PENILAIAN PERSEKITARAN HUBUNGAN PENCEMARAN AIR PAIP DOMESTIK OLER LOGAM LITIUM DAN ANTIMONI DENGAN TAHAP HORMON TIRO ID DALAM KALANGAN POPULASI DEW ASA DI DAERAH KUALA LANGAT

MUHAMMAD RIDZWAN BIN RAFI'I

UNIVERSITI KEBANGSAAN MALAYSIA

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Nama penuh pengarang (*Author's Full Name*)	DR MUHAMMAD RIDZWAN BIN RAFI'I		
No. Pendaftaran Pelajar (Student's Registration No.)	P137727	Sesi Akademik (*Academic Session*)	2023/2024
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TANDATANGAN PELAJAR ***(STUDENT'S SIGNATURE)***	PROFESSOR DR. AZMAWATI MOHAMMED NAWI MB(UKM), MComm Med (Epid & Stat) (UKM) PhD(UKM) MMC Reg. No. 37967 Public Health Specialist & Medical Lecturer Department of Public Health Medicine Faculty of Medicine, UKM **TANDATANGAN PENYELIA / PENGERUSI JK SISWAZAH** ***(SUPERVISOR'S / CHAIRPERSON SUPERVISION COMMITTEE SIGNATURE)***
Nama Pelajar *(Student name)*: DR MUHAMMAD RIDZWAN BIN RAFI'I No. Pendaftaran Pelajar *(Student's Registration No.)*: P137727 Tarikh: 7.9.2026 *(Date)*	Nama Penyelia / Pengerusi JK Siswazah : *(Supervisor's / Chairperson Supervision Committee Name)* AZMAWATI MOHAMMED NAWI Tarikh: 7.9.2026 *(Date)*

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Saya akui karya ini adalah hasil kerja saya sendiri kecuali nukilan dan ringkasan yang tiap-tiap satunya telah saya jelaskan sumbernya.

2 SEPTEMBER 2026

MUHAMMAD RIDZWAN BIN RAFI'I
P137727

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ABSTRAK

Penyakit tiroid (hipertiroid atau hipotiroid) kini semakin diiktiraf sebagai isu kesihatan awam global. Walaubagaimanapun, hubungan pendedahan kepada logam Litium (Li) dan Antimoni (Sb) masih kurang dikaji di negara ini. Kajian ini menilai pendedahan logam-logam tersebut serta perkaitannya dengan tahap hormon tiroid, faktor berkaitan, interaksi pendedahan dan nilai ambang dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor. Kajian hirisan lintang ini dijalankan kepada 120 responden yang dipilih melalui kaedah pensampelan secara rawak menggunakan pensampelan pelbagai peringkat. Data utama kajian ini dikumpul melalui soal selidik berpiawai, analisis air paip domestik, analisis Li urin dan Sb urin, serta penentuan tahap hormon tiroid (TSH, T_3, T_4). Hanya 6(5.0%) daripada responden kajian mempunyai bacaan hormon tiroid abnormal. Tiada hubungan yang signifikan antara kepekatan Li dan Sb dalam air paip domestik dengan tahap hormon TSH, T_3 dan T_4 ($p>0.05$). Analisis regresi linear berganda menunjukkan peningkatan Li urin (β =-0.08; $p<0.001$), wanita (β =-1.42; $p=0.004$) dan bekerja di bahagian pembuatan (β =-1.69; $p=0.032$) dikaitkan dengan penurunan signifikan hormon T_4. Manakala, pengambilan sayur-sayuran kurang daripada dua kali sehari mempunyai perkaitan signifikan dengan peningkatan hormon T_4 (β =1.04; $p=0.026$). Bagi hormon T_3, responden yang bekerja di bahagian pembuatan (β=0.96; $p=0.002$) atau pengambilan rokok tinggi (β =0.10 ; $p<0.001$) menunjukkan peningkatan hormon T_3 secara signifikan. Kajian ini juga mendapati tiada sebarang interaksi signifikan yang diperhatikan ($p>0.05$) serta terdapat beberapa penanda bio berpotensi Li urin dan Sb urin untuk menilai status tiroid (normal, hipotiroid dan hipertiroid). Kesimpulannya, dos dalaman Li (urin) berpotensi mempengaruhi tahap hormon tiroid walaupun pada tahap pendedahan yang rendah, menunjukkan bahawa dos dalaman merupakan petunjuk yang lebih sensitif berbanding kepekatan Li dalam air paip domestik. Berdasarkan pendekatan NOAEL, nilai 10µg/L bagi logam Li dicadangkan sebagai nilai pemantauan yang menyokong pertimbangan untuk dimasukkan di bawah Program Piawaian Kualiti Air Minuman Negara dan nilai logam Sb 5µg/L disyorkan untuk dikekalkan.

ASSESSMENT OF ENVIRONMENTAL LITHIUM AND ANTIMONY DOMESTIC PIPE WATER POLLUTION RELATIONSHIP ON THYROID HORMONES LEVELS AMONG THE ADULT POPULATION IN KUALA LANGAT

ABSTRACT

Thyroid disorder (hyperthyroid or hypothyroid) is increasingly recognized as a global public health issue. However, the relationship between exposure to metals such as Lithium (Li) and Antimony (Sb) is still poorly studied in this country. This study assessed exposure to Li and Sb metals and their association with thyroid hormone levels, associated factors, exposure interactions, and threshold values among adult residents in the Kuala Langat district, Selangor. This cross-sectional study was conducted with 120 respondents selected through a multistage random sampling process. Data from this study were collected through a standardized questionnaire, analysis of domestic tap water, analysis of urine Li and Sb, and measurement of thyroid hormone levels (TSH, T_3, T_4). Only n=6 (5.0%) of the study respondents had abnormal thyroid hormone levels. There was no significant relationship between Li and Sb concentrations in domestic tap water and TSH, T_3, and T_4 hormone levels ($p>0.05$). Multiple linear regression analysis showed that women (β =-1.42; p =0.004), an increase in urine Li (β = -0.08; $p < 0.001$), and those working in manufacturing (β =-1.69; p =0.032) were associated with a significant decrease in T4 hormone. Meanwhile, vegetable intake less than twice a day was significantly associated with higher T_4 levels (β =1.04; p =0.026). For the T_3 hormone, respondents who worked in manufacturing (β=0.96; p=0.002) or had high cigarette consumption (β=0.10; $p<0.001$) showed significantly higher T_3 hormone levels. This study also found no significant interactions ($p>0.05$) and identified several potential biomarkers of urinary Li and urinary Sb for assessing thyroid status (normal, hypothyroid, and hyperthyroid). In conclusion, internal Li dose (urine) can influence thyroid hormone levels even at low exposure levels, indicating that internal dose is a more sensitive indicator than lithium concentration in domestic tap water. Based on the NOAEL approach, a value of 10µg/L for Li is proposed as a new surveillance value for consideration and inclusion in the National Drinking Water Quality Standards Program, and a value of 5µg/L for Sb is recommended to be maintained.

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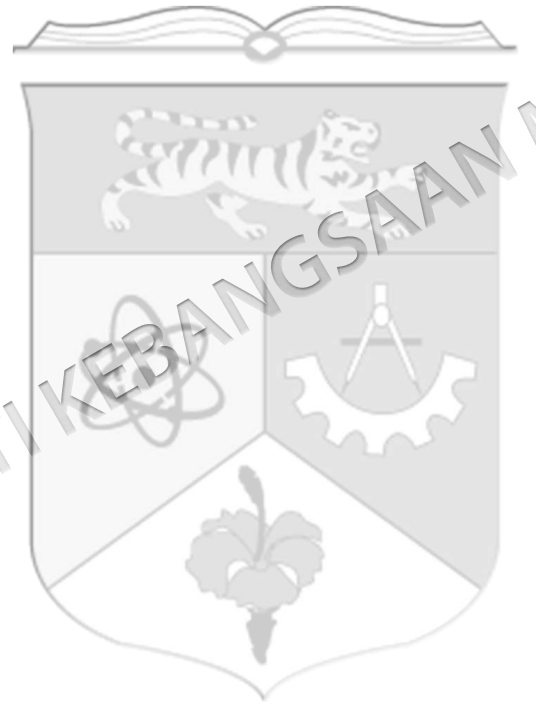

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SENARAI SINGKATAN

µg/L	mikrogram per Liter
95% SK	95 peratus selang keyakinan
As	Arsenik
aOR	Nisbah kebarangkalian
AF	Faktor peruntukan
ATSDR	Agensi Pendaftaran Bahan Toksik dan Penyakit
β	Beta diselaraskan
BMI	Indeks Jisim Badan
BPA	Bisfenol A
Cd	Kadmium
cm	sentimeter
Cr	Kromium
DM	Diabetes Melitus
EU	Kesatuan Eropah
et al.	(et alia) dan lain-lain
GV	nilai garis panduan
Hg	Merkuri
HSBL	Tahap saringan berasaskan kesihatan
HPT	Darah Tinggi
HPL	Dislipidaemia
ICP-MS	Induktif berganding Plasma Jisim Spektrometri
ICP-OES	Induktif berganding Plasma Spektroskopi Pelepasan Optik
JAS	Jabatan Alam Sekitar
kg	kilogram
kg/m²	kilogram per meter persegi
km^2	kilometer persegi
KKM	Kementerian Kesihatan Malaysia
LDL-C	kolesterol lipoprotein berketumpatan rendah
Li	Litium
LiB	Bateri Litium-ion
Li_2CO_3	Litium karbonat

LiCl	Litium klorida
Li_2SO_4	Litium sulfat
Log KoW	Pembahagian oktanol/air
LUAS	Lembaga Urus Air Selangor
mg/kg	miligram per kilogram
mg/L	miligram per Liter
ml	mililiter
mIU/L	milIU/L
MRL	Had risiko minimum
NDWQSP	Program Pengawasan Kualiti Air Minuman Kebangsaan
Ni	Nikel
NOAEL	Tahap tiada kesan buruk yang diperhatikan
Pb	Plumbum
PBDE	Polybrominated diphenyl ethers
PCB	Polychlorinated biphenyls
pmol/L	pikomol/L
ppb	bahagian per billion
ppm	bahagian per million
ppt	bahagian per trillion
R	Perisian R
RfC	Dos kepekatan penyedutan
RfD	Dos rujukan pengambilan oral
RM	Ringgit Malaysia
RO	Osmosis berbalik
ROC	Keluk Ciri Operasi Penerima
RSL	nilai tahap saringan serantau
Sb	Antimoni
SbIII	trivalen Sb
SbV	pentavalen Sb
Sb_2O_3	Antimoni trioksida
$Sb(OH)_3$	Antimoni trioksida kompleks
Se	Selenium
SDG	Matlamat Pembangunan Mampan

SPSS	Perisian Statistik Produk dan Penyelesaian Perkhidmatan
SW103	Sisa berjadual bateri mengandungi Li
SW104	Sisa berjadual habuk/slag/dross/abu mengandungi logam Sb
T_3	Triiodotironin
T_4	Tiroksin
TDI	nilai pengambilan harian yang boleh diterima
TPO	Antibodi tiroperoksidase
TRH	Hormon Pelepas Thyrotropin
TSH	Hormon Perangsang Tiroid
UF	Faktor ketidakpastian
USA	Amerika Syarikat
USEPA	Agensi Perlindungan Alam Sekitar Amerika Syarikat
WHO	Pertubuhan Kesihatan Sedunia
Zn	Zink

BAB I

PENGENALAN

1.1 PENGENALAN

Bab ini merangkumi latar belakang kajian ini yang memfokuskan penerangan berkenaan tahap hormon tiroid, penyakit tiroid (hipertiroid atau hipotiroid), logam Litium (Li), logam Antimoni (Sb), pencemaran air paip domestik oleh kedua-dua logam ini serta kesan terhadap kejadian penyakit tiroid, penetapan nilai piawaian pengawasan kualiti air minum (NDWQSP) berdasarkan pendekatan tahap tiada kesan buruk yang diperhatikan (NOAEL), serta kesan interaksi kedua-dua logam daripada perspektif toksikologi. Bab ini memberi tumpuan kepada pernyataan masalah, persoalan kajian daripada penyataan masalah, justifikasi kajian, sebagai elemen asas untuk objektif kajian serta beberapa hipotesis kajian. Bab ini juga memperkenalkan tujuan utama kajian toksikologi persekitaran ini iaitu menilai kesan pencemaran air di persekitaran oleh logam Li dan Sb serta kesan terhadap tahap hormon tiroid penduduk dewasa di daerah Kuala Langat.

1.2 LATAR BELAKANG PENYELIDIKAN

1.2.1 Tahap Hormon Tiroid

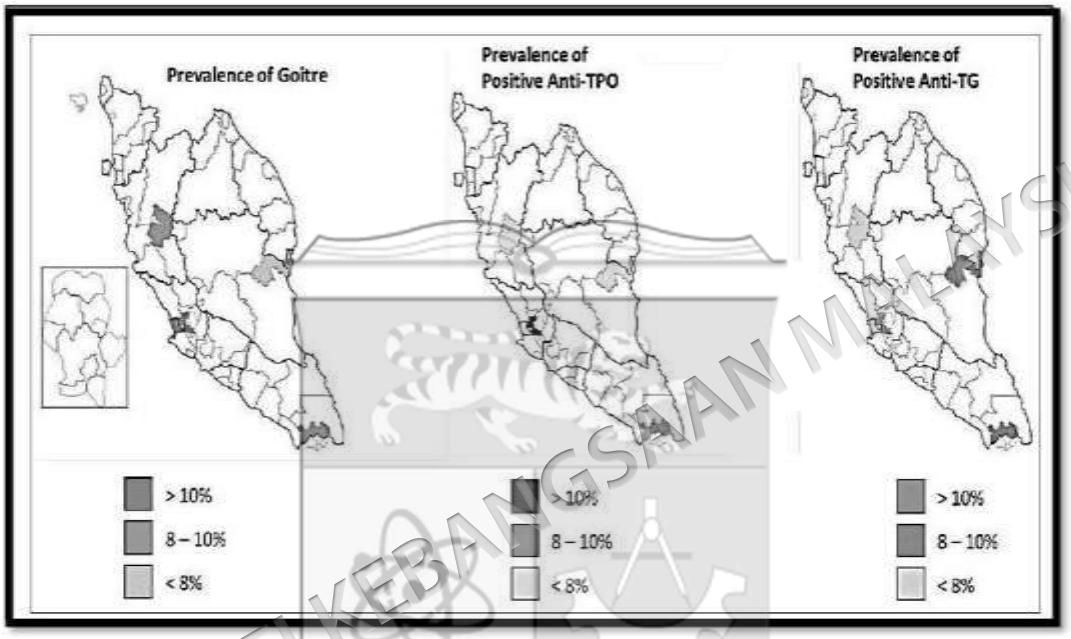
Tahap hormon tiroid ialah ukuran bacaan darah manusia untuk mengetahui sama ada seseorang individu mempunyai bacaan normal atau di luar julat normal hormon tersebut bagi penyakit tiroid (Spencer 2023). Dua keadaan utama tahap hormon tiroid tiroksin (T_4) dan triiodotironin (T_3) yang di luar julat normal sama ada berlebihan (hipertiroid) atau tidak mencukupi (hipotiroid) merupakan ciri utama penyakit tiroid. Penyakit tiroid juga mempunyai ciri khas iaitu kehadiran tahap hormon perangsang tiroid (TSH) yang

tinggi atau rendah dirembeskan oleh kelenjar pituitari (Shahid, Ashraf & Sharma 2023). Penyakit tiroid secara terperinci juga boleh didefinisikan sebagai sebarang keabnormalan terhadap fungsi tiroid yang terhasil apabila proses menyimpan, menghasilkan dan merembeskan hormon (T_4 dan T_3) terjejas. (Gupta & Singh 2022).

Penyakit tiroid yang tidak dapat dikesan melalui tahap hormon tiroid masih lagi tinggi di negara-negara membangun kerana ujian pengesanan tahap hormon tiroid yang masih tidak tersedia secara meluas di negara-negara tersebut (Ajlouni et al. 2022; Moini, Pereira & Samsam 2020). Masalah kesihatan ini juga menjejaskan ramai orang di seluruh dunia dan boleh menjejaskan kesejahteraan terutamanya dalam golongan rentan seperti kanak-kanak, warga emas, wanita hamil dan bayi (Liu et al. 2023d; Zhang, Wang, et al. 2023). Penyakit tiroid boleh menjejaskan kesihatan melalui gangguan metabolisma, fungsi kardiovaskular, sistem saraf, pertumbuhan dan perkembangan serta fungsi reproduktif akibat ketidakseimbangan hormon tiroid (He et al. 2024). Melalui semakan kajian terkini, faktor-faktor persekitaran menyumbang 30% daripada perkembangan penyakit tiroid manakala faktor-faktor bukan persekitaran menyumbang kepada 70% secara kumulatif (Babić Leko et al. 2021). Faktor persekitaran yang lazimnya boleh menyebabkan penyakit tiroid sama ada hipertiroid atau hipotiroid adalah daripada bahan-bahan pencemar seperti logam dan bahan kimia (Or Koca 2026; Thambirajah et al. 2022). Namun, masih mencabar untuk mendapatkan kesimpulan tentang bagaimana faktor-faktor persekitaran menyebabkan penyakit tiroid pada masa kini kerana terdapat banyak percanggahan dalam hasil yang diperoleh merentasi kajian. (Barbosa et al. 2023; Bolan et al. 2022; Costa et al. 2021; Nishad & Bhaskarapillai 2021).

Bagi penyakit tiroid di peringkat global, prevalens hipertiroid adalah antara 0.2% dan 1.4% manakala prevalens hipotiroid dianggarkan antara 3% dan 15% (Gosi, Kaur & Garla 2025; Lee & Pearce 2023). Negara-negara di Amerika Latin mendominasi bilangan hipertiroid tertinggi dengan prevalens lebih daripada 1% dalam kalangan penduduk mereka manakala negara-negara di Amerika Latin dan Timur Tengah mendominasi bilangan hipoiroid tertinggi dengan prevalens lebih daripada 7% dalam kalangan penduduk mereka (Kargar et al. 2024; Vera-Ponce et al. 2026; Zamwar & Muneshwar 2023). Kajian di Malaysia yang terdahulu juga mendapati bahawa 3.4%

rakyat negara ini menghidap hipertiroid manakala 2.1% rakyat negara ini menghidap hipotiroid (Shahar et al. 2017). Mengikut lokasi geografi kajian tersebut, negeri Selangor terutamanya di daerah Kuala Langat mempunyai prevalens hipotiroid tertinggi dalam kalangan populasi yang dikaji iaitu melebihi 10.0% diikuti oleh daerah Kinta, Johor Bahru dan Kuantan (Shahar et al. 2019) (Rajah 1.1).



Rajah 1.1 Prevalens hipotiroid di daerah-daerah utama Malaysia

Sumber: (Shahar et al 2019)

1.2.2 Logam Litium (Li) dan Antimoni (Sb)

Terkini, dua logam yang telah menimbulkan kebimbangan di seluruh dunia kerana potensi pencemaran air ialah Li dan Sb (Barbosa et al. 2023; Lai et al. 2022; Mrozik et al. 2021; Nishad & Bhaskarapillai 2021). Li adalah logam alkali semulajadi yang beredar secara meluas dalam kerak bumi dan ditemui dalam kepekatan yang berbeza-beza dalam air bawah tanah, air permukaan dan efluen industri (Balaram et al. 2024). Li kini digunakan secara meluas dalam pengeluaran bateri, ubat-ubatan, seramik dan pelincir kerana ciri fizikokimia yang istimewa. Tambahan pula, pergerakan dan potensi pengumpulannya dalam ekosistem akuatik telah menimbulkan kebimbangan tentang kehadirannya dalam air paip domestik dan kesan terhadap kesihatan manusia (Adeel et al. 2023; Voet & De Wolff 2023).

Manakala, Sb ialah unsur logam yang tersebar secara meluas di alam sekitar, terutamanya disebabkan oleh kedua-dua proses geologi semula jadi dan aktiviti antropogenik (Tylenda et al. 2022). Bentuk trivalen Sb (SbIII) dan pentavalen Sb (SbV) merupakan yang paling utama bagi logam Sb dalam alam sekitar daripada beberapa keadaan pengoksidaannya. Pengeluaran aloi, bateri asid plumbum, produk kalis api dan semikonduktor menggunakan logam Sb sebagai bahan utama, yang turut menambahkan kehadirannya di persekitaran (Nishad & Bhaskarapillai 2021). Selain itu, aktiviti antropogenik seperti perlombongan, efluen perindustrian dan pemendapan atmosfera juga merupakan sumber utama pelepasan Sb ke dalam air permukaan yang boleh membahayakan ekosistem dan kesihatan manusia (Bolan et al. 2022). Oleh itu, potensi pencemaran logam Sb dalam sistem akuatik semakin membimbangkan, serta diklasifikasikan sebagai pencemar keutamaan oleh Agensi Perlindungan Alam Sekitar Amerika Syarikat (USEPA) dan Kesatuan Eropah (EU) (Jiang et al. 2021).

1.2.3 Pencemaran Alam Sekitar Oleh Logam Li dan Sb dan Penyakit Tiroid

Kini, pencemaran alam sekitar berkembang pesat setiap hari di dunia disebabkan oleh aktiviti antropogenik yang tidak terkawal serta menyebabkan kesan besar terhadap kualiti tanah, udara dan air (Dagdag et al. 2023). Pencemaran ini juga semakin ketara dan dianggap sebagai isu global pada masa kini berikutan evolusi era semasa di dalam sektor industri dengan permintaan dan penggunaan tinggi global bagi peranti elektronik serta robotik (Torres-Agullo et al. 2021; Ukaogo et al. 2020). Sejak 1970, negara Malaysia telah beralih daripada mengeluarkan bahan mentah seperti komoditi pertanian dan ke arah perindustrian (Ehigiamusoe et al. 2024). Oleh yang demikian, perubahan ekonomi ini telah menyebabkan peningkatan dan penggunaan meluas logam Li dan Sb bagi sektor-sektor tersebut yang mana selanjutnya membawa kepada kesan pencemaran alam sekitar (Mathew et al. 2023; Yap et al. 2022).

Sumber antropogenik Li dan Sb yang boleh mencemari badan air adalah daripada kemudahan pengeluaran kimia, tumpahan daripada kemudahan pembuatan serta kitar semula, pelupusan peranti elektronik yang tidak betul, dan efluen industri (Bolan et al. 2022; Mahmudiono et al. 2024). Pencemaran logam ini juga kini

bertambah teruk kerana kekurangan langkah penguatkuasaan dan pemantauan di negara ini, yang menyebabkan pelepasan sejumlah besar toksin ke dalam alam sekitar (Jabatan Alam Sekitar 2020).

Daripada segi bukti pencemaran, pembuatan barangan elektronik adalah antara sumber utama kegunaan logam Li di negara ini, dan melalui kajian terdahulu telah menunjukkan bahawa majoriti rakyat Malaysia membuang peranti elektronik mereka ke dalam tong sampah dan tidak mengitar semula barangan tersebut (Li et al. 2022; Mathew et al. 2023). Pelupusan peranti elektronik secara tidak terkawal ini berpotensi melepaskan logam termasuk Li ke persekitaran melalui proses penguraian dan pengurusan sisa yang tidak sempurna, seterusnya mencemarkan tanah dan sumber air. Selain itu, terdapat juga bukti pencemaran Sb di Malaysia melalui kajian pensampelan air dan sedimen di Muara Linggi, di mana hasil kajian menunjukkan terdapat bukti pencemaran sederhana berpunca daripada aktiviti antropogenik oleh logam Sb melalui sampel sedimen dengan kepekatan purata 1.31(0.07)mg/kg (Elias et al. 2018).

Lebih memburukkan, terdapat peningkatan permintaan untuk penggunaan air paip domestik dalam kalangan penduduk Malaysia setiap tahun disebabkan oleh keperluan kesan pemodenan serta perubahan iklim (Anang et al. 2024). Oleh itu, perubahan ini mampu membawa kepada pendedahan penduduk yang lebih tinggi kepada pencemaran kedua-dua logam Li dan Sb di dalam air berbanding dengan pendedahan oleh kulit dan penyedutan udara, terutamanya dalam kawasan urbanisasi pesat dan pengembangan kepadatan penduduk yang tinggi (Ewuzie et al. 2020). Tambahan pula, logam Li kini masih belum dipantau melalui Program Pengawasan Kualiti Air Minuman Kebangsaan (NDWQSP) negara ini dan hanya logam Sb dipantau dengan nilai piawaian 20µg/L (KKM 2023; WHO 2021a).

Kesan negatif logam Li terhadap kesihatan tiroid manusia telah ditemui dalam beberapa kajian terdahulu yang mendapati perkaitan linear yang signifikan antara paras Li urin dengan tahap hormon tiroid yang abnormal (Broberg et al. 2011; Harari et al. 2016). Khususnya, kajian-kajian tersebut memperhatikan bahawa tahap Li urin yang lebih tinggi mempunyai perkaitan yang signifikan dengan kepekatan hormon T_4 yang lebih rendah serta tahap hormon TSH yang lebih tinggi. Selain itu, kajian terdahulu bagi

logam Sb turut mendapati bukti kesan negatif terhadap organ tiroid di mana individu dengan kepekatan kuintil tertinggi Sb urin mempunyai kemungkinan 2.24 kali lebih tinggi untuk mengalami penyakit tiroid berbanding dengan mereka yang berada dalam kuintil terendah (Liao & Xiwen 2019).

1.2.4 Penetapan Nilai Piawaian Pengawasan Kualiti Air Minum (NDWQSP) Berdasarkan Pendekatan Tahap Tiada Kesan Buruk Yang Diperhatikan (NOAEL)

Penetapan nilai piawaian di peringkat global dan NDWQSP negara ini lazimnya menggunakan pendekatan saintifik NOAEL, iaitu tahap pendedahan tertinggi yang tidak menunjukkan kesan buruk terhadap kesihatan manusia (Kale et al. 2022). Melalui pendekatan ini, nilai ambang kesihatan boleh diterjemahkan kepada nilai piawaian kualiti air melalui aplikasi faktor ketidakpastian atau keselamatan yang bersesuaian (Rathman et al. 2020).

Penggunaan NOAEL ini juga amat penting di dalam memastikan nilai piawaian yang dicadangkan bukan sahaja berasaskan pematuhan peraturan, tetapi juga mencerminkan perlindungan kesihatan yang mencukupi di dalam kesan pendedahan logam terhadap masyarakat melalui air minum (WHO 2021b). Seterusnya, penggunaan nilai piawaian ini boleh menjadi panduan di dalam penetapan polisi serta strategi pencegahan dan kawalan terhadap bahaya unsur kedua-dua logam demi kesihatan awam (Mondal et al. 2026).

1.2.5 Interaksi Logam Li dan Sb

Pendedahan populasi kepada campuran bahan pencemaran persekitaran yang kini lebih realistik telah menjadi isu utama dalam penilaian moden risiko kesihatan persekitaran (Forner-Piquer, Baig & Kortenkamp 2023). Seiring dengan perkembangan ini, pihak Agensi Perlindungan Alam Sekitar Amerika Syarikat (USEPA) dan Agensi Pendaftaran Bahan Toksik dan Penyakit (ATSDR) turut menekankan keperluan penilaian risiko berasaskan campuran bahan pencemar serta pemahaman terhadap kesan interaksi antara logam Li dan Sb yang wujud serentak dalam persekitaran (ATSDR 2022; USEPA 2021). Bukti toksikologi terkini antarabangsa turut menunjukkan bahawa pendedahan

kepada campuran logam boleh menghasilkan kesan lebih serius terhadap tahap hormon tiroid berbanding pendedahan kepada logam tunggal (Kim et al. 2022). Di samping itu, penggunaan urin sebagai kaedah saringan awal tidak invasif untuk menilai beban badan logam Li dan Sb manusia serta risiko hipertiroid atau hipotiroid juga penting dan perlu diterokai (Martinez-Morata et al. 2023).

1.3 PENYATAAN MASALAH

Penyakit tiroid adalah antara penyakit endokrin utama di peringkat global dengan dianggarkan seramai 200 juta orang menghidapi penyakit tersebut dan lebih 1.5 bilion individu berisiko akibat daripada faktor pengambilan iodin tidak mencukupi dan pendedahan kepada faktor persekitaran lain (Zhang et al. 2023). Kajian global juga telah menunjukkan bahawa prevalens penyakit tiroid bagi seluruh dunia adalah antara 2% sehingga 5%. Malangnya, hampir 50% kes penyakit tiroid di seluruh dunia tidak didiagnos dan penyakit ini boleh diambil kira sebagai epidemik semasa yang terjadi secara senyap (Moini, Pereira & Samsam 2020; Zhang et al. 2023;).

Di Malaysia, prevalens penyakit tiroid juga semakin meningkat dengan kajian terdahulu mendapati bahawa 5.5% daripada populasi negara menghidapi penyakit tiroid walaupun terdapat langkah pencegahan kesihatan awam dengan garam beriodin melebihi 25 tahun di negara ini (Shahar et al. 2017). Tambahan pula, prevalens penyakit tiroid negara ini adalah berada di dalam julat prevalens penyakit tiroid global secara keseluruhan iaitu sekitar 3-8% serta menunjukkan bahawa penyakit ini masih merupakan isu kesihatan awam yang signifikan di negara ini (Lee & Pearce 2023; Taylor et al. 2018). Lebih mengejutkan, kajian yang seterusnya juga telah mendapati penduduk dewasa di daerah Kuala Langat mempunyai prevalens penyakit tiroid yang tertinggi di Malaysia dengan lebih daripada 10% penduduk yang terjejas oleh penyakit ini (Shahar et al. 2019). Majoriti mereka yang mengalami penyakit tiroid ini juga kebanyakannya tidak dikenal pasti sebelum ini, dan hanya melalui kajian khusus untuk mengukur tahap hormon tiroid atau selepas individu bergejala hadir ke fasiliti kesihatan, penyakit tiroid ini dikesan dalam kalangan populasi negara ini.

Selain itu, kajian terdahulu di negara ini hanya menyiasat faktor-faktor bukan

persekitaran tertentu sahaja seperti umur, jantina, etnik, tempat tinggal, tahap autoantibodi dan jisim berat badan (Shahar et al. 2019). Berdasarkan kajian antarabangsa, faktor-faktor bukan persekitaran yang lain sebanyak 70% juga menyumbang kepada kejadian penyakit tiroid seperti status perkahwinan, pendapatan isi rumah, pekerjaan, tahap pendidikan, komorbiditi, sejarah keluarga, status merokok, pengambilan ubatan, penggunaan penapis air, pengambilan alkohol dan corak pemakanan yang masih tidak dikaji oleh kajian tersebut (Babić Leko et al. 2021; Cheng et al. 2025; Díez & Iglesias 2023; Drogge et al. 2023; Herkert et al. 2020; Hussein, Jumaa & Hosi 2025; Mogahed et al. 2024; Perros et al. 2025; Puttaswamy et al. 2024; Wiersinga et al. 2023; Yang et al. 2024).

Di samping itu, prevalens penyakit tiroid yang tinggi ini boleh juga dijelaskan oleh perkaitan dengan faktor-faktor persekitaran yang masih kurang dikaji kajian yang sama dan ketiadaan nilai parameter pemantauan bagi logam Li (Shahar et al. 2019). Kajian ulasan saintifik terdahulu menunjukkan bahawa 30% daripada kejadian penyakit tiroid juga boleh disebabkan oleh faktor-faktor persekitaran seperti pendedahan kepada unsur-unsur logam (Babić Leko et al. 2021). Tambahan pula, beberapa kajian di negara lain telah berjaya menemui perkaitan signifikan antara penyakit tiroid dengan logam Li serta Sb di dalam air paip domestik (Guo et al. 2018; Harari et al. 2015; Margetaki et al. 2021).

Selain itu, terdapat kajian toksikologi terhad mengenai penyakit tiroid di negara ini pada masa kini dengan kajian-kajian semasa adalah lebih tertumpu kepada aspek klinikal sahaja (Lee et al. 2023). Perkembangan ini lebih membimbangkan kerana terdapat peningkatan penggunaan logam Li dan Sb di dalam industri pembuatan elektrik dan elektronik negara ini semenjak 2014 (Bahrudin et al. 2023; Rafi'i et al. 2024). Tekanan pencemaran di lembangan Sungai Langat termasuk aktiviti perindustrian, pelepasan efluen dan pengurusan sisa yang tidak terkawal menunjukkan wujudnya sumber pencemaran yang berpotensi menjejaskan kualiti persekitaran dan meningkatkan kemungkinan pendedahan penduduk kepada bahan pencemar melalui sumber air dan persekitaran setempat (LUAS 2019).

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terhadap gabungan toksisiti logam Li dan Sb, serta peranan pendedahan air paip domestik sebagai faktor pengubah hubungan antara dos dalaman dan tahap hormon tiroid berdasarkan kesan interaksi, juga perlu diterokai. Garis panduan pendekatan toksikologi kini oleh USEPA dan ATSDR juga menekankan kepentingan penilaian risiko yang lebih ke hadapan ini kerana banyak bukti saintifik telah menjurus ke arah kesan interaksi bahan pencemar yang mampu memberikan tahap kesihatan yang lebih teruk dan prevalens yang tinggi berbanding pendedahan logam tunggal secara signifikan (ATSDR 2022; USEPA 2021). Malangnya, kajian setakat ini yang melihat kesan interaksi logam Li dan Sb terhadap penyakit tiroid masih sangat terhad (Broberg et al. 2011; Harari et al. 2016; Margetaki et al. 2021).

Penentuan kebolehan ujian tidak invasif seperti ujian urin sebagai saringan awal untuk menentukan beban badan populasi yang terdedah kepada kedua-dua logam Li dan Sb terhadap status tiroid abnormal (hipertiroid atau hipotiroid) juga sangat penting (Martinez-Morata et al. 2023). Tambahan pula, pembuktian kesahan dan kebolehpercayaan kaedah ini adalah berasaskan penyingkiran kedua-dua logam terutamanya melalui urin serta membolehkan pertimbangan penggunaannya secara berkesan (Broberg et al. 2011; Liao & Xiwen 2019; Margetaki et al. 2021). Kepentingan ini adalah amat selaras dengan garis panduan keperluan praktikal penanda biologi dalam penilaian risiko pendedahan bahan pencemar (ATSDR 2022; Przybyla et al. 2021; USEPA 2021). Namun, sehingga kini masih terdapat kewujudan jurang pengetahuan daripada segi kebolehgunaan Li urin dan Sb urin ini sebagai kaedah saringan awal bagi populasi berisiko di negara ini.

1.4 JUSTIFIKASI KAJIAN

Selangor adalah salah satu negeri yang paling maju di Malaysia dengan jumlah aktiviti perindustrian terutamanya perusahaan elektrik serta elektronik yang tertinggi di negara ini (Bachok et al. 2022). Di negeri Selangor, Kuala Langat merupakan salah satu daerah utama yang telah menyaksikan banyak berlakunya episod pencemaran hasil aktiviti antropogenik dan telah membawa kepada pencemaran Sungai Langat yang terletak berhampiran dengan kawasan industri utama daerah tersebut (Ahmed et al. 2022; Januri et al. 2025; LUAS 2019). Lebih membimbangkan, Sungai Langat ini merupakan

bekalan air utama bagi penduduk di daerah berkenaan dan boleh membawa risiko kesihatan kepada mereka.

Dalam laporan Lembaga Urus Air Selangor (LUAS) pada 2019, terdapat 860 premis industri berdaftar di sepanjang Sungai Langat dengan 181 (21%) industri mengeluarkan dua atau lebih efluen sisa berjadual ke Sungai Langat (LUAS 2019). Menurut laporan Jabatan Alam Sekitar (JAS) Selangor pada tahun 2019, Sungai Langat berada dalam kategori sederhana tercemar dengan indeks kualiti air 76 (Jabatan Alam Sekitar 2020; LUAS 2019). Di samping itu, laporan tersebut juga mendapati bahawa terdapat 27 buah kilang tanpa kebenaran yang beroperasi di sekitar lembangan Sungai Langat dan statistik menunjukkan kira-kira 30 buah kilang haram telah diarahkan tutup pada tahun sebelumnya . Selain itu, beberapa episod pencemaran Sungai Langat juga telah menyebabkan penutupan kemudahan rawatan air di Sungai Langat. Beberapa laporan kejadian pencemaran di tapak pelupusan sampah tanpa kebenaran di Banting juga mendapati penemuan longgokan serpihan timbunan sarung dawai serta papan litar elektronik yang disyaki telah dibakar secara terbuka (Jabatan Alam Sekitar 2020).

Di samping itu, loji rawatan air di Lembangan Langat kini masih mengikut kaedah konvensional yang tidak mampu mengeluarkan ion logam halus seperti logam Li dan Sb secara berkesan, terutamanya apabila tahap kekeruhan meningkat (Ahmed & Mokhtar 2020). Kekangan kemampuan loji rawatan air ini seterusnya menyebabkan kedua-dua logam tersebut kekal dalam air terawat (Gan et al. 2023; Lim et al. 2023; USEPA 2021). Daripada segi penyelidikan, terdapat beberapa kajian terdahulu juga yang telah menyokong bukti pencemaran Sungai Langat di daerah tersebut dengan beberapa kepekatan bahan pencemar yang didapati melebihi had kualiti air yang ditetapkan oleh Kementerian Kesihatan Malaysia (KKM) (Ahmed et al. 2022; Danish et al. 2024; Elias et al. 2018; Hasib & Othman 2020; Rajaram et al. 2026).

Pemilihan logam Li dan Sb untuk dikaji berbanding logam-logam lain adalah berdasarkan kepentingan kesihatan awam dan jurang pengetahuan yang masih wujud di negara ini (Praveena et al. 2024). Beberapa negara luar kini telah mengesan kewujudan kedua-dua logam di negara mereka dan telah menjadi kebimbangan sebagai bahan baru muncul yang menjejaskan kesihatan penduduk mereka (Sharma, Westerhoff & Zeng

2022; Fu et al. 2023). Li merupakan unsur yang semakin mendapat perhatian sebagai pencemar persekitaran baharu susulan peningkatan penggunaannya dalam industri bateri dan teknologi moden, manakala kesannya terhadap fungsi tiroid pada tahap pendedahan persekitaran masih kurang difahami berbanding pendedahan terapeutik (Chevalier et al. 2024). Sb pula merupakan unsur yang telah diberi perhatian dalam pemantauan kualiti air minuman dengan bukti epidemiologi berkaitan kesannya terhadap sistem endokrin secara khususnya fungsi tiroid manusia masih tidak konsisten (Margetaki et al. 2021).

Tambahan pula, bukti pencemaran logam Li dan Sb di negara ini juga diperhatikan daripada aspek amalan buruk pembuangan sisa elektronik ke dalam sisa domestik dan kelemahan kitar semula bahan tersebut dalam kalangan rakyat Malaysia (Mathew et al. 2023). Di samping itu, kesan pencemaran logam Li ini kini tidak pernah dipantau di negara ini dan hanya logam Sb yang sedang dipantau di bawah program NDWQSP. Tambahan pula, tiada penambahan parameter pemantauan bahan cemar air yang baru muncul seperti logam Li di dalam program tersebut dan terdapat kekurangan penambahan bukti kajian saintifik kesan logam Sb kepada populasi penduduk negara ini selama lebih daripada 25 tahun walaupun ia merupakan salah satu program kesihatan alam sekitar tertua di negara ini (Praveena et al. 2024).

Selain itu, berdasarkan Matlamat Pembangunan Mampan (SDG 3: Kesihatan dan Kesejahteraan yang Baik) serta (SDG 6: Air Bersih dan Sanitasi) yang menekankan akses kepada air selamat serta pengurangan pencemaran air, kajian ini menyokong matlamat utama yang telah digariskan bagi kesihatan masyarakat melalui pendekatan saintifik berasaskan bukti (UN 2015). Kajian ini juga selari dengan komitmen pelaksanaan Dasar Alam Sekitar Negara 2021 yang menekankan pengurusan pencemaran air dan perlindungan kesihatan penduduk negara ini daripada bahaya persekitaran (KASA 2021). Menurut Pelan Tindakan Kesihatan Persekitaran Kebangsaan 2016-2020, isu yang dikaji ini juga berada di kedudukan ketiga dalam keutamaan isu kesihatan persekitaran Malaysia (KKM 2016). Begitu juga, isu pencemaran ini diperkuatkan lagi dengan keperluan di dalam penyelidikan KKM sepertimana yang telah diterbitkan dalam dokumen penyelidikan Institut Kesihatan Negara Malaysia bagi Rancangan Malaysia Ke-12, bahawa bahan cemar air akibat

pembandaran pesat seperti logam Li serta Sb adalah antara keutamaan penyelidikan dalam usaha mengenalpasti kesan pencemaran alam sekitar tersebut kepada kesihatan penduduk negara ini (Muhamad et al. 2021).

Maka, kesemua bukti dan situasi ini telah mencetuskan minat untuk menyelidik situasi sebenar pencemaran air paip domestik di daerah Kuala Langat dengan mencari kepekatan air paip domestik Li dan Sb yang abnormal, termasuk mengkaji bukti faktor biologi, sosiodemografi, sosioekonomi, gaya hidup serta kesan yang berkaitan dengan kejadian penyakit tiroid dalam kalangan penduduk daerah tersebut.

1.5 PERSOALAN KAJIAN

a. Apakah tahap hormon tiroid dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor?

b. Apakah perkaitan faktor-faktor bukan persekitaran (umur, jantina, etnik, status perkahwinan, tempoh tinggal di daerah, pendapatan isi rumah, pekerjaan, tahap pendidikan, komorbiditi, sejarah keluarga berpenyakit tiroid, status merokok, BMI, pengambilan ubatan, pengambilan alkohol, penggunaan penapis air rumah, corak pemakanan) dan faktor-faktor persekitaran (paras air paip domestik Li, Sb, serta kepekatan Li urin, Sb urin) dengan tahap hormon tiroid dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor?

c. Apakah nilai panduan (parameter) pemantauan air paip domestik yang disyorkan dalam kalangan penduduk di Kuala Langat, Selangor?

d. Adakah terdapat interaksi antara logam Li dan Sb dalam air paip domestik serta urin? Selain itu, adakah pendedahan air paip domestik yang mengandungi Li dan Sb mempengaruhi hubungan antara dos dalaman (urin) dengan tahap

hormon tiroid (TSH, T_3, T_4) dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor?

e. Apakah nilai ambang Li urin serta Sb urin bagi penentuan (hipertiroid, hipotiroid atau normal) dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor?

1.6 OBJEKTIF KAJIAN

Objektif kajian ini dibahagikan kepada objektif umum dan objektif khusus.

1.6.1 Objektif Umum

Menilai pendedahan logam Li dan Sb serta perkaitannya dengan tahap hormon tiroid, faktor berkaitan, interaksi pendedahan dan nilai ambang dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor.

1.6.2 Objektif Khusus

a. Menentukan tahap hormon tiroid dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor.

b. Menganalisis perkaitan faktor-faktor bukan persekitaran (umur, jantina, etnik, status perkahwinan, tempoh tinggal di daerah, pendapatan isi rumah, pekerjaan, tahap pendidikan, komorbiditi, sejarah keluarga berpenyakit tiroid, status merokok, BMI, pengambilan ubatan, pengambilan alkohol, penggunaan penapis air rumah, corak pemakanan) dan faktor-faktor persekitaran (paras air paip domestik Li, Sb, serta kepekatan Li urin, Sb urin), dengan tahap hormon tiroid (TSH, T_3, T_4) dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor.

c. Menentukan nilai panduan (parameter) pemantauan air paip domestik yang disyorkan dalam kalangan penduduk di daerah Kuala Langat, Selangor.

d. Menyiasat interaksi antara logam Li dan Sb dalam air paip domestik serta urin. Selain itu, menyiasat interaksi pendedahan air paip domestik yang mengandungi logam Li dan Sb terhadap hubungan antara dos dalaman (urin) dengan tahap hormon tiroid (TSH, T_3, T_4) dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor.

e. Menentukan nilai ambang Li urin serta Sb urin bagi penentuan (hipertiroid, hipotiroid atau normal) dalam kalangan penduduk dewasa di daerah Kuala Langat, Selangor.

1.7 HIPOTESIS KAJIAN

a. Terdapat perkaitan yang signifikan antara faktor-faktor bukan persekitaran (umur, jantina, etnik, status perkahwinan, tempoh tinggal di daerah, pendapatan isi rumah, pekerjaan, tahap pendidikan, komorbiditi, sejarah keluarga berpenyakit tiroid, status merokok, BMI, pengambilan ubatan, pengambilan alkohol, penggunaan penapis air rumah, corak pemakanan) dengan tahap hormon tiroid.

b. Terdapat perkaitan yang signifikan antara faktor persekitaran (paras air paip domestik Li, Sb, dan kepekatan Li urin, Sb urin) dengan tahap hormon tiroid.

c. Terdapat interaksi yang signifikan antara kepekatan Li dan Sb dalam urin serta antara kepekatan Li dan Sb dalam air paip domestik terhadap tahap hormon tiroid (TSH, T_3 dan T_4).

d. Terdapat kesan interaksi yang signifikan antara kepekatan Li dan Sb dalam air paip domestik dengan kepekatan Li dan Sb dalam urin terhadap tahap hormon tiroid (TSH, T_3, T_4).

e. Terdapat nilai ambang Li urin serta Sb urin yang signifikan untuk menentukan tahap hormon tiroid (hipertiroid, hipotiroid atau normal).

1.8 KESIMPULAN

Bab ini menerangkan latar belakang kajian dengan penekanan pada penyakit tiroid (hipertiroid atau hipotiroid) yang menjejaskan ramai manusia di seluruh dunia, termasuk di negara ini, terutamanya di Daerah Kuala Langat. Faktor persekitaran merupakan salah satu penyebab ketara penyakit tiroid yang kini masih tidak diterokai secara meluas. Di antara faktor persekitaran yang penting kini adalah kehadiran unsur bahaya seperti logam Li serta Sb yang telah dikenal pasti mampu menyebabkan penyakit tiroid kepada masyarakat melalui pendedahan pencemaran air hasil daripada aktiviti antropogenik. Selanjutnya, pemahaman tentang perkaitan antara logam Li dan Sb dalam air paip domestik termasuk kesan interaksi dan penyakit tiroid dapat memberikan gambaran penting tentang keperluan pengawasan, pencegahan dan kawalan terhadap kepekatan abnormal kedua-dua logam tersebut dalam air paip domestik. Bab ini juga telah mengemukakan pernyataan masalah yang jelas, iaitu kewujudan jurang pengetahuan dalam kajian persekitaran dan kesihatan di negara ini berkaitan logam Li dan Sb serta implikasinya terhadap fungsi tiroid penduduk daerah Kuala Langat. Seterusnya, persoalan kajian, objektif umum dan khusus, serta hipotesis yang digariskan adalah untuk menunjukkan bahawa penyelidikan ini bersifat sistematik.

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