Quantitative Microbial Risk Assessment of **Pseudomonas aeruginosa** in Municipal Swimming Pools: A Case Study from Patras, Greece

Authors:
A. Palaiologou, M. Athanasiou, A. Vantarakis
Affiliation:
Lab of Public Health, Epidemiology and Quality of Life

Introduction

Swimming pools can be potential **microbial risk sources** due to high user load at they are widely used in recreational facilities

Pseudomonas aeruginosa → opportunistic pathogen linked to **ear, skin and respiratory infections**
WHO & EPA set acceptable infection risk at **1×10^{-4} per exposure**
Normally safe under regulations but lapses in disinfection or overcrowding can raise risk.
P. aeruginosa is resilient → key target organism in QMRA studies.

Objectives

Estimate infection risk from P. aeruginosa in four municipal swimming pools
Assess influence of water quality parameters (pH, chlorine, alkalinity, temperature)
Identify key risk drivers through sensitivity analysis

Methodology

Case study: 4 municipal pools (3 indoor, 1 outdoor), 2022–2025

Microbial indicators: E. coli, total coliforms, staphylococci, aerobic bacteria, P. aeruginosa

Steps of QMRA:

- **Exposure assessment** – water renewal, swimmers/hour, exposure duration
- **Dose–response model** – exponential function for P. aeruginosa
- **Monte Carlo simulations** (10,000 runs) using ModelRisk®
- **Adjustment / normalization factors**:(1+|pH−7.2|), (1−Cl/3), (1+|Alk−100|/100), (1+(Temp−25)/10), (Time/30), (1+Bathers/100)→ **Integrate physicochemical conditions into infection risk estimates**

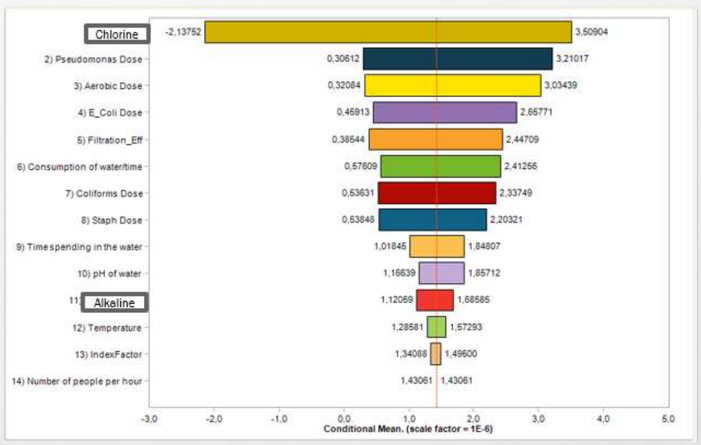
Results

Site 1

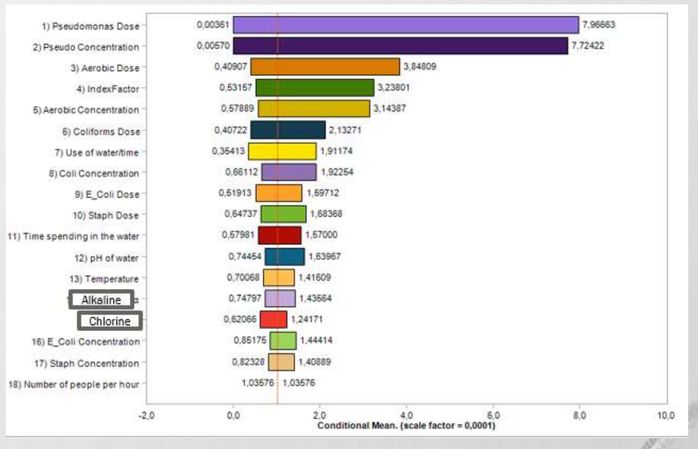
Mean	1,4176E-06
Minimum	-1,94454E-05
Maximum	1,59683E-05
N. Of Errors	0
N. Of Filtered	0
St. dev.	2,21329E-06
Variance	4,89864E-12
Risk ratio	4,292060214
CofV	1,561292709

Site 1
Pool A (outdoor)
No simulations > threshold (1×10^{-4})
Classification: Safe

Pool A

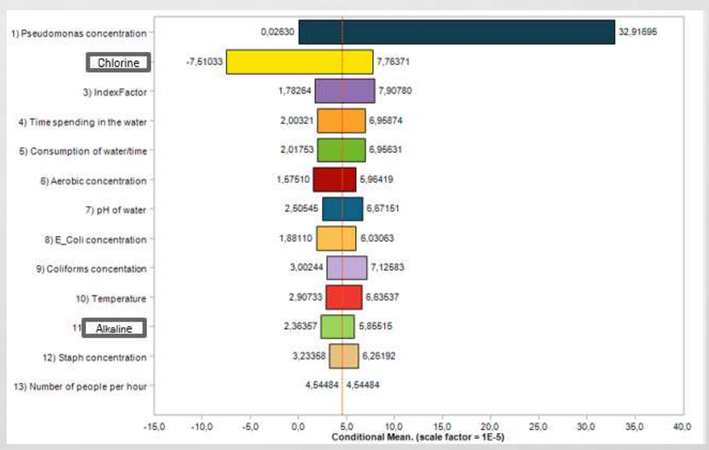


Pool B



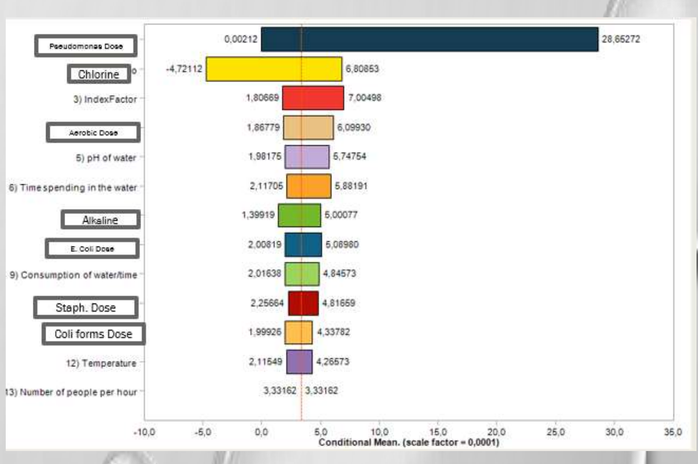
Site 2
Pool C (indoor) **No simulations > threshold (1×10^{-4})**
Classification: Safe

Pool C



Site 2

Pool D



Site 2

Mean	6,31529E-05
Minimum	1,61897E-09
Maximum	0,044789366
N. Of Errors	0
N. Of Filtered	0
St. dev.	0,000542684
Variance	2,94506E-07
Risk ratio	16,84032557
CofV	8,593178924

Site 1
Pool B (indoor)
15 – 20 % simulations > threshold (1×10^{-4})
Classification: Slightly elevated risk

Mean	0,000125271
Minimum	-0,003406146
Maximum	0,13915039
N. Of Errors	0
N. Of Filtered	0
St. dev.	0,001629502
Variance	2,65528E-06
Risk ratio	16,81005671
CofV	13,00781736

Site 2
Pool D (indoor)
15 – 20% simulations > threshold (1×10^{-4})
Classification: **Slightly elevated risk**

Mean	0,000333162
Minimum	-0,044805954
Maximum	0,131713005
N. Of Errors	0
N. Of Filtered	0
St. dev.	0,002960667
Variance	8,76555E-06
Risk ratio	49,25923759
CofV	8,886555788

Conclusions

Outdoor and indoor pools (A, C): The tornado chart show chlorine concentration, water refreshment and dose parameters as high influential. Sunlight (UV) and higher water renewal dilute/kill bacteria, so infection risk stays below the threshold

Interpretation: Environmental factors (sunlight, aeration, dilution) drive safety outdoors

Indoor pools (B, D): Chlorine concentration and Pseudomonas dose dominate sensitivity. In both pools, small fluctuations in chlorine cause big changes in risk, which explains why 10–20% of simulations exceeded the 1×10^{-4} threshold

Interpretation: Disinfection efficiency is critical indoors, where natural UV is absent and bacterial persistence is higher

Discussion

- QMRA indicates variable risk across pools
- Outdoor pool safest & two indoor pools show exceedances
- Chlorine stability & proper water quality monitoring are critical
- QMRA is a powerful management tool for public health