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Public perception on human exposure risk: A case study on endocrine disrupting compounds in the environment

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ABSTRACT

Humans are exposed to environmental risks owing to the broad usage of endocrine disrupting compounds (EDCs). However, the subjective evaluation of risk levels and characteristics, as well as the variation in risk processing, have not been thoroughly examined. The objective was to understand the public's perception of the risk associated with human exposure to environmental EDCs and identify any variations in risk perception. In this pioneering study conducted within the distinctive social and cultural context of Malaysia, a developing nation, a quantitative analysis approach was employed to assess the subjective evaluation of risk levels and characteristics among the public while developing a risk perception model. Data gathered from surveys and questionnaires were analyzed to gather information on the public's perception of environmental and health issues pertaining to pesticides, hormones, plastics, medicines, and cosmetics. The analysis revealed that the majority of the public assessed the level of human exposure to environmental risks based on experiential processing, which was influenced by cognitive and affective variables. Interestingly, a higher proportion of individuals in the community had a low risk perception of environmental EDCs, surpassing the overall risk perception by 19.3%. Furthermore, the public showed significant awareness of environmental and health issues related to pesticides, hormones, and plastics but had a lesser inclination to acknowledge the vulnerability of humans to risks associated with medicines and cosmetics. These findings suggest that the public is likely to be exposed to environmental EDCs based on their current perceived risks, and that sociopsychological factors play a significant role in shaping perceptions and judgments. This understanding can inform the development of targeted risk management strategies and interventions to mitigate the potential harm caused by environmental EDCs.

1. Introduction

Endocrine disrupting compounds (EDCs) have been extensively used as flame retardants, surfactants, plasticizers, fragrances, pharmaceuticals, additives, and pesticides, and have emerged as contaminants that can disrupt the endocrine system upon exposure (Wee and Aris, 2017). EDCs are present in trace concentrations in the global environment and pose potential health risks to the individuals and populations exposed to them. These risks primarily involve disruption of the endocrine system, such as the induction of xenobiotic metabolism, hormone-mediated modes of action, and oxidative stress response, impacting growth and development and causing behavioral changes, reproductive disorders (infertility and infecundity), reduced immunity, cardiometabolic diseases, and neurological disabilities (Priyadarshini et al., 2023; Rosenmai et al., 2018; Wee and Aris, 2017). Diseases such as diabetes, obesity, and cancer, which have a significant impact on global health, are often associated with endocrine dysfunction (Giulivo et al., 2016; Priyadarshini et al., 2023; Wee and Aris, 2017). Furthermore, EDCs commonly exist in the form of mixtures that exhibit higher toxicity than individual compounds owing to their combined effects (Wee et al., 2019).

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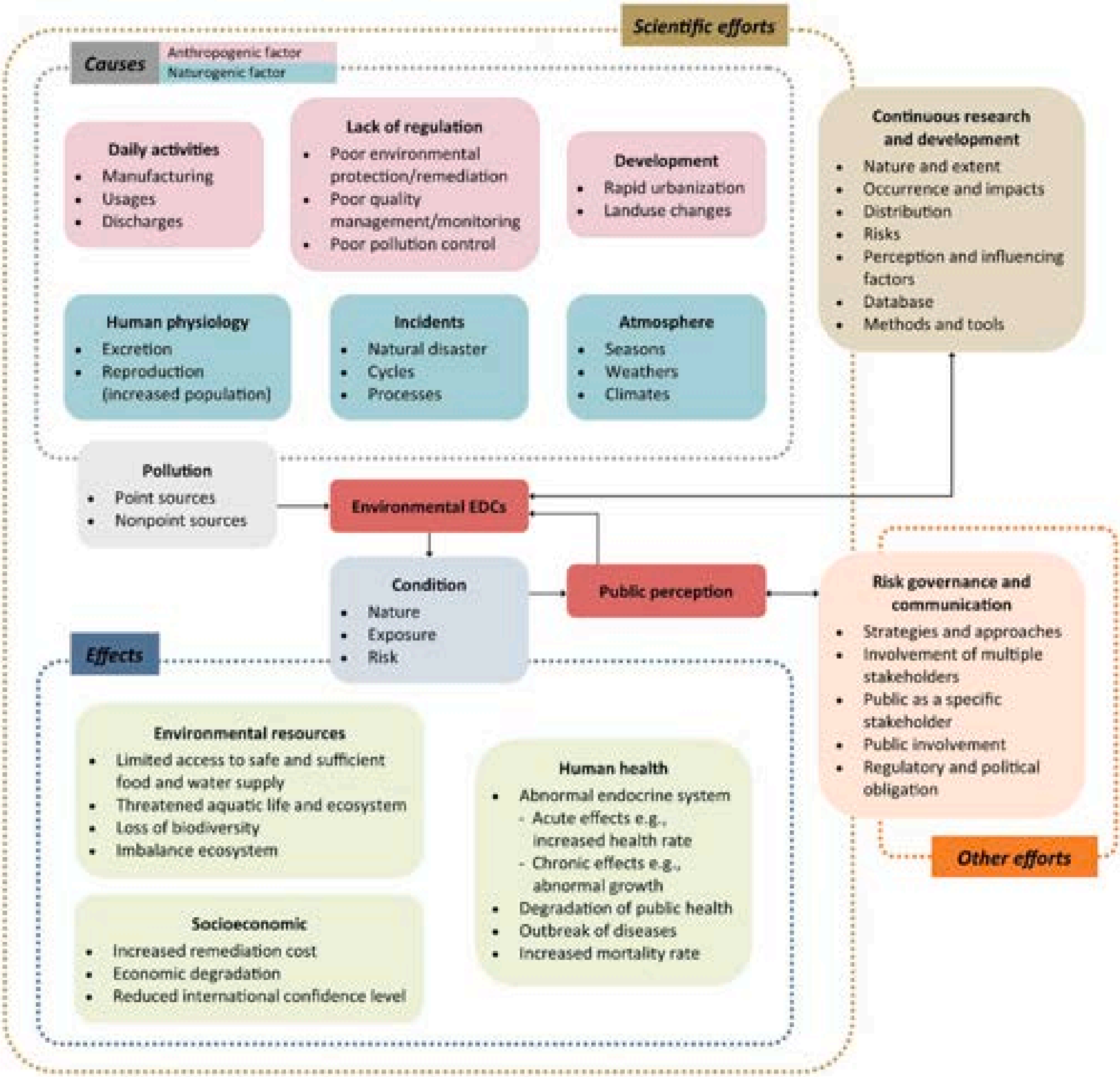

Fig. 1. Causes and effects of environmental EDCs and their associated risks. A limited understanding of EDC exposure and environmental risks is primarily attributed to ineffective communication and governance, particularly in developing countries. As a result, knowledge of EDC exposure and risks remains confined to the scientific community.

Addressing this emerging environmental issue is paramount for attaining sustainable development, marked by enhanced environmental quality, preserved biodiversity, improved environmental and public health, and efficient resource management, aligned with the objectives of the United Nations Sustainable Development Goals (SDGs).

Environmental EDCs originate from both anthropogenic activities and natural processes and cycles (Fig. 1). These contaminants undergo bioaccumulation, bioconcentration, biomagnification, and transport with toxins along the food chain or within the food web and water cycles, ultimately reaching humans as the final consumers and impacting all life stages (Ismail et al., 2017; Wee et al., 2020, 2022). Migration from consumer products (furniture, textiles, packaging, toys, construction materials, paints, cosmetics, etc.) also results in human exposure to EDCs via food ingestion, inhalation, and dermal absorption (Ismail et al., 2017; Wee and Aris, 2017). The situation becomes more concerning when the demand, production, usage, and discharge of EDCs are unregulated and greatly increased, particularly in the context of extensive urbanization encompassing economic growth, industrial expansion, and population increase (Fig. 1). Coupled with the high persistence and resistance to transformation of EDCs (chemical, physical, and biological), the extensive and unregulated production and utilization of these compounds has led to increased environmental pollution, which poses challenges for their effective removal within wastewater and water treatment facilities, perpetuating pollution throughout the water cycle (wastewater-aquatic ecosystem-drinking water) (Gou et al., 2016; Rosenmai et al., 2018; Simazaki et al., 2015; Sukatis et al., 2022). It is evident that EDC contamination in the environment not only poses hazards to the environment but also to humans through various exposure pathways.

The causes and pollution of EDCs have significant implications for the environment, human health, and socioeconomic aspects, with greater impacts and health issues observed in low-income households (Fig. 1). This emerging issue has raised public awareness and emphasized the need for scientific research to address knowledge gaps related to the nature, exposure, and risks associated with EDCs. Additionally, effective risk communication with public involvement and the development of risk behaviors are crucial for enhancing awareness and promoting the adoption of preventive and mitigation measures to regulate environmental EDCs and minimize their impacts on human health (Martin et al., 2009; Wachinger et al., 2013; Wee and Aris, 2019). There is growing interest in the environmental, occupational safety, and health risks associated with EDCs, particularly in relation to risk perception regarding policy support, handling and disposal practices, occupational safety and health practices, and usage behaviors (Dohle et al., 2013; Jallow et al., 2017; Vellinga et al., 2014; Yeh and Liao, 2016). However, regulation of these emerging contaminants in the environment, food, and drinking water is not a universal practice, regardless of the level of development in countries.

Owing to a lack of effective communication and governance, particularly in developing countries, the understanding of exposure and risks associated with EDCs in the environment has been limited mainly to the scientific community (Fig. 1). The dissemination of information on environmental safety and human health, regulatory and political obligations, and public involvement faces challenges without community-based two-way interactive communication and governance that incorporate top-down and bottom-up approaches. Consequently, emerging issues related to EDCs tend to be relatively underrated (Wee and Aris, 2019). This situation is further exacerbated when the public is unaware of or fails to perceive the significance of these issues, hindering positive changes in behavioral intentions. Therefore, it is crucial to evaluate and improve the perception of risks and the factors that influence them, as the likelihood of the public engaging in risk-related behaviors such as preparedness, reduction, prevention, and mitigation is positively associated with risk perception (Martin et al., 2009). Hence, effective communication and governance can only be achieved through enhanced public awareness and political responsibility, leading to the efficient regulation of EDCs and addressing environmental and public health concerns.

Understanding the public's perception of risk related to human exposure to environmental EDCs, evaluating the subjective assessment of risk severity based on factors such as likelihood and consequence, and analyzing variations in risk processing are essential for developing effective strategies for risk communication and management. Effective strategies involve significant goal-setting, method selection, and material development. It is crucial to recognize that different levels of risk perception can significantly impact risk-related behaviors, including individuals' willingness to pay to avoid health risks associated with pollution (Istamto et al., 2014). Furthermore, previous research has underscored the importance of studying risk perception, risk behavior, risk outcomes, and their determinants, particularly in relation to EDCs in the environment, which are currently yet to be explored (Wee and Aris, 2019). Moreover, risk analysis has been employed by key stakeholders, including international and intergovernmental entities, such as the United Nations High Commissioner for Refugees (UNHCR), World Health Organization (WHO), European Commission (EC), and Organization for Economic Co-operation and Development (OECD). These entities recommend risk analysis as a standard approach for monitoring and providing early warnings about risks, facilitating the formulation of action plans and contingency measures, particularly using the risk matrix as a tool (European Commission, 2016; OECD, 2012; UNHCR, 2023; WHO, 2012). Rapid risk management of acute public health events not only mitigates or prevents disease within affected populations but also minimizes adverse social and economic repercussions (WHO, 2012).

Thus, this study investigated the public's perception of risks related to human exposure to various environmental hazards, with a specific focus on EDCs. This research constitutes a pioneering study in Malaysia, a developing country, employing a quantitative analysis approach to identify the factors influencing the public's risk perception and processing, and to develop a risk perception model. It is hypothesized that the public has a relatively low perception of risk regarding human exposure to EDCs compared with other environmental risks. The lack of available data and challenges associated with studying this emerging issue may contribute to a lack of awareness and concern among the public. Additionally, it is speculated that the public's risk perception is influenced by experiential (non-rational) processing systems rather than analytical (rational) processing systems that consider the probabilities of occurrence and consequences. This is because the thinking and judgment of the public, who are mostly laypeople, are influenced by various cognitive and affective factors, including trust, knowledge, attitudes, practices, experiences, emotions, and values (Dohle et al., 2013; Etale et al., 2018; Janmaimool and Watanabe, 2014). The findings of this study are expected to be valuable for enhancing risk governance and communication by establishing risk levels and understanding the relationship between analytical and experiential risk processing.

2. Methods

2.1. Sampling and data collection

Putrajaya, located within the Greater Kuala Lumpur area, also known as the Klang Valley (GKL/KV), is a National Key Economic Area (NKEA) undergoing significant urbanization. The questionnaire survey was conducted between April 2018 and March 2019 and targeted residents of Putrajaya, Malaysia. The survey was carried out using a combination of hand-delivered questionnaires and online platforms. The sample size was determined using the Daniel (1995) sample size formula (Eq. 1), with an additional 20% added to account for the various factors. Due to the lack of available data on the prevalence of exposure to EDCs and its impact on health, the closest available prevalence value ($p = 0.083$), representing the total number of deaths attributed to environmental exposure, was incorporated from the works of Lichtenberg (2005) and Prüss-Ustün et al. (2011). A confidence level of 95% ($Z = 1.96$) and margin of error of 5% ($d = 0.05$) were assumed in the calculations.

$$n = (Z^2) \times (p\ (1 - p))/d^2 \quad (1)$$

2.2. Participants

The survey involved 140 respondents, consisting of 48.6% males ($n = 68$) and 51.4% females ($n = 72$). On average, the participants had been residents of Putrajaya for seven years. The study population included individuals aged 18 years and above, categorized as follows: ≤ 19, 20–29, 30–50, 51–59, and ≥ 60 years. Participation encompassed respondents from various educational levels, including secondary education, Diploma, Bachelor's, Master's, and Doctorate degrees. The majority of the participants (45%) held a Bachelor's degree. Additionally, the majority of them were government servants (60%). The remaining participants encompassed various occupational categories, including private workers, household workers, retired individuals, self-employed individuals, students, and those in other professions. Household income in Malaysia was grouped into percentages representing different economic classes: bottom 40% (B40), middle 40% (M40), and top 20% (T20). Putrajaya comprises households from all three income groups, with a median and mean monthly household income of RM 7512 and RM 10,401, respectively. The income groups were classified as follows: ≤ RM 2999, RM 3000–4999, RM 5000–6999, RM 7000–8999, RM 9000–10,999, RM 11,000–12,999, and ≥ RM 13,000 (RM 1 = USD 0.24,

Table 1
Mean score of risk characteristics and perceived risk level (based on analytical and experiential processing) for human exposure to environmental risk activities. SD: Standard deviation; [a] Risk level obtained from questionnaire survey representing experientially processed risk; [b] Risk level classified based on calculated risk score representing analytically processed risk; *Activity that contributes to environmental risks of EDCs.

Activity	Mean score (SD)			
	Likelihood	Consequence	Risk Level[a]	Risk level[b]
Increasing size of human population	3.67 (0.91)	3.54 (1.08)	3.53 (1.05)	3.21 (1.39)
Large-scale logging	4.14 (0.96)	4.07 (1.08)	4.00 (1.04)	3.91 (1.36)
Garbage and landfills	4.14 (0.94)	4.06 (1.02)	4.03 (0.95)	3.94 (1.30)
Limited access to safe water supply	4.14 (1.09)	4.24 (0.93)	4.15 (0.98)	3.97 (1.33)
Wind power generation	3.11 (1.16)	3.11 (1.11)	3.12 (1.12)	2.56 (1.35)
Hydroelectric power generation	3.24 (1.07)	3.29 (1.04)	3.26 (1.07)	2.71 (1.33)
Pesticide usage*	3.99 (0.93)	3.93 (0.95)	3.94 (0.96)	3.70 (1.26)
Hormone control in agriculture*	3.79 (1.01)	3.85 (0.94)	3.84 (0.97)	3.53 (1.32)
Medicine usage*	3.67 (0.93)	3.61 (1.00)	3.66 (0.99)	3.24 (1.33)
Cosmetic usage*	3.54 (0.96)	3.54 (0.92)	3.56 (0.96)	3.06 (1.29)
Plastic product usage*	3.95 (0.83)	3.89 (0.88)	3.89 (0.87)	3.66 (1.26)
Indoor air pollution	3.98 (0.97)	3.96 (0.95)	3.90 (0.95)	3.74 (1.27)

approximately in 2019).

2.3. Questionnaire and data analysis

The survey included questions aimed at gathering the opinions of respondents regarding human exposure to 12 different environmental risks. The risks were assessed in terms of likelihood, consequence, and risk level. Table 1 provides a comprehensive list of these risk activities. The enumeration of activities contributing to the environmental risks posed by EDCs was adopted from the existing literature reviews concerning pollution sources of environmental EDCs (Giulivo et al., 2016; Ismail et al., 2017; Wee and Aris, 2017). In addition to the five risk activities (5) specifically related to environmental pollution of EDCs, seven other non-EDC environmental risk activities (7) were also included. This differentiation was made to examine the public's perception of risks associated with non-EDC activities, which are commonly known environmental risks, compared with EDC activities, which are newly emerging environmental risks. The non-EDC activities were sourced from previous studies and reports (Carlton and Jacobson, 2013; Dohle et al., 2013; Weber et al., 2016). Respondents' perceptions of human exposure to each environmental risk were evaluated using a five-point Likert scale (Supplementary Table 1).

Likelihood was assessed on a scale ranging from "1 = rare" to "5 = almost certain," while consequence was evaluated on a scale from "1 = negligible" to "5 = catastrophic". Risk perception can be influenced by either an analytical or experiential system (Carlton and Jacobson, 2013; Janmaimool and Watanabe, 2014). By asking the public “What is the level of risk of the following activity to humans?”, the risk level, ranging from “1 = very low” to “5 = very high”, indicates the public's experiential processing of risk.

Using a risk-based approach, risk scores were calculated by integrating survey responses regarding the likelihood and consequence of environmental risks to humans into Eq. (2). The risk scores were subsequently classified on a 5-point scale of risk level:1 (very low, risk score 1 – 4), 2 (low, risk score 5 – 9), 3 (medium, risk score 10 – 12), 4 (high, risk score 15 – 16), and 5 (very high, risk score 20 – 25).

$$\text{Risk} = \text{Likelihood} \times \text{Consequence} \quad (2)$$

Further, the public's perception of the effects of EDCs was assessed by posing the question, "I am concerned about the effects of EDCs", using a five-point Likert scale ranging from "1 = strongly disagree" to "5 = strongly agree" (Wee et al., 2022). Sociodemographic questions (11 items) were included in the questionnaire for categorization. The questionnaire was validated by experts and pre-tested, resulting in a Cronbach's alpha value of 0.935. The questionnaire was copyrighted (LY2018000940) by the Intellectual Property Corporation of Malaysia (MyIPO) through Putra Science Park and approved by the Universiti Putra Malaysia Ethics Committee for Research Involving Human Subjects (JKEUPM-2017–181).

Statistical analysis was conducted using the IBM SPSS software (Version 22.0). The datasets were subjected to verification procedures prior to statistical analysis, involving the application of the

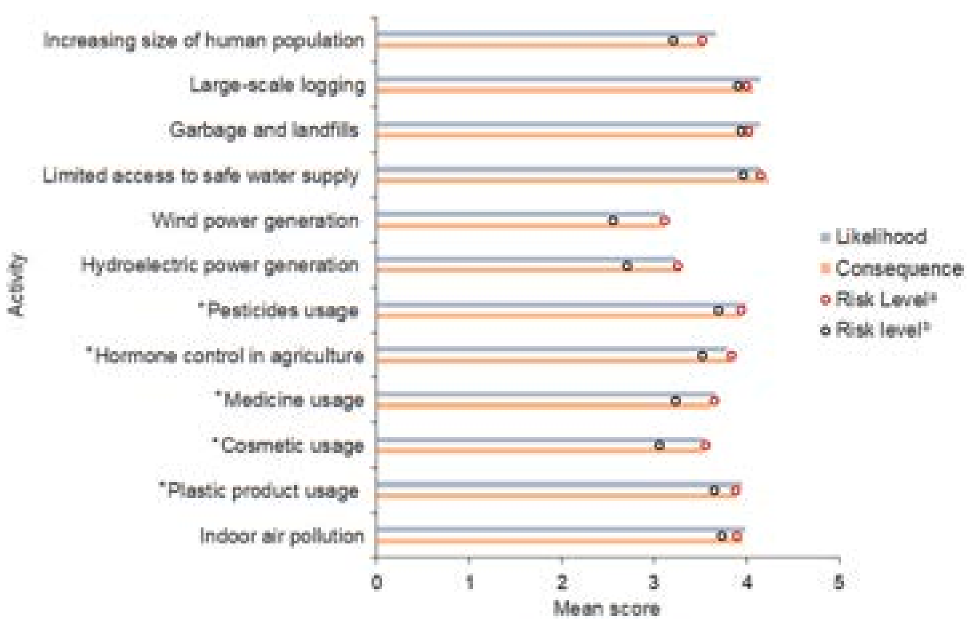

Fig. 2. Risk characteristics and risk level perceived (based on analytical and experiential processing) on human exposure to environmental risks. [a] Risk level obtained from questionnaire survey representing experientially processed risk; [b] Risk level classified based on calculated risk score representing analytically processed risk; *Activity that contributes to environmental risks of EDCs.

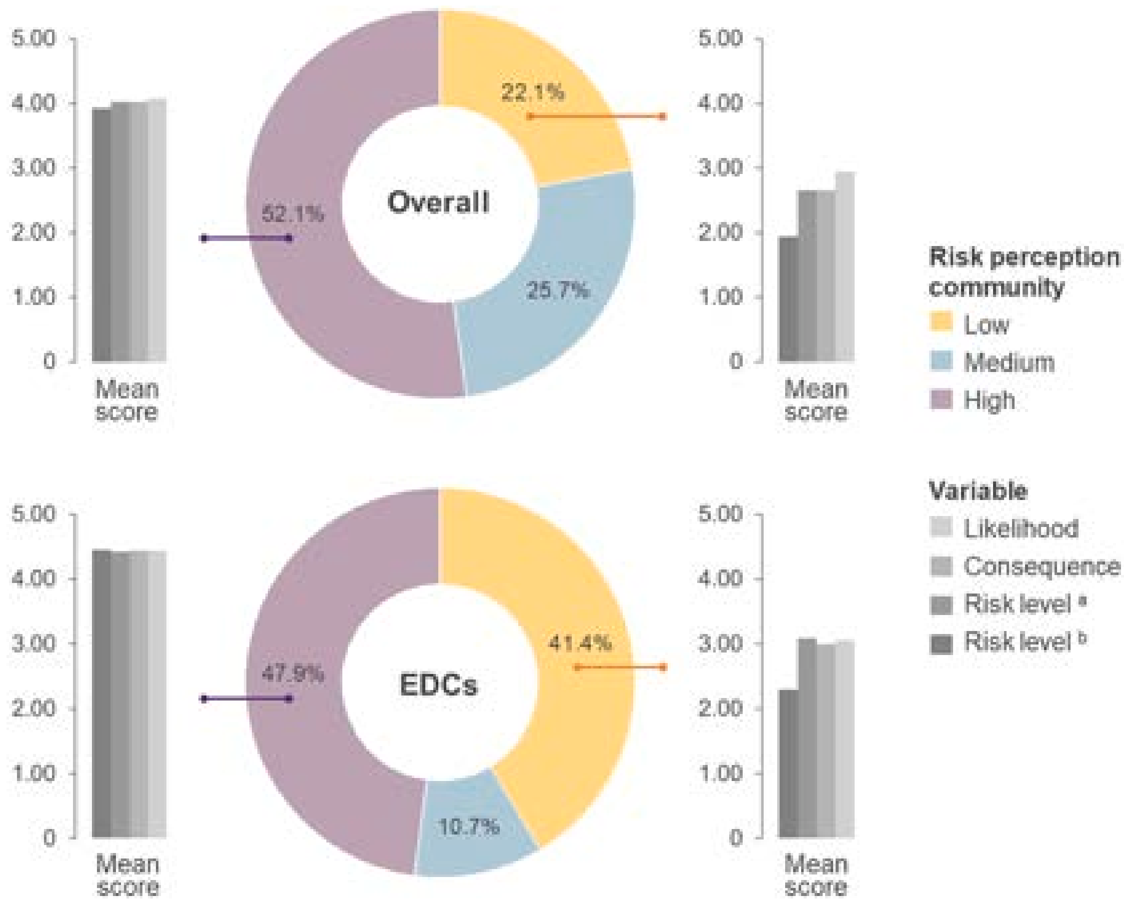

Fig. 3. Comparison of risk perception communities and respondents' mean responses to the risk perception of human exposure to environmental risk. [a] Risk level obtained from questionnaire survey representing experientially processed risk; [b] Risk level classified based on calculated risk score representing analytically processed risk.

Shapiro–Wilk test to assess normality, Levene's test to evaluate homogeneity of variances, and a multicollinearity test. Statistical significance of the differences was tested using one-way analysis of variance (ANOVA) and independent *t*-test, while the significance of relationships was evaluated through bivariate correlation analysis. A risk perception model was constructed using multiple linear regressions (MLR). Descriptive statistics were used to estimate the scores and percentages for questions with multiple responses based on the total number of answers provided.

3. Results and discussion

3.1. Public risk perception

In general, a majority of the public exhibited an experiential perception towards the risk level, ranging from "medium" to "high" (with mean scores ranging from 3.12 to 4.15 out of 5), regarding human exposure to environmental risks. Table 1 presents a breakdown of the mean scores for the risk perception variables for each environmental risk, while Fig. 2 illustrates the observed differences. The findings revealed that wind power generation is perceived as the least severe environmental risk to human health. Conversely, limited access to safe water supplies was perceived to be the most severe risk factor. It is worth noting that the efficiency of drinking water treatment technologies may not guarantee complete removal of contaminants, potentially resulting in human exposure to environmental pollutants through daily water ingestion (Wee and Aris, 2017). When considering the trade-off between human health and environmental safety, the emphasis appears to lean more towards addressing health concerns (Dohle et al., 2013).

Currently, the public's perception of risks related to drinking water quality has mainly focused on physical properties (such as pH and turbidity), microbiological parameters (including total coliforms and *Escherichia coli*), chemical contents (such as disinfectants, disinfection by-products, nutrients, metals, and major ions), and aesthetic concerns (including taste, odor, and color) (Chappells et al., 2014; Flanagan et al., 2015; Ochoo et al., 2017; Wedgworth et al., 2014). Most of the population (85%) expressed high levels of concern regarding tap water quality; however, this concern was less likely to be associated with EDCs (Wee et al., 2022). Furthermore, uncertainty exists among the public regarding the safety of tap water and the effectiveness of Malaysia Drinking Water Quality Standard in governing EDCs within tap water. A substantial proportion of respondents (39.3%) perceived that existing drinking water guidelines were capable of regulating EDCs in tap water; however, it is noteworthy that most EDCs were not presently subject to regulation under this guideline. In the context of addressing emerging contaminants, many developing and underdeveloped nations often lack the necessary monitoring and regulation, in contrast to developed countries that have made significant progress in implementing stringent guidelines (Wee and Aris, 2019, 2023). Moreover, Praveena et al. (2020) reported low public awareness (knowledge, attitude, and practice) regarding pharmaceutical handling and its impact on tap water quality, with only 44.5% of the population exhibiting good knowledge, 27.5% demonstrating a positive attitude, and only 1.6% displaying good practices in this context.

Water security and sanitation improvements are closely linked to SDG 6, which focuses on clean water and sanitation. Many countries have committed to implementing and managing water systems, while actively involving local communities to enhance water and sanitation

Table 2
Mean responses of respondents with low- and high-risk perceptions of human exposure to environmental risk. SD: Standard deviation; [a] Risk level obtained from questionnaire survey representing experientially processed risk; [b] Risk level classified based on calculated risk score representing analytically processed risk; * All differences significant at the 0.001 level (2-tailed).

Activities	Overall					EDCs				
Variables	Low risk ($n = 31$)		High risk ($n = 73$)		Difference*	Low risk ($n = 58$)		High risk ($n = 67$)		Difference*
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Likelihood	2.94	0.57	4.07	0.89	$t(85) = -7.8$	3.05	0.38	4.44	0.45	$t(122) = -18.8$
Consequence	2.65	0.71	4.03	1.07	$t(102) = -6.6$	3.00	0.46	4.44	0.48	$t(121) = -17.2$
Risk level[a]	2.65	0.80	4.03	0.96	$t(102) = -7.0$	3.08	0.48	4.42	0.50	$t(123) = -15.1$
Risk level[b]	1.94	0.73	3.92	1.28	$t(93) = -10.0$	2.29	0.50	4.45	0.47	$t(123) = -25.1$

management. Thus, this study recommends further investigation into the public's perceived risks associated with emerging water quality issues, specifically regarding the presence of EDCs in drinking water, along with an examination of the factors influencing these perceptions. This will enable a comprehensive conceptualization of models and predictors related to the emerging issue of drinking water supply security, considering the potential EDC contamination. This approach supports the implementation of a multi-barrier system for monitoring and managing the drinking water supply, encompassing the entire system from the environment to the final drinking water product (Wee and Aris, 2017). Additionally, safeguarding public health in this context is connected to SDG 3, which promotes good health and well-being, and also contributes to SDG 8, which aims for decent work and economic growth. Given the widespread use of EDCs in daily products and human activities, finding a balance between Goals 3, 6, and 8 is crucial in striving to decouple economic growth from environmental degradation.

3.2. Risk perception community

To examine the disparities between individuals with low- and high-risk perceptions regarding human exposure to environmental issues, the mean responses to the variables were categorized as follows: low-risk perception (scores ≤ 3.00), which accounted for 22.1% of the sample, and high-risk perception (scores ≥ 3.75), which accounted for 52.1% of the sample (Fig. 3). These two groups exhibited significant differences in their perceptions of environmental risks in both experiential ($t(102) = -7.0$, $p < 0.001$) and analytical ($t(93) = -10.0$, $p < 0.001$) processing (Table 2). Furthermore, the high-risk perception group displayed significantly higher mean responses across all variables than the low-risk perception group. Remarkably, the proportion of the low-risk community regarding environmental EDCs ($n = 58$, 41.4% of the sample) was higher than the overall risk perception ($n = 31$, 22.1% of the sample) (19.3% higher than the overall risk perception) (Fig. 3). In contrast, a lower proportion of the high-risk perception community viewed EDC-related activities as high-risk (4.2% lower than the overall risk perception). Surprisingly, 11.4% of them perceived the risk level of EDC activities as "low" or "very low".

Currently, the nature, characteristics, and evidence of these emerging contaminants are still under investigation by the scientific community. As a result, the public is not expected to exhibit a strong inclination toward good risk behavior (awareness and concern) regarding this emerging issue, namely EDCs in the environment and human exposure (Wee and Aris, 2019). Nonetheless, it is important to note that the listed EDC risk activities are proven to be common sources of multiclass EDCs found in various compartments of the global environment, posing potential risks (Ismail et al., 2019, 2020; Omar et al., 2019; Wee et al., 2019). Even at trace concentrations, EDCs can disrupt the endocrine system, affecting the central nervous system, reproductive system, growth and development, cell proliferation, and metabolism (Hua et al., 2016; Kong et al., 2013; Li et al., 2012; Wee and Aris, 2017). Diseases such as diabetes, obesity, and cancer, which are prevalent worldwide, can be attributed to endocrine dysfunction (Giulivo et al., 2016; Priyadarshini et al., 2023; Wee and Aris, 2017). Furthermore, EDCs could potentially present the most substantial risk during prenatal and early postnatal development, a critical period when organs and systems undergo formation, especially thyroid dysfunction with associated severe neurogenesis impairment, including cognitive and behavioral deficits (Yilmaz et al., 2020). These findings suggest a potential discrepancy between the perceived and actual risks. Previous studies have also reported that respondents' risk perceptions differ from the actual environmental risks (Dohle et al., 2013; Götz et al., 2019).

3.3. The influencing factors and risk perception model

The public's perception of the likelihood of occurrence (overall: 3.78 ± 0.70; EDCs: 3.79 ± 0.77) and the negative effects of risk activities on humans (overall: 3.76 ± 0.75; EDCs: 3.77 ± 0.81) did not show a significant difference (overall: $t(278) = 0.261$, $p > 0.05$; EDCs: $t(278) = 0.241$, $p > 0.05$). Furthermore, a significant positive correlation was observed between the risk characteristics (overall: $r = 0.885$, $p < 0.001$; EDCs: $r = 0.867$, $p < 0.001$) (Fig. 4). This indicates that the perceived probability of an environmental hazard and its subsequent

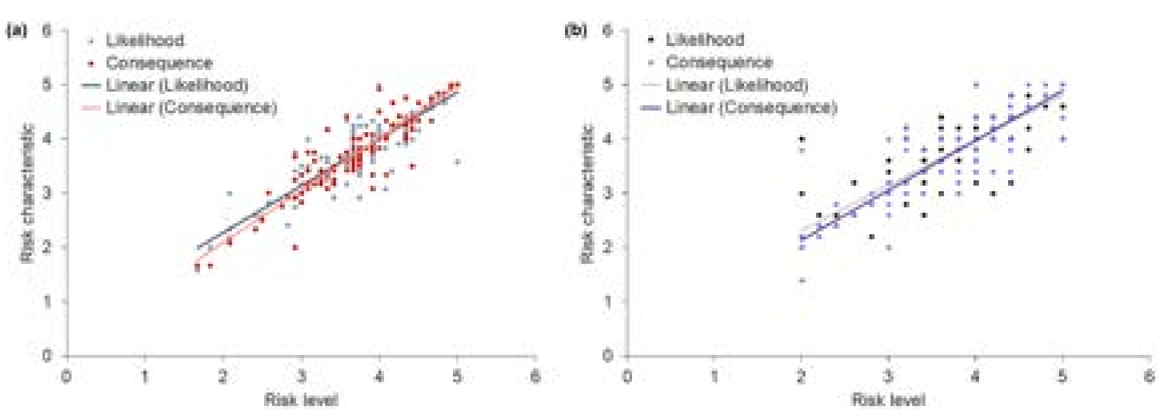

Fig. 4. Relationship between risk characteristics (likelihood and consequence) and public-perceived risk level of (a) overall environmental activities and (b) EDC-related activities for humans.

impacts are directly related to the perceived risk level. In theory, the risk level is determined by risk characteristics, namely, the likelihood and consequences of environmental hazards. In this study, the consequences of the hazards ($r = 0.936$, $p < 0.001$) had a stronger influence on the risk level than the likelihood ($r = 0.894$, $p < 0.001$) (Fig. 4a). Evidently, the public considered the consequences of hazards if they were to occur more than the likelihood of the hazards actually occurring. The consequences of the hazards were the primary factor influencing how laypeople perceived risks, even though individuals may analytically process risks based on the probability of occurrence and the consequences of the hazards as a whole (Janmaimool and Watanabe, 2014). The influence of risk characteristics on the public's perception of risks related to human exposure to EDC-related hazards was similar (likelihood: $r = 0.874$, $p < 0.001$; consequence: $r = 0.908$, $p < 0.001$; Fig. 4b).

There were differences in the perception of risk characteristics and levels between male and female participants; however, there were no significant gender differences in risk processing ($p > 0.05$). Additionally, risk perception varied among different age groups, with the 20–29 age group perceiving most environmental risks as more severe. In contrast to the study by Dohle et al. (2013), older adults (40–60 age group) evaluated the environmental risks of pharmaceutical usage as more severe than younger adults aged 20–39 years. It is worth noting that the respondents ranked the risk level of limited access to water supply and indoor air pollution as significantly "high" to "very high" ($p = 0.03$ and $p = 0.02$, respectively), which was not the case for the other environmental risks, including EDC risks.

Previous studies have indicated a significant influence of education and income on the perception of environmental risks (Chatterjee et al., 2017; Flanagan et al., 2015). In the present study, there were variations in education levels and income groups among the residents; however, no significant difference was found between these variables and the public's perception of the risks related to human exposure to environmental hazards ($p > 0.05$). These insignificant effects align with the findings of van der Linden (2015). It is important to note that education and income are no longer the sole factors that determine risk perception through knowledge alone.

The effects of sociodemographics and risk characteristics were further examined to determine the significant factors influencing the risk perception of EDCs through the development of a risk perception model. All estimated values, including tolerance values above 0.10 and VIF values below 10 (Supplementary Table 2), indicated no multicollinearity in the regression model (O'Brien, 2007). Risk characteristics were significant predictors, with Likelihood ($\beta = 0.359$, $p < 0.001$) and Consequence ($\beta = 0.595$, $p < 0.001$) playing key roles. A mathematical model for public risk perception of the risk level associated with EDC-related activities in humans ($R^2 = 0.861$) was established using Eq. (3).

$$\text{Risk perception} = 0{\cdot}376\ (\text{Likelihood}) + 0{\cdot}588\ (\text{Consequence}) - 0{\cdot}025 \quad (3)$$

The positive coefficients of the factors indicate that the public perceives higher environmental risks associated with human exposure when confronted with elevated likelihood and consequences in environmental risk activities. Nonetheless, other factors such as cognitive processes and affective reactions may also play a role in shaping individuals' perception of risks (Chappells et al., 2014). Contextual factors such as cost and convenience prominently influence individual behavior and decision-making (Etale et al., 2018). Prominent factors driving plastic usage, specifically bisphenol A-containing baby bottles, in African markets are high availability, accessibility, and affordability (Pouokam et al., 2014). The risk perception model could be enhanced by broadening the research scope to include other cognitive and affective variables as well as other sociopsychological factors that may influence risk perception, the development of risk behaviors, and choice-making.

3.4. Analytical and experiential risk processing

Furthermore, the risk levels obtained from the survey, representing experientially processed risk scores, were consistently higher than those based on analytically processed risk scores for all environmental risks (Table 1 and Fig. 2). Notably, sociopsychological factors may play a mediating role in the development of risk perception and behavior. This is evident when the public's perceived risk, as determined by the survey, cannot be fully explained analytically. Interestingly, wind power generation and hydroelectric power generation were categorized as "low" to "medium" risk levels (mean score of 2.56 ± 1.35 and 2.71 ± 1.33, respectively) based on the analytically processed risk scores. However, they were ranked as "medium" to "high" risk levels (mean score of 3.12 ± 1.12 and 3.26 ± 1.07, respectively) based on the experientially processed risk scores. In contrast, the other environmental risks were consistently ranked as "medium" to "high" risk levels (mean score ranging from 3.06 to 3.97) under analytical risk processing.

The differences between analytical ($M = 3.44$, $SD = 1.39$) and experiential ($M = 3.74$, $SD = 1.04$) processing of all environmental risks were found to be statistically significant ($p < 0.001$), as was the case for environmental EDCs ($p < 0.01$). It appears that the public, who are predominantly laypeople, tends to process risk levels based on an experiential processing system rather than an analytical processing system. This experiential processing is often influenced by cognitive and affective variables to a similar or even greater extent than by the risk characteristics such as likelihood and consequence, as observed in previous studies (Dohle et al., 2013; Etale et al., 2018; Janmaimool and Watanabe, 2014). Therefore, it is highly recommended to conduct additional research and further investigate this aspect, particularly concerning environmental EDCs. It is crucial to understand the underlying sociopsychological factors that influence perception and judgment to develop effective measures, such as prevention and interventions, to enhance risk communication.

3.5. Implications of perceived risk and solution

Regarding the environmental risks of EDCs, significant differences were observed in the perception of human health risks ($F(4, 695) = 3.83$, $p = 0.004$). The use of cosmetics such as perfume and toothpaste ($M = 3.56$, $SD = 0.96$) was perceived as less severe than the use of plastic products ($M = 3.89$, $SD = 0.87$) and pesticides such as insect repellents ($M = 3.94$, $SD = 0.96$), with p values of 0.04 and 0.01, respectively. The public was generally more aware of the environmental and health issues associated with pesticide, hormone, and plastic use. This awareness aligns with current findings of the presence of specific residues in the environment, including pesticides (chlorpyrifos, quinalphos, and diazinon), hormones (testosterone, progesterone, estrone, 17β-estradiol, and 17α-ethynylestradiol), and plasticizers (bisphenol A, 4-octylphenol, and 4-nonylphenol) (Ismail et al., 2019, 2020; Omar et al., 2019; Wee et al., 2019). In contrast, people in Cameroon and Nigeria are largely unaware of issues related to plastic usage, such as leaching, contamination, and the potential health effects of bisphenol A, and only a few individuals were found to be aware of the existence of different types of plastic materials (Pouokam et al., 2014).

Comparatively, the public seemed to be less aware of the risks associated with the use of medicines ($M = 3.66$, $SD = 0.99$) and cosmetics ($M = 3.56$, $SD = 0.96$). It is worth noting that pharmaceutical and personal care products, such as caffeine and diclofenac, were detected at high concentrations (up to 19.3 ng/L) in riverine water and the raw water of the drinking water treatment plant in the study's water basin, originating from human activities (Wee et al., 2019). In addition, these pharmaceutical and personal care product residues have been found in coastal and estuarine water bodies, sediments, and organisms (Ismail et al., 2019, 2020; Omar et al., 2019). High hazard quotient values for human health risks associated with ciprofloxacin (an antibiotic) and dexamethasone (an anti-inflammatory drug) (HQ > 1, ranging from

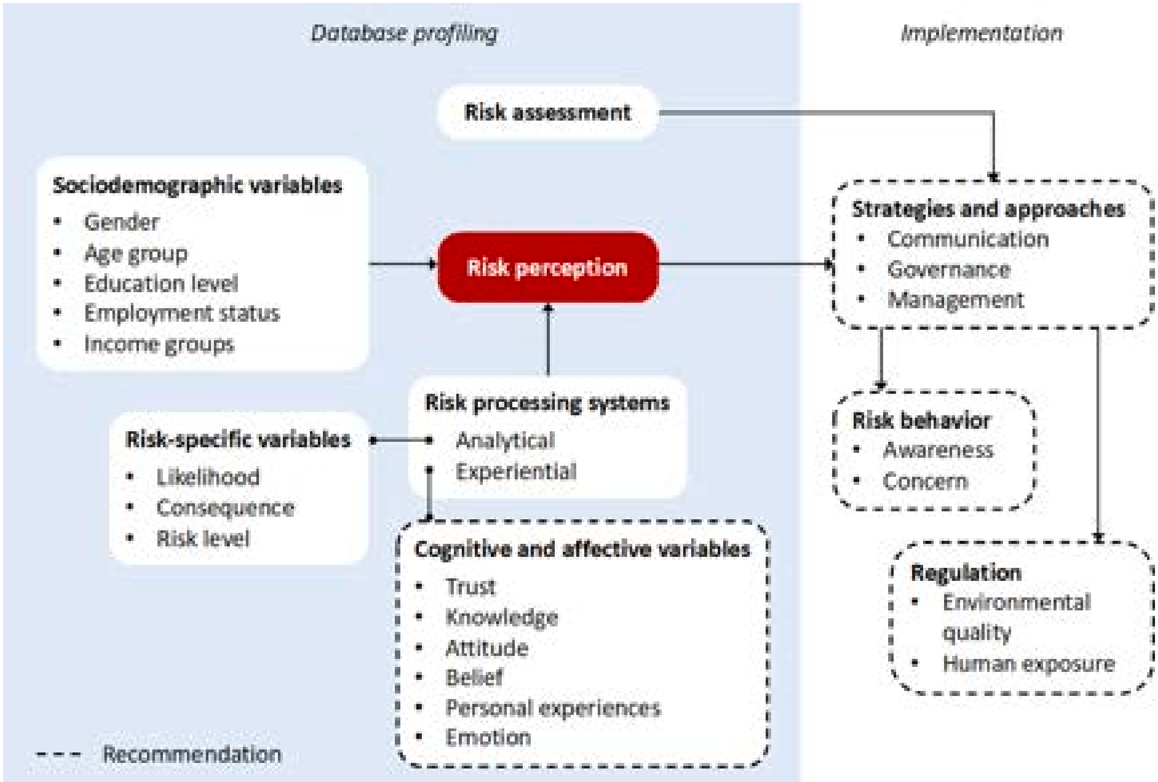

Fig. 5. Overview of current research findings on the public perception of human exposure risks to environmental EDCs and recommendations for future studies and implementation.

1.52 – 41.36), along with ecotoxicological risk quotient values for eight pharmaceuticals (RQ values between 1 and 10, indicating moderate risk) and diclofenac (RQ value > 30, high risk) have been documented in Malaysian water resources (Praveena et al., 2018). These contaminants have been detected not only in local environments but also in global contaminants (Wee and Aris, 2017). It is estimated that more than 80% of the world's wastewater is discharged back into the environment without undergoing treatment or reuse, adversely affecting at least 2 billion people worldwide (United Nations, 2023). Adequate funding, technical capacity, and infrastructure are imperative for water and wastewater treatment; however, they are frequently lacking in rural areas and developing countries, leading to the direct discharge of a significant proportion of wastewater into surface water. In Africa, the minimal removal of EDCs through wastewater treatment processes has resulted in the occurrence of EDCs, with the highest reported concentration being 167 μg/L of lamivudine, an antiretroviral, in surface water and sediment concentrations ranging from μg/kg to mg/kg (K'oreje et al., 2020). Additionally, the treated and untreated drinking water in Africa were revealed to contain EDCs in concentrations ranging from 0.02 ng/L to 34 μg/L and 0.1 ng/L to 18 μg/L, respectively.

The perceived risks associated with emerging EDC activities were lower than other widely recognized environmental risks, such as logging, waste disposal, and water supply issues (Fig. 3). Moreover, the public exhibited an average response of "unsure" and "agree" ($M = 3.57$, $SD = 0.64$) regarding their level of concern about the effects of EDCs. This skewed public perception of environmental risk problems contributes to ongoing environmental pollution, with the subsequent monitoring and management plan within the ecosystem, as well as in the domains of food and water supply and water cycle (resource protection, treatment and remediation, policy and legislation, etc.) demonstrating relative ineffectiveness in regulating emerging pollutants. The presence of a wide range of multiclass EDCs in environmental matrices at concentrations that can disrupt endocrine functions has been extensively reviewed (Wee and Aris, 2017). Exposure to EDCs and the associated health risks can occur through various pathways, such as dietary intake, inhalation, and dermal absorption. Human exposure and its impacts have been observed, particularly in cases where Malaysia tap water contains diclofenac at the highest mean concentration of 6.5 ng/L, followed by triclosan and caffeine at concentrations of 2.6 ng/L and 2.4 ng/L, respectively (Wee et al., 2020). Additionally, contamination of the food supply with EDCs and subsequent exposure through food ingestion are global concerns (Ismail et al., 2017; Omar et al., 2019). A range of EDCs, including testosterone, progesterone, dexamethasone, primidone, propranolol, caffeine, sulfamethoxazole, diclofenac, chloramphenicol, diethylstilbestrol, quinalphos, diazinon, and chlorpyrifos, were detected at levels up to 43.56 ng/g within mariculture fish species, specifically *Trichinous blochii*, *Lutjanus campechanus*, *Lutjanus erythropterus*, *Lutjanus argentimaculatus*, *Carangoides armatu*, and *Lates calcarifer*, which serve as pivotal protein sources for human consumption and export commodities (Ismail et al., 2021).

In addition, Ochoo et al. (2017) and Ford et al. (2019) highlighted the role of multiple stakeholders in facilitating communication and management to enhance public perception. There is a need for information dissemination and public participation in risk management along with the development of effective communication strategies and governance approaches, including clear goals and methods. In this regard, stakeholders should not overlook the importance of providing understandable and scientifically accurate communication materials such as information in appropriate formats and types (Janmaimool and Watanabe, 2014). Limited access to new policies and advancements in technology and chemical innovations remain a perennial challenge in environmental risk management practices, particularly in developing countries (Ho and Watanabe, 2020). Fostering communication and collaboration between developed and developing nations, which involves the transfer of pertinent and cost-effective technologies, including both novel and well-established approaches, should be prioritized. An overview of current research findings regarding public perceptions of human exposure risks to environmental EDCs, along with suggestions for future studies and implementation, is presented in Fig. 5. This serves as a basis for the formulation of effective risk communication and governance strategies, leading to improved risk behaviors, such as preparedness, reduction, prevention, and mitigation, and ensuring sufficient regulation of environmental quality and human exposure.

4. Conclusion

Overall, the public's perception of human exposure to environmental risks was primarily based on experiential processing, with a perceived risk level ranging from "medium" to "high" (mean score ranging from 3.12 to 4.00). The most severe risk was perceived to be limited access to safe water supply. In terms of EDC risk perception, disseminating information is highly recommended to increase public awareness and participation. This is particularly important because a higher proportion of the sample (41.4%) had a low-risk perception than the overall perception of environmental risks (22.1% of the sample). Additionally, a lower proportion of the high-risk perception community viewed EDC-related activities as high-risk, which was 4.2% lower than the overall perception of risks. The public's concerns primarily revolved around the environmental and health issues associated with pesticide, hormone, and plastic usage, although there is also the risk of adverse effects from medicine and cosmetic use. Furthermore, the public tends to perceive risks through an experiential processing system that is heavily influenced by cognitive and affective variables. As a result, sociopsychological effects may play a significant role in shaping risk perception and behavior. Undertaking an in-depth analysis of the public's responses to risk perception, especially in the context of environmental risks and water quality concerns, is crucial (Fig. 5). Additional databases on the determinants of risk perception and actual risk assessment are essential for formulating comprehensive conceptual models and predictors, facilitating effective risk governance and communication within stakeholder groups and communities.

CRediT authorship contribution statement

Sze Yee Wee: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing - original draft, Writing - review & editing; **Ahmad Zaharin Aris**: Conceptualization, Funding acquisition, Supervision, Validation, Writing - review & editing; **Fatimah Md. Yusoff**: Methodology, Writing - review & editing; **Sarva Mangala Praveena**: Methodology, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All relevant data supporting the findings of this study are available within the paper and its Supplementary Material file.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ecoenv.2023.115830.

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