Health Risk Analysis from Multi-Exposure to Trihalomethanes in Public Indoor Swimming Pools. A Case Study.

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Abstract: - Disinfection mitigates the risk of waterborne disease proliferation, but produces some by-products (SPDs), resulting from chlorine's reaction with natural organic matter and may lead to the presence of potentially carcinogenic substances, such as trihalomethanes (THMs). The primary objectives of this research were to evaluate the health risks associated with multi-exposure to THMs in several swimming pools located in the municipality of Porto (Portugal), assessing both carcinogenic and non-carcinogenic risks across different exposure and analysis scenarios. Risk assessment uses a calculation model (CRacel), based on the USEPA's model, with several modifications in input parameters. This model calculates Cancer Risk (CR) and Hazard Index (HI) values for multi-pathway exposure among different user groups. Considering a non-severe exposure scenario, results indicated that CR values in all swimming pools exceeded the risk threshold of 10^{-6}. However, under a severe exposure scenario, CR was up to 250 times higher than the acceptable limit.

Key-Words: - Health risk analysis, indoor swimming pools, THMs exposure, *CRacel* model.

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1 Introduction

The awareness of the health benefits associated with swimming pools, along with the remoteness and/or overcrowding of coastal bathing areas, has led to a significant increase in the demand for and use of public swimming pools. This trend tends to exacerbate water pollution (e.g., natural organic matter, pathogens) in pools, as users are the primary source of contamination introducing body secretions and personal hygiene products (such as cosmetics and deodorants), often unintentionally. In indoor pools, high temperature and humidity, along with poor ventilation, create favourable conditions for the development of microorganisms (including pathogens) and the accumulation of toxic substances (e.g., trihalomethanes, trichloramine), which may pose risks to users through water, air, and their interface. To prevent the proliferation of diseases, it is essential to implement effective water treatment to ensure safe swimming conditions. One of the mandatory unit treatment processes involves the use of disinfectants (such as bromine, ozone, chlorinated compounds, or UV radiation), aiming to eliminate potentially pathogenic microorganisms.

Water disinfection in swimming pools depends on an adequate contact time between the disinfectant agent and the water throughout the recirculation system, ensuring the desired disinfectant residual concentration. Chlorinated compounds have been widely used in swimming pools due to their low cost, strong bactericidal effect, ease of handling, and residual disinfection capacity. One of the major issues with chlorine-based disinfection is the formation of disinfection by-products (DBPs), which result from reactions with organic matter and bromide. These by-products can have harmful effects on the health of swimming pool users, including dermatological and allergic conditions such as dermatitis, conjunctivitis, eye, nasal, and skin irritations, mycosis, and otitis, [1].

Some chlorine by-products (CBPs) are potential carcinogens, particularly halogenated organic by-products (e.g., THMs, acetylonitriles), which can cause tumors, male infertility, and may even increase the probability of spontaneous abortions, [2]. Generally, THMs represent the highest concentration of CBPs and consist of four major compounds: chloroform, bromodichloromethane bromoform and dibromochloromethane.

The use of hypochlorite disinfectants in pools where tap water is the primary water source increases THM formation. However, using calcium hypochlorite instead of sodium hypochlorite has been shown to reduce THM formation, [3]. Another common complaint is the strong "chlorine odor" characteristic of swimming pools, which results

from the presence of chloramines, particularly trichloramines, at the water/air interface.

Unlike other DBPs, THMs are volatile, leading to significant concentrations in both water and indoor air. Consequently, exposure to THMs among indoor swimming pool users occurs not only through accidental water ingestion and dermal absorption but also via inhalation, which can be the most significant exposure pathway, [4].

Although THM concentrations in pool air are recognized to be high, there are no mandatory standards regulating their levels. However, since chloroform is typically the predominant THM, Portuguese standards limit its indoor air concentration to 10 mg/m³. Additionally, temperature, free chlorine levels, and dissolved organic carbon (DOC) concentrations in pools should be continuously monitored to mitigate DBPs like THMs.

This case study was conducted in eleven indoor swimming pools in the Porto municipality, with the following objectives: to analyse THM occurrence in pool air and water and to assess both carcinogenic and non-carcinogenic risks associated with multiple exposure pathways to THMs across different genders and user groups — competitive swimmers (SC), non-competitive swimmers (SNC), and coaches (C).

This research was pioneering in Portugal and represents a significant and original contribution to raising awareness among health authorities and managers of these leisure facilities about the health risks posed by multi-exposure to THMs, [4].

More research has been published in the meantime, proving the recognized timeliness and relevance of this topic for promoting public health, [5], [6]. The results of this study revealed that swimmers faced constant risk during their time in the pools.

2 Methods

The study was conducted in public indoor swimming pools, comprising 21 tanks, across eleven facilities located in the municipality of Porto. All data regarding pool characteristics, disinfection systems, and water quality monitoring (covering the period from 2010 to 2019) were provided by a Public Health Unit (USP-ACES Porto Oriental).

The tank areas, functional typologies, and disinfectant products used in the monitored swimming pools are collected and summarized in Table 1.

Table 1. Synthesis of swimming pool characteristics

Pool	Area (m^2)	Functional typology	Disinfection product
A	8	learning, recreational	Sodium hypochlorite (NaOCl)
B	250	sporty	
C1	321		
C2	100		
D1	112		
D2	1000		
E1	121		
E2	8	hydromassage	
F1	77	sporty	NaOCl + UV
F2	21	hydromassage	
G1	375	sporty	NaOCl
G2	224		
G3	137		
G4	168	hydromassage	
H	312	sporty	
I1	72		
I2	8	hydromassage	
J1	136	sporty	NaOCl + UV
J2	40		
J3	10	hydromassage	
K	72	sporty	NaOCl

Source: created by the authors

The standard sampling strategy for measuring THM concentration involves the simultaneous collection of water samples from different points at depths of 0.25 m and 0.50 m from the borders of the pool.

2.1 Characterization of THMs Exposure

Table 2 (Appendix) summarizes the maximum and average annual values of THMs observed in water swimming pools during the period 2010-2019.

Data analysis indicates that most of the monitored swimming pools recorded maximum values exceeding the EU standards (100 µg/L) for drinking water supply systems. According to reports from USP-ACES Porto Oriental, more than one hundred instances of non-compliance in THM concentrations were detected among the six hundred water analyses conducted in swimming pools during this period.

Standard deviation is a crucial metric for understanding the variability of a series of values. In this case, the greatest dispersion of observed values occurs at the maximum concentrations and in pools K, F2, I1, and E. This finding aligns with the pools where the values associated with cancer risk were more severe. The difference between the mean values of THM concentrations across different pools is so pronounced that performing a *t-test* is deemed unnecessary.

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2.2 Health Risk Analysis

The present health risk analysis was based on the method proposed by the USEPA [7], which has been widely used in global research for health risk assessment, [8], [9], [10], [11], [12], [13], [14], [15]. Several existing databases provide a simple and reliable means of evaluating lifetime cancer risks for any population, using datasets such as ingestion rate, body weight, lifespan, and skin area for respective populations and conditions. This method aims to analyze the risk of human exposure to chemical compounds, characterized across four key areas: i) component identification and verification of its consequences for public health. ii) exposure pathways leading to potential aftereffects. iii) analysis of conditions necessary for exposure to become harmful to human health. iv) types of risks affecting humanity, [16].

Risk characterization plays a crucial role in assessing any form of human health risk, whether carcinogenic (*Lifetime Cancer Risk*) or non-carcinogenic (*Hazard Index*). This evaluation enables the entities responsible for managing the studied infrastructures to establish links between risk management, economics, technical feasibility, and regulatory compliance.

The total cancer risk (CR_{total}) quantifies the increased probability of developing oncological diseases due to carcinogen exposure over time, [17]. From a quantitative standpoint, risk characterization is typically expressed through a dimensionless indicator, which is only considered acceptable if it remains below 10^{-6}, meaning that out of one million people, only one individual would develop cancer under the same exposure conditions.

Given the complexity of the calculations required for this risk assessment, a calculation model (named *CRacel*) was developed using Microsoft Excel. Excel was chosen due to its universal accessibility, making it an easy-to-use tool for risk managers and health authorities worldwide. Table 3 (Appendix) outlines all general input parameters used in the CRacel model, which were adapted for the Portuguese population and building environment.

Additional specific input parameters for inhalation, ingestion, and dermal absorption exposure contributions were also tailored accordingly, with their detailed values available in references, [4], [16].

The concentration of THMs varies between indoor pool air and the air/water interface. Thus, THM-related risks due to inhalation must be calculated separately for swimmers and coaches. While swimmers experience multi-exposure via inhalation, dermal contact, and accidental ingestion, coaches are only exposed through inhalation.

For this health risk analysis, users were categorized into swimmers (competitive and non-competitive) and coaches, all of whom faced multi-exposure to THMs via inhalation, ingestion, and dermal absorption. All user groups were classified by gender due to differences in input parameters such as body weight, body surface area, and average life expectancy. Due to the functional typology of tanks A, E2, F2, G4, I2, and J3, competitive swimmers were excluded from the risk assessment for these pools.

The carcinogenic risk was evaluated using the *Lifetime Cancer Risk* parameter (CR_{total}), while non-carcinogenic risk was assessed using the total *Hazard Index* (HI), considering two distinct exposure scenarios (severe and non-severe) and twenty-four analysis scenarios.

2.3 Cancer Risk Assessment

The characterization of carcinogenic risk represents the quantification of the increased probability of developing oncological diseases because of exposure to a carcinogenic agent over a given period, [20].

Risk is generally associated with the product of the measures of probability and severity of a given hazardous event. The adoption of an acceptable reference value is based on different perspectives and dimensions of analysis, such as the general acceptance by professionals in that sector and the population, the level of scientific knowledge in that field, and the consideration of the costs of risk reduction. So, the prerequisite for assessing the risk

of any substance with threshold effect is the knowledge of the reference dose (RfD) value [mg/kg/day], which may be calculated using the equation (1):

$$RfD = C_{NAE} \times UF^{-1} \times MF^{-1} \quad (1)$$

where C_{NAE} is the concentration of contaminant which no adverse health effects are monitored, UF is an aggregate uncertainty factor ($=10^x$, being x the number of uncertainties) and MF is a modification factor, which characterizes the uncertainties not covered by the UF

The second step in cancer risk analysis is exposure assessment, which involves quantifying the chronic daily intake (CDI) in mg/kg/day, considering the age category, contaminant type, and exposure pathway. This quantification is performed using the following equations: (2) and (3) for inhalation, (4) for ingestion, and (5) for dermal absorption.

$$CDI_{inh.,swim} = \frac{C_{WSA} \cdot R_S \cdot AE \cdot ET \cdot ED \cdot CF_{inh.}}{BW \cdot AT} \quad (2)$$

$$CDI_{inh.,coach} = \frac{C_{SA} \cdot R_R \cdot AE \cdot ET \cdot ED \cdot CF_{inh.}}{BW \cdot AT} \quad (3)$$

$$CDI_{ing.,swim} = \frac{C_W \cdot IR \cdot ET \cdot ED \cdot CF_{ing.}}{BW \cdot AT} \quad (4)$$

$$CDI_{der,swim} = \frac{C_W \cdot S_{skin} \cdot F \cdot K_P \cdot ET \cdot ED \cdot CF_{der.}}{BW \cdot AT} \quad (5)$$

where,

C_W, C_{SA} (mg/day)	are the average concentrations of THM in water and air.
R_S, R_R (m^3/h)	are the respiratory flow during swimming session and at at rest.
AE (%)	is the alveolar absorption efficiency.
ET (hour /day)	is the daily exposure time.
ED (year)	is the exposure duration.
CF (day/year)	is the annual exposure frequency of each source.
BW (kg)	is the average body weight of population.
AT (day)	is the time during which the concentration Cw remains constant.
IR (L/day)	is the daily rate of ingested water
S_{skin} (cm^2)	is the skin area which is in contact with contaminated water.
Kp (cm/hour)	is the coefficient of skin permeability.
F	is a conversion factor.

Given the type of activity performed by coaches in pools, only swimmers are subject to exposure through ingestion and dermal adsorption

The indicator *Lifetime Cancer Risk* (CR) was calculated by equation (5), as a sum of products between these CDI values (mg/kg/day) and a slope factor (SF) associated at each THMs (i) and exposure pathway (j).

$$CR = \sum_{i=1}^{m} * \sum_{j=1}^{n} CDI_{ij} * SF_{ij} \quad (5)$$

The slope factor (SF) represents an estimate of the increased likelihood of getting cancer through exposure to a dose of 1 mg/day of a given chemical compound for a predefined time interval. Basically, it is defined as a toxicity value, located at the 95th percentile, which establishes a relationship between the absorbed dose and the organism's response [20].

The USEPA calculation model allows us to assess differently the risks associated with exposure to each of the four compounds of total THMs. For swimming pools waters, the following THMs composition pattern was used [22]: 43.8% of chloroform; 21.4% of bromodichloromethane; 27.0% of dibromochloromethane; and 7.8% of bromoform.

Regarding the non-carcinogenic risk associated with exposure to THM, its quantification is determined by the quotient of chronic daily exposure (CDI) resulting from the three considered exposure pathways, and the chronic reference dose (RfD), using equation (6).

$$HI = \sum_{i=1}^{m} \frac{CDI_j}{R_f D_i} \quad (6)$$

Facing the observed high variability of THMs concentration in the monitored swimming pool waters, the performed carcinogenic risk assessment has considered two different THMs exposure scenarios (ES):

- ES-A (severe) corresponds to a continuous exposure at a THMs concentration equal to the maximum annual value recorded.
- ES-B (non-severe) corresponds to a continuous exposure at a THMs concentration equal to the average annual value recorded.

In the performed human health risk assessment, for each one of the exposure scenarios considered, several analyses scenarios (Table 4, Appendix) were defined to compare: the carcinogenic and non-carcinogenic risks contribution of each exposure pathway, considering the same user group

(scenarios S) and both genders; and the total cancer risk (CR_{total}) and the hazard index values (HI) for each users group considering all exposure pathways (scenarios T).

Figure 1 (Appendix) illustrates the procedure carried out in the simulation of the various scenarios using the Cracel model to obtain the CR values, namely the partial MS Excel sheet used to perform input data task. Similar sheets were used for the health risk assessment.

In summary, for each one of the monitored swimming pools, the simulations performed using the CRacel model for the health risk assessment, considered the following different issues:

- 3 user groups (SC, SNC, C).
- 3 exposure pathways (inhalation, ingestion, dermal adsorption).
- 2 genders (male, female).
- 2 health risk (cancer and non-carcinogenic).
- 2 exposure scenarios (severe, non-severe).

3 Results and Discussion

In this study, the results correspond to the following sets of analysis scenarios:

- S1 to S7: designed to evaluate the relative contribution of each exposure pathway for scenario A, considering all user groups and the gender with the highest CR value.
- T1 to T6: aiming to assess the total cancer risk level for both exposure scenarios (A and B), considering all user groups and the gender with the highest CR_{total} value.
- T7 to T9: focused on evaluating the non-carcinogenic risk level for scenario A, considering all user groups and the gender with the highest HI value.

3.1 Carcinogenic Risk Analysis

Table 5 (Appendix) presents a summary of the total cancer risk values (CR_{total}) for each pool, based on the full set of scenarios simulated using the CRacel model. The values are categorized by user group and gender, to allow a more detailed comparative analysis, considering both exposure scenario (ES-A and B) for each of the monitored pools.

For the severe exposure scenario (ES-A), the results of the CRacel model simulations are depicted in Appendix in Figure 2, Figure 3 and Figure 4, illustrating the cancer risk levels associated with each exposure pathway: inhalation, ingestion, and dermal absorption, respectively.

An overall analysis of all monitored swimming pools indicates that air inhalation presents the highest cancer risk levels for THM exposure, consistently exceeding the acceptable health risk threshold (1E-06).

Unlike drinking water risk assessments, where ingestion is a primary concern, in swimming pools, ingestion results in lower cancer risk values, always remaining below the adopted reference limit.

Pool K presents the worst results for scenario S1, with CR values of 2.5E-04 and 5.0E-05 for female competitive and non-competitive swimmers, respectively. The first value is 250 times higher than the acceptable cancer risk threshold.

The lowest CR values were observed in pool D, with 4.0E-05 for competitors, 7.9E-06 for non-competitors, and 5.5E-06 for coaches. However, all values remain above the acceptable limit – by up to 40 times. Among user groups, coaches exhibited the lowest CR values for air inhalation exposure, with a risk level eight times lower than that of competitive swimmers.

Regarding water ingestion exposure, the highest CR values for women occurred in pool F2, with 5.0E-07 for competitors and 4.0E-07 for non-competitors.

Also in this case, both values remain below the 1E-06 limit, making ingestion a less critical pathway in this assessment. For dermal absorption, results indicate that only half of the monitored pools presented acceptable CR values.

The worst CR values for men occurred in pool F2, with 5.1E-06 for competitors and 2.0E-06 for non-competitors, exceeding the acceptable limit.

By comparing the results of scenarios S1, S4, and S6 (Figure 5, Appendix) for swimmers' competitors, who exhibit the highest cancer risk levels, we can rank the contribution of each exposure pathway and quantify its average relative weight in the lifecycle assessment. The findings reveal a strong dominance of inhalation exposure (98.2%), with minimal contributions from dermal absorption (1.6%) and ingestion (0.2%), based on mean CR values across all pools.

The results obtained from the *CRacel* model calculations to assess lifecycle cancer risk (CR_{total} values) are illustrated in Figure 6 (Appendix), which corresponds to the severe exposure scenario (A), and in Figure 7 (Appendix), which represents the non-severe exposure scenario (B). These figures align with the sets of analysis scenarios T1-T3 and T4-T6, respectively.

Comparing these two sets of model results enables a sensitivity analysis of the criteria applied in the processing and utilization of THM monitoring data, which are often limited and do not fully

represent the heterogeneity of THM concentrations in indoor swimming pools.

Since coaches are not exposed to ingestion or dermal absorption, their CR_{total} values are determined solely by inhalation exposure results.

Analysis of the model results also indicates that CR_{total} values for women are consistently higher than those for men in inhalation and ingestion exposures, due to their longer average life expectancy. Conversely, cancer risk from dermal absorption is higher in men, as their greater body surface area is a key input parameter in risk calculations.

As expected from previous findings, the lifecycle cancer risk (CR_{total}) for ES-A consistently exceeds acceptable levels, with a peak value of 2.6E-04 recorded in pool K for female competitive swimmers under exposure scenario A.

Within this user group, carcinogenic risk levels range between 40 to 253 times higher than the acceptable limit. In contrast, the lowest CR_{total} value (3.8E-05, for men) was observed in pool D2.

For non-competitive swimmers, the highest risk level (5E-05) was also recorded in pool K, while the lowest CR_{total} value (8E-06) was found in pool D2, with carcinogenic risk levels ranging from 8 to 50 times higher than the acceptable threshold.

For coaches, pool K also presented the worst case, with a maximum cancer risk value of approximately 3.5E-05. Meanwhile, the minimum CR_{total} value was near 5E-06 in pool D2, with carcinogenic risk levels ranging from 5 to 35 times above the acceptable threshold.

Results obtained for the non-severe exposure scenario (ES-B) indicate that, on average, c values are approximately 60% lower than those recorded for the severe exposure scenario (ES-A) across both swimmer groups.

In scenario ES-B, the carcinogenic risk for competitive swimmer ranges from 28 to 120 times higher than the acceptable risk threshold, with the highest CR observed in pool E and the lowest in pool J.

For non-competitive swimmers, the highest and lowest risks were also found in pools E and J, respectively, with carcinogenic risk levels ranging from 5 to 25 times above the acceptable threshold.

Similarly, for coaches, the inhalation-related cancer risk varied between 3 and 25 times greater than the acceptable limit, following the same pool distribution.

3.2 Non-carcinogenic Risk Analysis

The non-carcinogenic risk assessment was conducted using the CRacel model, with the Hazard Index (HI) values obtained for the severe exposure scenario (ES-A) presented in Figure 8 (Appendix).

This analysis helps evaluate potential health risks that, while not directly linked to cancer, could still impact swimming pool users through prolonged exposure to THMs. The HI values provide insight into whether exposure levels exceed acceptable thresholds, guiding necessary preventive measures and risk mitigation strategies for pool environments.

The analysis of the model results allows us to conclude that, in all monitored swimming pools, non-carcinogenic health risks can be considered negligible, as HI values were consistently below unity, which is regarded as the threshold for negligible risk, [23].

The highest HI value was observed in pool K, among competitive swimmers, yet it remained five times lower than the adopted risk limit. Consequently, only the most severe scenario (A) was considered in this health risk analysis.

4 Conclusions

The research conducted in eleven swimming pools in the municipality of Porto supports the following key conclusions.

THM concentrations exceeding EU standards: out of the 601 water quality analyses performed, 107 (18%) showed THM concentrations significantly above the EU standard limit of 100 μg/L for drinking water. The highest concentration was recorded in pool K, reaching a maximum value of 1243 μg/L.

THM exposure pathways and cancer risk: unlike drinking water systems, where ingestion plays a major role, in swimming pools, inhalation is the primary contributor to cancer risk, accounting for 98.2%, followed by dermal absorption (1.6%) and ingestion (0.2%). Given their minimal impact, ingestion contributions can be disregarded in future cancer risk analyses.

Carcinogenic risk exceeds acceptable limits: in all swimming pools, users faced a higher carcinogenic risk due to THM inhalation than the acceptable limit, with the highest risk observed in pool K, where female competitive swimmers experienced exposure levels 250 times above the safe threshold.

Comparing swimmer groups: despite their shorter exposure time, competitive swimmers exhibited a cancer risk level five times higher than non-competitive swimmers. Coaches, who primarily experience inhalation exposure, had a cancer risk level seven times lower than competitive swimmers.

Impact of exposure scenarios: The cancer risk assessment was conducted under severe (A) and non-severe (B) exposure scenarios.

CRacel model results for exposure scenario B were approximately 40% lower than those for scenario A, for both swimmer groups. However, the acceptable cancer risk level (1.0E-06) was consistently exceeded, indicating that THM concentrations must be carefully regulated.

Non-carcinogenic risk remains negligible: the Hazard Index (HI) values show that the non-carcinogenic risk can be considered negligible across all monitored swimming pools, even in the severe exposure scenario.

Future research should focus on studying and analysing the variability in the relative weight of THMs' presence in the air and water of indoor swimming pools. This includes assessing the influence of ventilation cycles on the concentration of these compounds in the air within these facilities to enhance the reliability of health risk assessment models. By replacing correlations established in previous studies with pool-specific data, model calibration and validation will become more rigorous, fostering the integration of artificial intelligence tools into management models and decision-support systems.

Another promising area for research involves the intelligent and continuous monitoring of various indoor air and water quality parameters. This would improve the operational control of water treatment and recirculation systems while minimizing the risks associated with user exposure to harmful compounds such as trichloramines, THMs, and haloacetic acids.

Additionally, a further challenge is the promotion of greater accessibility to water quality data of public indoor swimming pools. For instance, developing an open digital platform for compiling, analysing, and disseminating information on the websites of the respective managing entities – like existing systems for water supply data – would greatly enhance knowledge, transparency and public awareness.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

APPENDIX

Table 2. Total THMs concentration in swimming pools water of Porto municipality

Indoor Pool	Anual value	THMs concentration in swimming pool water (µg/L)											
		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Average	Standard deviation
A	Max.	-	-	-	93	77	104	92	78	68	41	79	17%
	Mean	-	-	-	74	39	56	55	22	31	29	44	43%
B	Max.	-	31	84	128	172	181	71	34	64	29	88	66%
	Mean	-	19	52	106	138	123	47	32	62	22	67	66%
C1	Max.	-	41	-	83	76	86	110	52	92	42	73	32%
	Mean	-	24	-	64	76	62	77	46	90	42	60	37%
C2	Max.	-	38	-	71	83	130	70	66	52	42	69	42%
	Mean	-	22	-	65	83	86	60	55	48	42	58	38%
D1	Max.	-	-	-	131	43	-	16	23	50	35	50	92%
	Mean	-	-	-	66	36	-	14	23	47	33	36	57%
D2	Max.	-	-	-	48	25	-	15	40	42	82	42	32%
	Mean	-	-	-	33	19	-	13	31	30	58	30	29%
E1	Max.	100	41	245	280	148	127	112	623	223	84	198	87%
	Mean	62	31	113	231	122	108	112	361	134	67	134	74%
E2	Max.	16	75	333	-	-	48	-	94	-	57	104	121%
	Mean	16	75	153	-	-	40	-	60	-	36	63	83%
F1	Max.	-	-	-	116	116	107	162	111	44	24	97	39%
	Mean	-	-	-	116	61	66	101	82	28	20	68	46%
F2	Max.	-	-	-	107	517	695	517	276	103	73	327	75%
	Mean	-	-	-	107	281	333	357	197	89	72	205	56%
G1	Max.	-	50	76	44	34	44	32	-	23	-	43	40%
	Mean	-	50	63	35	27	33	23	-	17	-	36	45%
G2	Max.	-	53	68	58	33	57	30	-	26	-	46	36%
	Mean	-	53	31	43	31	40	28	-	19	-	35	32%
G3	Max.	-	51	53	65	25	36	46	-	29	-	44	32%
	Mean	-	51	32	32	23	32	33	-	21	-	32	30%
G4	Max.	-	55	39	50	43	52	40	-	32	-	44	19%
	Mean	-	55	19	26	32	36	32	-	23	-	32	37%
H	Max.	-	41	168	167	140	139	51	56	69	-	104	53%
	Mean	-	33	121	97	92	105	32	37	36	-	69	55%
I1	Max.	-	722	229	344	130	250	106	103	59	-	243	89%
	Mean	-	158	161	169	83	174	50	57	53	-	113	50%
I2	Max.	-	-	-	-	97	203	24	54	28	-	81	91%
	Mean	-	-	-	-	77	131	19	40	25	-	58	80%
J1	Max.	95	110	40	37	28	25	30	-	35	-	50	66%
	Mean	58	67	25	19	20	17	25	-	27	-	32	60%
J2	Max.	65	91	46	30	37	13	22	-	42	-	43	58%
	Mean	36	48	28	14	21	10	15	-	24	-	24	53%
J3	Max.	81	54	44	44	26	15	48	-	40	-	44	44%
	Mean	42	31	24	26	19	12	29	-	19	-	25	37%
K	Max.	-	225	184	200	1243	119	71	53	49	-	268	149%
	Mean	-	132	131	119	310	60	50	39	40	-	110	82%

Source: created by the authors

Table 3. Input parameter values for cancer risk analysis

Acronym	Parameter	Unit	Average value	Reference
AT	Average life expectancy	days	Men: 78.5*365 Women 84.6*365	
BW	Body mass	kg	Men: 74 Women 64	[17]
h	Height	cm	Men: 173 Women: 163	
ET	Time of exposure	hr/year	Elite swimmers: 773 Leisure swimmers: 82 Coaches: 336	[18], [19]
ED	Duration of exposure	year	Elite swimmers: 8 Leisure swimmers: 30 Coaches: 11	
RfD	Reference dose	mg/kg/day	$CHCl_3$: 0.01 $CHCl_2Br$: 0.02 $CHClBr_2$: 0.02 $CHBr_3$: 0.02	[20], [21]

Source: created by the authors

Table 4. Analysis scenarios used for health risk assessment

	Exposure pathway (ES-A)			CR_{total}		HI
User group	Inhalation	Ingestion	Dermal absorption	ES-A	ES-B	ES-A
Swimmer competitor	S1	S4	S6	T1	T4	T7
Swimmer non- competitor	S2	S5	S7	T2	T5	T8
Coaches	S3	-	-	T3	T6	T9

Source: created by the authors

Table 5. Comparison of cancer risk values for all user groups across the two exposure scenarios (ES-A and ES-B)

Pools	Cancer Risk (CR_{total})											
	Competitors				Non-competitors				Coaches			
	Scenario ES-A		Scenario ES-B		Scenario ES-A		Scenario ES-B		Scenario ES-A		Scenario ES-B	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
A	7.10E-05	7.60E-05	3.90E-05	4.20E-05	1.60E-05	1.70E-05	8.70E-06	9.30E-06	9.50E-06	1.00E-05	5.30E-06	5.60E-06
B	7.90E-05	8.50E-05	6.00E-05	6.40E-05	1.80E-05	1.90E-05	1.30E-05	1.40E-05	1.10E-05	1.10E-05	8.00E-06	8.60E-06
C1	6.50E-05	6.90E-05	5.40E-05	5.70E-05	1.40E-05	1.50E-05	1.20E-05	1.30E-05	8.60E-06	9.40E-06	7.20E-06	7.80E-06
C2	6.40E-05	6.90E-05	5.30E-05	5.70E-05	1.40E-05	1.50E-05	1.20E-05	1.30E-05	8.60E-06	8.90E-06	7.20E-06	7.40E-06
D1	3.90E-05	4.10E-05	2.80E-05	3.00E-05	8.70E-06	9.30E-06	6.30E-06	6.80E-06	5.10E-06	6.40E-06	3.70E-06	4.70E-06
D2	3.80E-05	4.10E-05	2.80E-05	3.00E-05	8.50E-06	9.10E-06	6.20E-06	6.60E-06	5.10E-06	5.40E-06	3.70E-06	3.90E-06
E1	1.70E-04	1.90E-04	1.20E-04	1.30E-04	3.80E-05	4.10E-05	2.60E-05	2.80E-05	2.30E-05	2.60E-05	1.60E-05	1.70E-05
E2	1.70E-04	1.80E-04	1.10E-04	1.20E-04	3.60E-05	3.90E-05	2.40E-05	2.60E-05	2.30E-05	1.30E-05	1.60E-05	8.20E-06
F1	1.30E-04	1.40E-04	8.60E-05	9.20E-05	2.80E-05	3.00E-05	1.90E-05	2.00E-05	1.80E-05	1.30E-05	1.20E-05	8.70E-06
F2	1.40E-04	1.50E-04	9.10E-05	9.80E-05	3.40E-05	3.70E-05	2.20E-05	2.40E-05	1.80E-05	4.20E-05	1.20E-05	2.60E-05
G1	4.00E-05	4.30E-05	3.10E-05	3.30E-05	8.80E-06	9.40E-06	6.80E-06	7.30E-06	5.30E-06	5.60E-06	4.10E-06	4.60E-06
G2	4.00E-05	4.30E-05	3.10E-05	3.30E-05	8.90E-06	9.50E-06	6.80E-06	7.30E-06	5.30E-06	6.00E-06	4.10E-06	4.50E-06
G3	4.00E-05	4.30E-05	3.10E-05	3.30E-05	8.80E-06	9.40E-06	6.70E-06	7.20E-06	5.30E-06	5.60E-06	4.10E-06	4.10E-06
G4	4.00E-05	4.30E-05	3.10E-05	3.30E-05	8.80E-06	9.50E-06	6.70E-06	7.20E-06	5.30E-06	5.70E-06	4.10E-06	4.10E-06
H	9.30E-05	1.00E-04	6.20E-05	6.70E-05	2.10E-05	2.20E-05	1.40E-05	1.50E-05	1.30E-05	1.30E-05	8.30E-06	8.90E-06
I1	2.00E-04	2.20E-04	9.70E-05	1.00E-04	4.60E-05	4.90E-05	2.20E-05	2.30E-05	2.70E-05	3.10E-05	1.30E-05	1.50E-05
I2	2.00E-04	2.10E-04	9.50E-05	1.00E-04	4.10E-05	4.40E-05	2.00E-05	2.20E-05	2.70E-05	1.00E-05	1.30E-05	7.50E-06
J1	4.30E-05	4.70E-05	2.70E-05	2.90E-05	9.70E-06	1.00E-05	6.10E-06	6.50E-06	5.80E-06	6.50E-06	3.60E-06	4.10E-06
J2	4.30E-05	4.60E-05	2.70E-05	2.90E-05	9.50E-06	1.00E-05	5.80E-06	6.30E-06	5.80E-06	5.60E-06	3.60E-06	3.20E-06
J3	4.30E-05	4.60E-05	2.70E-05	2.90E-05	9.50E-06	1.00E-05	5.90E-06	6.30E-06	5.80E-06	5.70E-06	3.60E-06	3.30E-06
K	2.40E-04	2.60E-04	9.90E-05	1.10E-04	5.30E-05	5.70E-05	2.20E-05	2.40E-05	3.20E-05	3.50E-05	1.30E-05	1.40E-05

Source: created by the authors

CRAcel

Cancer Risk Assessment Excel Tool - 2021

INPUT DATA (Competitors swimmers)

Maximum differentiated concentrations of trihalomethanes in water (µg/L): CW

Pools	$CHCl_3$	$CHBr_3$	$CHCl_2Br$	$CHBr_2Cl$
A	34,60	6,16	16,91	21,33
B	38,62	6,88	18,87	23,81
C1	31,84	5,67	15,56	19,63
C2	30,23	5,38	14,77	18,63
D1	21,78	3,88	10,64	13,42
D2	18,37	3,27	8,97	11,32
E1	86,79	15,46	42,41	53,50
E2	45,43	8,09	22,20	28,01
F1	42,56	7,58	20,79	26,24
F2	143,16	25,49	69,94	88,25
G1	18,93	3,37	9,25	11,67
G2	20,31	3,62	9,92	12,52
G3	19,07	3,40	9,32	11,75
G4	19,43	3,46	9,50	11,98
H	45,50	8,10	22,23	28,05
I1	106,38	18,94	51,98	65,58
I2	35,56	6,33	17,37	21,92
J1	21,92	3,90	10,71	13,51
J2	18,92	3,37	9,24	11,66
J3	19,28	3,43	9,42	11,88
K	117,36	20,90	57,34	72,34

Model variables

Type	Parameter	Var.	Unity	Value
Geral	Life expectancy - Men	AT	day	28649
	Life expectancy - Women			30879
	Body mass - Men	BW	Kg	74
	Body mass - Women			64
	Conversion factor	CF_{ina}	-	0,001
		CF_{ing}	-	0,001
		$CF_{abs.}$	-	0,01
	Exposure duration - Men	ED	year	8
	Exposure duration - Women			8
	Exposure time	t	min/day	35
		ET	h/year	773
Ingestion	Intake rate	IR	L/h	0,0125
Dermic absorption	Skin contact area - Men	SA	m^2	1,88
	Skin contact area - Women			1,69
	Proportion of skin in contact with water	F	%	100%
Inalation	Respiratory rate - Men	RS	m^3/h	3,2
	Respiratory rate - Women			3,2
	Alveolar absorption efficiency	AE	%	50%
	Bathroom volume	V_S	m^3	9,6
	Shower water flow rate	Q_L	L/min	9
	Ventilation flow rate	Q_G	L/min	780
	Water temperatur	T	ºC	40

Fig. 1: CRacel model: initial input data procedure (MS Excel sheet extract)
Source: created by the authors

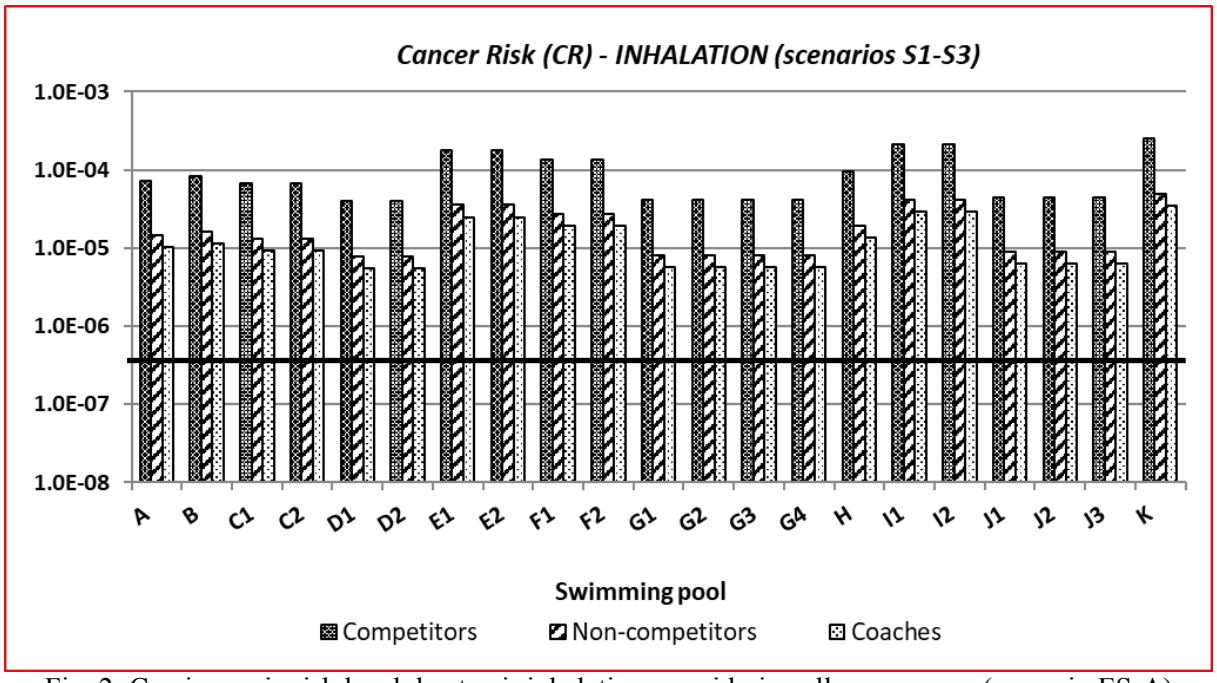

Fig. 2: Carcinogenic risk level due to air inhalation, considering all user groups (scenario ES-A)
Source: created by the authors

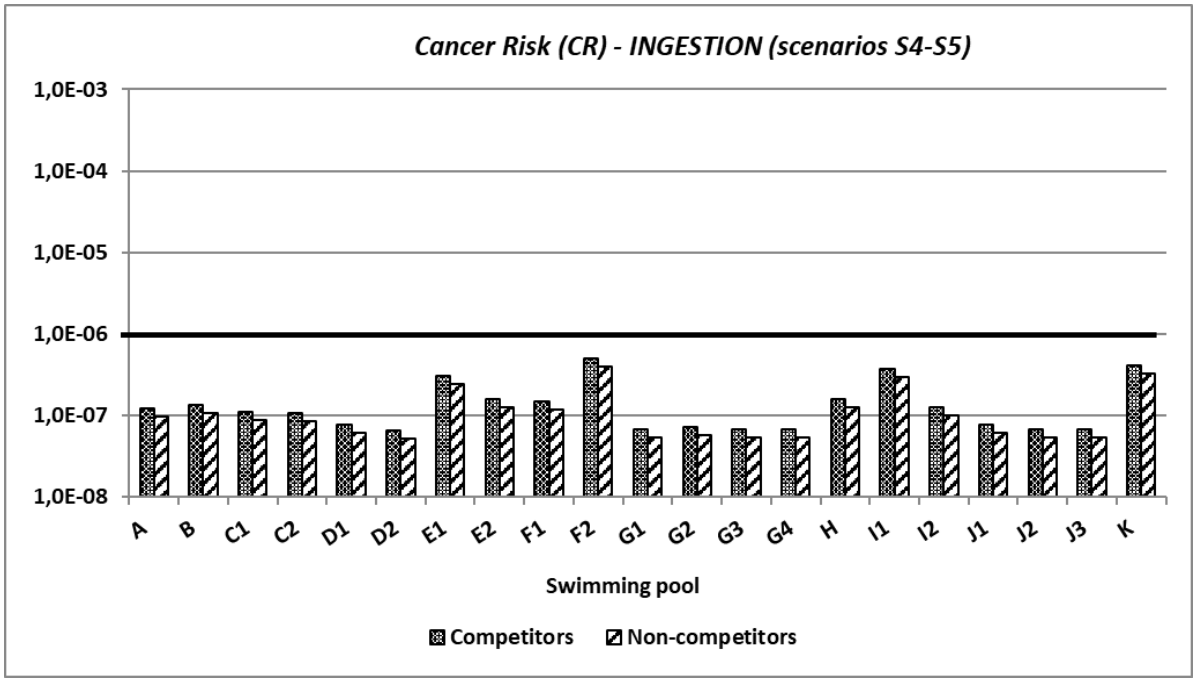

Fig. 3: Carcinogenic risk level due to water ingestion, considering all user groups (scenario ES-A)
Source: created by the authors

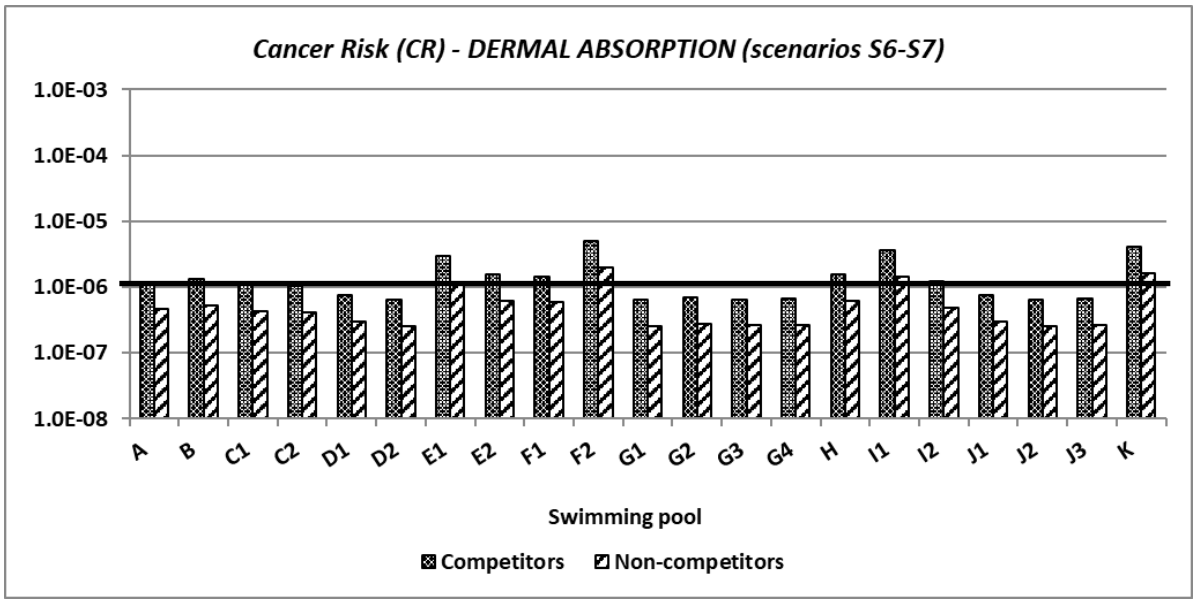

Fig. 4: Carcinogenic risk level due dermal absorption, considering all user groups (scenario ES-A)
Source: created by the authors

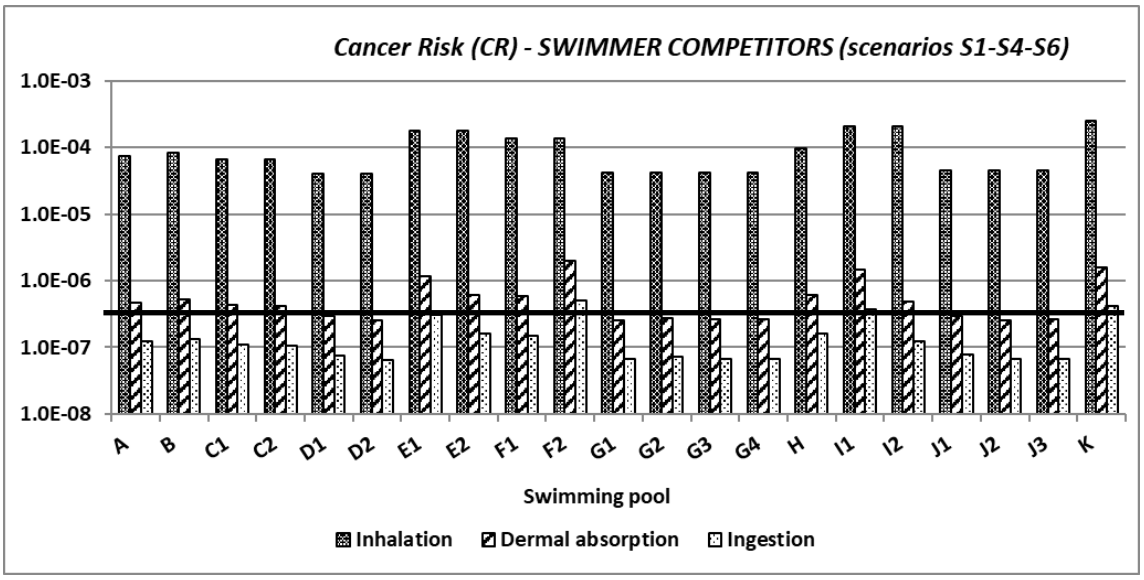

Fig. 5: Carcinogenic risk level for swimming competitors due to all exposure pathways (for ES-A)
Source: created by the authors

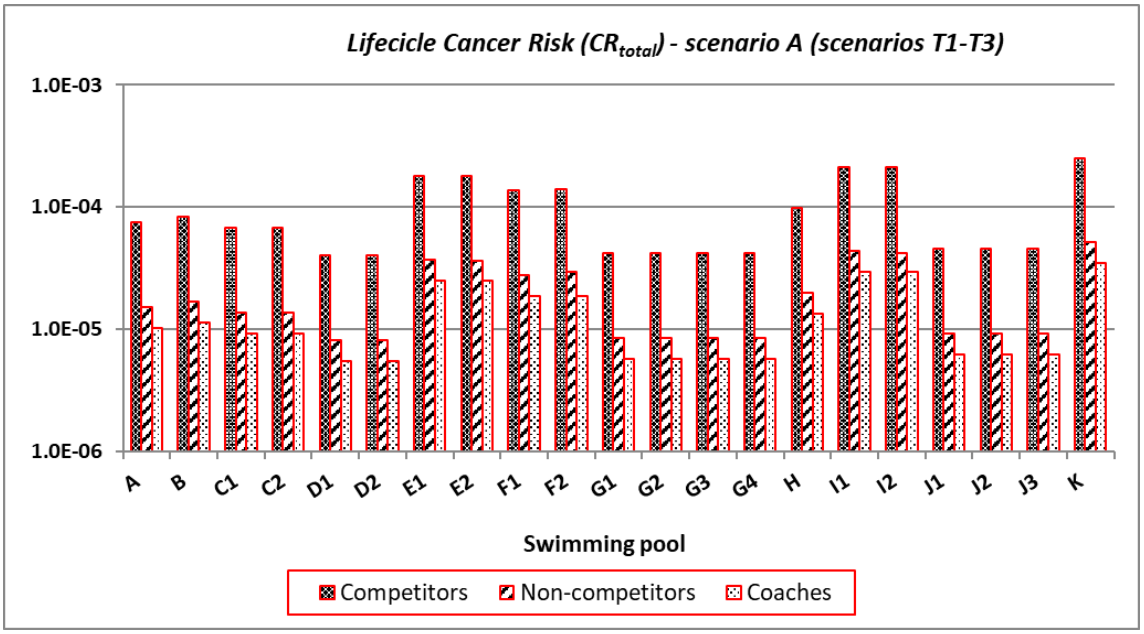

Fig. 6: Lifecycle cancer risk (CR_{total}) for all user groups, considering a severe exposure scenario (A)
Source: created by the authors

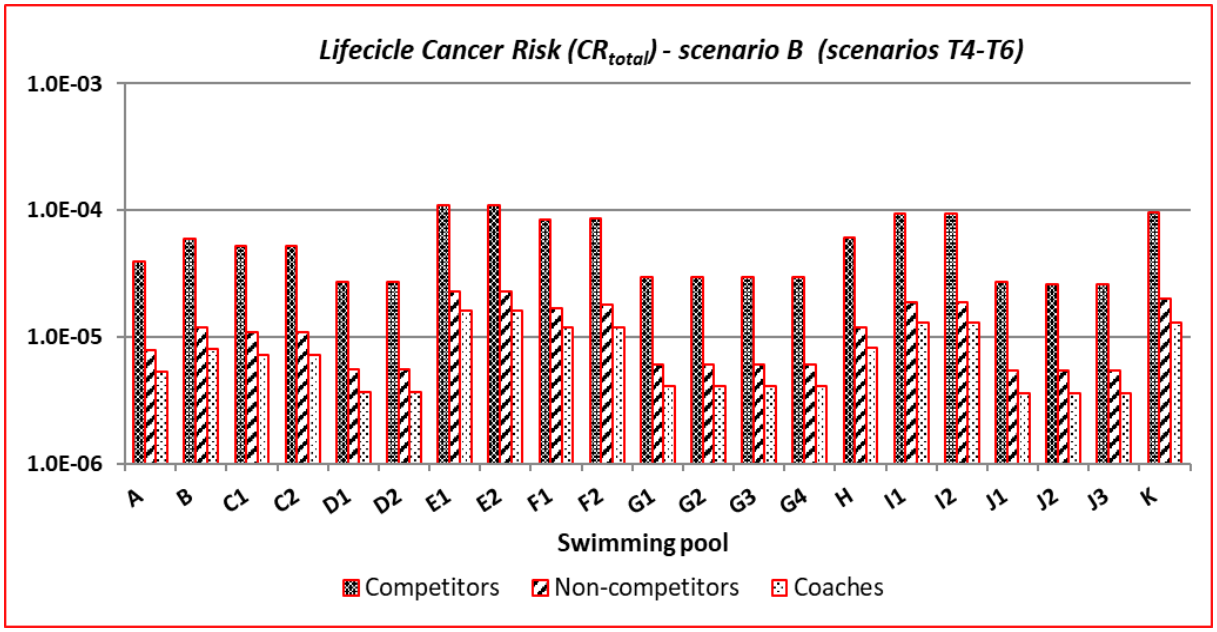

Fig. 7: Lifecycle cancer risk (CR_{total}) for all user groups, considering a non-severe exposure scenario (B)
Source: created by the authors

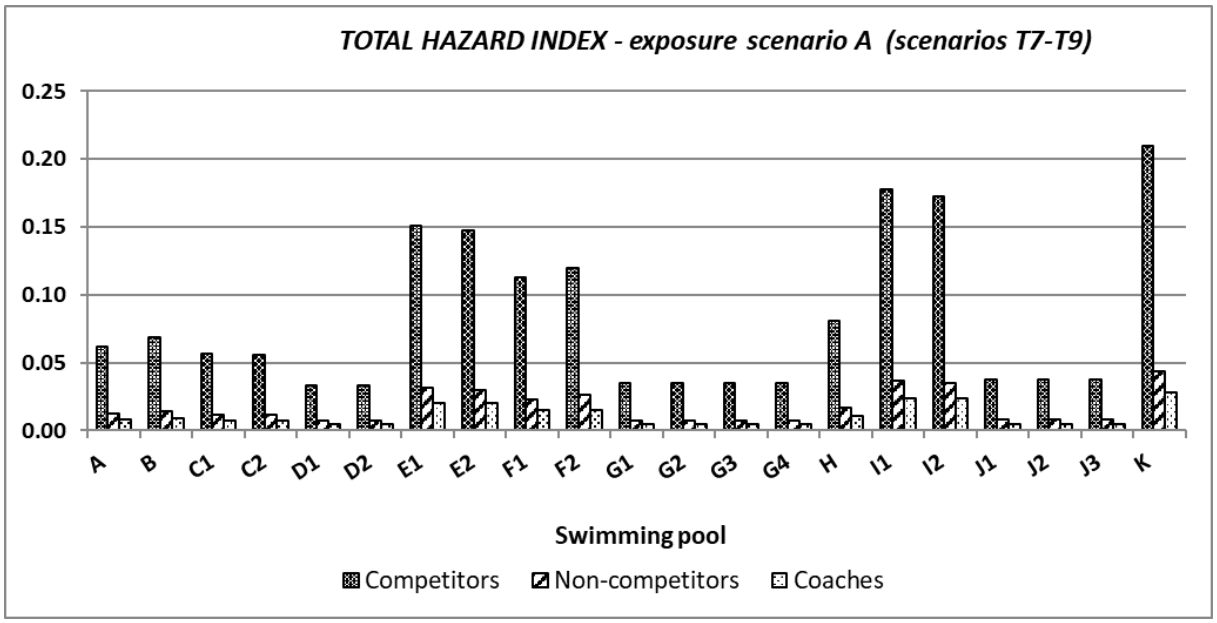

Fig. 8: Non-carcinogenic risk level (HI), considering all user groups (for ES-A)
Source: created by the authors