ticks mod 40279 = 0
  [
    set windd item 0 csv:from-row file-read-line
    set windsp item 0 csv:from-row file-read-line
  ]

  ask winds
  [
   set heading windd
    ask pedestrians with [time - initial-time > 1384] in-cone ((windsp * 0.9) / 2)
vision-angle
      [set spraytime spraytime + 1]
  ]



;------Output
  file-open "Experiment1.txt"
  ask pedestrians
 [
```

```
    file-write last [counting2] of pedestrians file-write last [totalexposed] of
pedestrians file-write last [totalgrey] of pedestrians file-write (last
[totalexposed] of pedestrians - last [totalgrey] of pedestrians) file-write ticks
  ]
  ;records the following: total no. visitors, total no. exposed, total no. exposed
on bench, total no. exposed in fountain, ticks
  tick

  ;file-close

end
```

Appendix B: Model Americain

```
extensions [ gis csv]

breed [pedestrians pedestrian]
breed [winds wind]

globals [windd windsp totalgrey totalexposed counting2 counting
rest_location distance_nearest_fountain pedestrian_speed exit_location
exit_location2 exit_location3 exit_location4 last_sprout_tick]
patches-own [Fountain-infected1 rest-value distance-value exit-value exit-
value2 exit-value3 exit-value4]
pedestrians-own [spraytime turtlecounter exposed phase initial-time time
exitpoint]

to load
  ca
  file-close-all
  file-open "JulyDirectionSpeed.csv"
  reset-ticks

  set distance_nearest_fountain gis:load-dataset
"CostDistanceAmericain.asc" ;Costdistance file of the fountain
  gis:set-world-envelope-ds gis:envelope-of distance_nearest_fountain ;Make
the environment fit the cost distance file
  gis:apply-raster distance_nearest_fountain distance-value ;distance-value
is distance to fontian (fountain has a value of 0)
  ask patches with [distance-value = 0]
  [set pcolor yellow]
  ask patches with [distance-value > 1000]
  [set pcolor white]

  set exit_location gis:load-dataset "CDExitAme1.asc" ;cost-distance file
exit 1
  gis:set-world-envelope-ds gis:envelope-of exit_location
  gis:apply-raster exit_location exit-value
  ask patches with [exit-value = 0]
  [set pcolor blue] ;exit1 has exit-value 0 is blue

  set exit_location2 gis:load-dataset "CDExitAme2.asc" ; same as cost-
distance exit 1
  gis:set-world-envelope-ds gis:envelope-of exit_location2
  gis:apply-raster exit_location2 exit-value2
  ask patches with [exit-value2 = 0]
  [set pcolor blue]

  set exit_location3 gis:load-dataset "CDExitAme3.asc"
  gis:set-world-envelope-ds gis:envelope-of exit_location3
  gis:apply-raster exit_location3 exit-value3
  ask patches with [exit-value3 = 0]
```

```
  [set pcolor blue]

  set exit_location4 gis:load-dataset "CDExitAme4.asc"
  gis:apply-raster exit_location4 exit-value4
  ask patches with [exit-value4 = 0]
  [set pcolor blue]

  set rest_location gis:load-dataset "RestlocationAmericain.asc" ;Loading
rest location raster
  gis:set-world-envelope-ds gis:envelope-of rest_location
  gis:apply-raster rest_location rest-value
  ask patches with [rest-value = 1]
  [set pcolor brown]

  set last_sprout_tick 0
  set counting 0
  set counting2 0
  set totalexposed 0
  set totalgrey 0


  create-winds 1
  [set color yellow
   setxy 0 -4]

end
;------------------------------------Sprouting pedestrians-----------------
-------------------------------

to go

  ask (patch-set patch -53 -54 patch -22 -52 patch 65 6 patch -22 53)
  [
    ifelse ticks > 0 and ticks < 40279
    or ticks > 241674 and ticks < 322232
    or ticks > 523627 and ticks < 604185
    or ticks > 805580 and ticks < 886138
    or ticks > 1087533 and ticks < 1168091

  [if ticks > last_sprout_tick + 94; Makes the model keep on sprouting
pedestrians. I want around 4 agents per hour, so 4 agents every 2517 ticks.
2517/4 = 630. Otherwise constant groups of 4 every hour
    [sprout-pedestrians 1
   [
        set last_sprout_tick ticks
        set exposed false ; nobody is exposed yet
        set phase "walking to fountain"
        set initial-time random 3776 ; waiting time of the agent. Maximum
of 3376 ticks = 90 minutes
        set size 5
        set shape "person"
        set color blue
        fd 1 ; to prevent agents from dying when they are sprouted --->
exit [die]
        set pedestrian_speed 1 ;pedestrian speed = 1,4 meter per tick. Cell
size is 2 meters,so agent moves 2 meter per tick, which makes 1 tick 1.43
seconds.
        set counting counting + 1
        set counting2 counting2 + 1
        set turtlecounter counting ;turtlecounter keeps track of total
amount of sprouted turtles
```

```
        set spraytime 0
  ]]]
    [if ticks > last_sprout_tick + 229; Makes the model keep on sprouting
pedestrians. I want around 4 agents per hour, so 4 agents every 2517 ticks.
2517/4 = 630. Otherwise constant groups of 4 every hour
    [sprout-pedestrians 1
   [
        set last_sprout_tick ticks
        set exposed false ; nobody is exposed yet
        set phase "walking to fountain"
        set initial-time random 3776 ; waiting time of the agent. Maximum
of 3376 ticks = 90 minutes
        set size 5
        set shape "person"
        set color blue
        fd 1 ; to prevent agents from dying when they are sprouted --->
exit [die]
        set pedestrian_speed 1 ;pedestrian speed = 1,4 meter per tick. Cell
size is 2 meters,so agent moves 2 meter per tick, which makes 1 tick 1.43
seconds.
        set counting counting + 1
        set counting2 counting2 + 1
        set turtlecounter counting ;turtlecounter keeps track of total
amount of sprouted turtles
        set spraytime 0
  ]]]]



;----------------------------------Pedestrian directions-------------------
---------------------------------
     ask pedestrians [
    let d min-one-of neighbors [distance-value] ;d is patch with lowest
distance-value
    let u min-one-of neighbors [exit-value] ;u is patch with lowest exit-
value (this is exit 1)
    let u2 min-one-of neighbors [exit-value2] ;u2 is patch with lowest
exit-value2 (this is exit 2)
    let u3 min-one-of neighbors [exit-value3] ;""
    let u4 min-one-of neighbors [exit-value4] ;""
;-----------------------------------Fountain infection---------------------
------------------------------------
    if ticks mod 281955 = 0
    [set counting 0]

  ifelse turtlecounter > infection_rate ;if there have been more than 300
visitors, fountain becomes infected
  [set Fountain-infected1 "yes"]
  [set Fountain-infected1 "no"]


;----------------------------------Pedestrian infection--------------------
----------------------------------------

    if phase = "walking to fountain"
    [face d fd pedestrian_speed] ;when phase = walking to fountain agent
moves to d to reach fountain

    if distance-value = 0
    [set phase "walking to exit" ;after reaching fountain phase turns to
walking to exit
```

```
     if initial-time < 2518 ; This is about 2/3 of the agents. The group
with avarage/longer waiting time. They will move to the benches
      [move-to one-of patches with [rest-value = 1]]]

    if distance-value = 0
    [set time time + 1 ;agents with a shorter waiting time 1/3 do not move
to benches.
      if time > 3776 ;after 3776 the agent moves away. This is '90
minutes', but agent already has intial time. Time - initial time = time
agent has to wait before it moves.
      [set exitpoint one-of (range 1 5)] ;select exit point
      if time < 3776
      [set time time + 1]] ;agent stays put until they reach the waiting
time limit
      if time - initial-time > 336 and Fountain-infected1 = "yes";
Calculates the time they spent in the fountain. If this exceeds 336 (8 min)
AND fountain is infected, agent becomes exposed
   [set exposed true]

    if rest-value = 1 ; this is for agents that wait on the benches
      [set time time + 1
      if time > 3776
      [set exitpoint one-of (range 1 5)] ; agent selects exitpoint
     if time < 3776 ;time - initial time is the time that agent waits. Time
starts counting from initial time.
        [set time time + 1]] ;agent stays put until they reach the waiting
time limit.
    if time - initial-time > 1384 and Fountain-infected1 = "yes" and color
= grey; calculates the time they spent on the benches. If this exceeds 1384
(33min) AND fountain is infected, agent becomes exposed.
      [set exposed true]

    if exposed = true and [pcolor] of patch-ahead 1 = blue
    [set totalexposed totalexposed + 1]

    if color = grey and exposed = true and [pcolor] of patch-ahead 1 = blue
    [set totalgrey totalgrey + 1]

    if exitpoint = 1 and time > 3776
    [face u fd pedestrian_speed] ;if agent chose exitpoint 1, follow
costdistance raster of exitpoint 1
    if exitpoint = 2 and time > 3776
    [face u2 fd pedestrian_speed] ;if agent chose exitpoint 2, follow
costdistance raster of exitpoint 2 etc.
    if exitpoint = 3 and time > 3776
    [face u3 fd pedestrian_speed] ;""
    if exitpoint = 4 and time > 3776
    [face u4 fd pedestrian_speed] ;""

    if pcolor = blue
    [die]
    if spraytime > 50
    [set color grey]]


;--------Winddata-----------
  file-open "JulyDirectionSpeed.csv"
  if ticks = 1248649 [stop]
  if ticks mod 40279 = 0
  [
    set windd item 0 csv:from-row file-read-line
```

```
    set windsp item 0 csv:from-row file-read-line
  ]

  ask winds
  [
   set heading windd
    ask pedestrians with [time - initial-time > 1384] in-cone ((windsp *
0.9) / 2) vision-angle
      [set spraytime spraytime + 1]
  ]



;------Output
  file-open "Output30.txt"
  ask pedestrians
 [
    file-write last [counting2] of pedestrians file-write last
[totalexposed] of pedestrians file-write last [totalgrey] of pedestrians
file-write (last [totalexposed] of pedestrians - last [totalgrey] of
pedestrians) file-write ticks
  ]
  ;records the following: total no. visitors, total no. exposed, total no.
exposed on bench, total no. exposed in fountain, ticks
  tick

  ;file-close

end
```

Appendix C: Model Haarlemmerplein

```
extensions [ gis csv]

breed [pedestrians pedestrian]
breed [winds wind]

globals [windd windsp totalgrey totalexposed counting2 counting
rest_location distance_nearest_fountain pedestrian_speed exit_location
exit_location2 exit_location3 exit_location4 exit_location5 exit_location6
last_sprout_tick]
patches-own [Fountain-infected1 rest-value distance-value exit-value exit-
value2 exit-value3 exit-value4 exit-value5 exit-value6]
pedestrians-own [spraytime turtlecounter exposed phase initial-time time
exitpoint]

to load
  ca
  file-close-all
  file-open "JulyDirectionSpeed.csv"
  reset-ticks

  set distance_nearest_fountain gis:load-dataset "CostDistanceHaarlem1.asc"
;Costdistance file of the fountain
  gis:set-world-envelope-ds gis:envelope-of distance_nearest_fountain ;Make
the environment fit the cost distance file
  gis:apply-raster distance_nearest_fountain distance-value ;distance-value
is distance to fontian (fountain has a value of 0)
  ask patches with [distance-value = 0]
  [set pcolor yellow]
  ask patches with [distance-value > 1000]
  [set pcolor white]
```

```
  set exit_location gis:load-dataset "CDExitHH1.asc" ;cost-distance file
exit 1
  gis:set-world-envelope-ds gis:envelope-of exit_location
  gis:apply-raster exit_location exit-value
  ask patches with [exit-value = 0]
  [set pcolor blue] ;exit1 has exit-value 0 is blue

  set exit_location2 gis:load-dataset "CDExitH2.asc" ; same as cost-
distance exit 1
  gis:set-world-envelope-ds gis:envelope-of exit_location2
  gis:apply-raster exit_location2 exit-value2
  ask patches with [exit-value2 = 0]
  [set pcolor blue]

  set exit_location3 gis:load-dataset "CDExitHH3.asc"
  gis:set-world-envelope-ds gis:envelope-of exit_location3
  gis:apply-raster exit_location3 exit-value3
  ask patches with [exit-value3 = 0]
  [set pcolor blue]

  set exit_location4 gis:load-dataset "CDExitH4.asc"
  gis:apply-raster exit_location4 exit-value4
  ask patches with [exit-value4 = 0]
  [set pcolor blue]

  set exit_location5 gis:load-dataset "CDExitH5.asc"
  gis:apply-raster exit_location5 exit-value5
  ask patches with [exit-value5 = 0]
  [set pcolor blue]

  set exit_location6 gis:load-dataset "CDExitHH6.asc"
  gis:apply-raster exit_location6 exit-value6
  ask patches with [exit-value6 = 0]
  [set pcolor blue]

  set rest_location gis:load-dataset "RestlocationHaarlemmerplein.asc"
;Loading rest location raster
  gis:set-world-envelope-ds gis:envelope-of rest_location
  gis:apply-raster rest_location rest-value
  ask patches with [rest-value = 1]
  [set pcolor brown]

  set last_sprout_tick 0
  set counting 0
  set counting2 0
  set totalexposed 0
  set totalgrey 0


  create-winds 1
  [set color yellow
   setxy 11 -6]

end
;------------------------------------Sprouting pedestrians-----------------
-------------------------------

to go

  ask (patch-set patch -59 -32 patch 11 -59 patch 59 -28 patch 58 -16 patch
9 59 patch -26 59)
```

```
 [
  ifelse ticks > 0 and ticks < 40279
  or ticks > 241674 and ticks < 322232
  or ticks > 523627 and ticks < 604185
  or ticks > 805580 and ticks < 886138
  or ticks > 1087533 and ticks < 1168091

 [if ticks > last_sprout_tick + 94; Makes the model keep on sprouting
pedestrians. I want around 4 agents per hour, so 4 agents every 2517 ticks.
2517/4 = 630. Otherwise constant groups of 4 every hour
  [sprout-pedestrians 1
  [
    set last_sprout_tick ticks
    set exposed false ; nobody is exposed yet
    set phase "walking to fountain"
    set initial-time random 3776 ; waiting time of the agent. Maximum
of 3376 ticks = 90 minutes
    set size 5
    set shape "person"
    set color blue
    fd 1 ; to prevent agents from dying when they are sprouted --->
exit [die]
    set pedestrian_speed 1 ;pedestrian speed = 1,4 meter per tick. Cell
size is 2 meters,so agent moves 2 meter per tick, which makes 1 tick 1.43
seconds.
    set counting counting + 1
    set counting2 counting2 + 1
    set turtlecounter counting ;turtlecounter keeps track of total
amount of sprouted turtles
    set spraytime 0
 ]]]
  [if ticks > last_sprout_tick + 229; Makes the model keep on sprouting
pedestrians. I want around 4 agents per hour, so 4 agents every 2517 ticks.
2517/4 = 630. Otherwise constant groups of 4 every hour
  [sprout-pedestrians 1
  [
    set last_sprout_tick ticks
    set exposed false ; nobody is exposed yet
    set phase "walking to fountain"
    set initial-time random 3776 ; waiting time of the agent. Maximum
of 3376 ticks = 90 minutes
    set size 5
    set shape "person"
    set color blue
    fd 1 ; to prevent agents from dying when they are sprouted --->
exit [die]
    set pedestrian_speed 1 ;pedestrian speed = 1,4 meter per tick. Cell
size is 2 meters,so agent moves 2 meter per tick, which makes 1 tick 1.43
seconds.
    set counting counting + 1
    set counting2 counting2 + 1
    set turtlecounter counting ;turtlecounter keeps track of total
amount of sprouted turtles
    set spraytime 0
 ]]]]



;----------------------------------Pedestrian directions------------------
---------------------------------
   ask pedestrians [
```

```
    let d min-one-of neighbors [distance-value] ;d is patch with lowest
distance-value
    let u min-one-of neighbors [exit-value] ;u is patch with lowest exit-
value (this is exit 1)
    let u2 min-one-of neighbors [exit-value2] ;u2 is patch with lowest
exit-value2 (this is exit 2)
    let u3 min-one-of neighbors [exit-value3] ;""
    let u4 min-one-of neighbors [exit-value4] ;""
    let u5 min-one-of neighbors [exit-value5] ;""
    let u6 min-one-of neighbors [exit-value6] ;""

;-----------------------------------Fountain infection---------------------
------------------------------------
    if ticks mod 281955 = 0
    [set counting 0]

  ifelse turtlecounter > infection_rate ;if there have been more than 300
visitors, fountain becomes infected
  [set Fountain-infected1 "yes"]
  [set Fountain-infected1 "no"]


;----------------------------------Pedestrian infection--------------------
----------------------------------------

    if phase = "walking to fountain"
    [face d fd pedestrian_speed] ;when phase = walking to fountain agent
moves to d to reach fountain

    if distance-value = 0
    [set phase "walking to exit" ;after reaching fountain phase turns to
walking to exit
     if initial-time < 2518 ; This is about 2/3 of the agents. The group
with avarage/longer waiting time. They will move to the benches
      [move-to one-of patches with [rest-value = 1]]]

    if distance-value = 0
    [set time time + 1 ;agents with a shorter waiting time 1/3 do not move
to benches.
      if time > 3776 ;after 3776 the agent moves away. This is '90
minutes', but agent already has intial time. Time - initial time = time
agent has to wait before it moves.
      [set exitpoint one-of (range 1 7)] ;select exit point
      if time < 3776
      [set time time + 1]] ;agent stays put until they reach the waiting
time limit
      if time - initial-time > 336 and Fountain-infected1 = "yes";
Calculates the time they spent in the fountain. If this exceeds 336 (8 min)
AND fountain is infected, agent becomes exposed
   [set exposed true]

    if rest-value = 1 ; this is for agents that wait on the benches
      [set time time + 1
      if time > 3776
      [set exitpoint one-of (range 1 7)] ; agent selects exitpoint
     if time < 3776 ;time - initial time is the time that agent waits. Time
starts counting from initial time.
        [set time time + 1]] ;agent stays put until they reach the waiting
time limit.
    if time - initial-time > 1384 and Fountain-infected1 = "yes" and color
= grey; calculates the time they spent on the benches. If this exceeds 1384
```

```
(33min) AND fountain is infected, agent becomes exposed.
      [set exposed true]

    if exposed = true and [pcolor] of patch-ahead 1 = blue
    [set totalexposed totalexposed + 1]

    if color = grey and exposed = true and [pcolor] of patch-ahead 1 = blue
    [set totalgrey totalgrey + 1]

    if exitpoint = 1 and time > 3776
    [face u fd pedestrian_speed] ;if agent chose exitpoint 1, follow
costdistance raster of exitpoint 1
    if exitpoint = 2 and time > 3776
    [face u2 fd pedestrian_speed] ;if agent chose exitpoint 2, follow
costdistance raster of exitpoint 2 etc.
    if exitpoint = 3 and time > 3776
    [face u3 fd pedestrian_speed] ;""
    if exitpoint = 4 and time > 3776
    [face u4 fd pedestrian_speed] ;""
    if exitpoint = 5 and time > 3776
    [face u5 fd pedestrian_speed] ;""
    if exitpoint = 6 and time > 3776
    [face u6 fd pedestrian_speed] ;""

    if pcolor = blue
    [die]
    if spraytime > 50
    [set color grey]]


;--------Winddata-----------
  file-open "JulyDirectionSpeed.csv"
  if ticks = 1248649 [stop]
  if ticks mod 40279 = 0
  [
    set windd item 0 csv:from-row file-read-line
    set windsp item 0 csv:from-row file-read-line
  ]

  ask winds
  [
   set heading windd
    ask pedestrians with [time - initial-time > 1384] in-cone ((windsp *
0.9) / 2) vision-angle
      [set spraytime spraytime + 1]
  ]



;------Output
  file-open "Output29.txt"
  ask pedestrians
 [
    file-write last [counting2] of pedestrians file-write last
[totalexposed] of pedestrians file-write last [totalgrey] of pedestrians
file-write (last [totalexposed] of pedestrians - last [totalgrey] of
pedestrians) file-write ticks
  ]
  ;records the following: total no. visitors, total no. exposed, total no.
exposed on bench, total no. exposed in fountain, ticks
  tick
```

```
  ;file-close
end
```