REVIEW ARTICLE

UPI JOURNAL OF CHEMICAL AND LIFE SCIENCES (UPI-JCLS)

ISSN: 2581-4648 (An International online Peer Reviewed, Open Access Journal)

www.uniquepubinternational.com Published by Unique Pub International (UPI)

ALGAL AND CYANOBACTERIAL REGROWTH IN HOUSEHOLD ROOFTOP WATER STORAGE TANKS UNDER HOT-ARID CONDITIONS: OCCURRENCE, TASTE-AND-ODOUR AND TOXIN RISKS, AND CONTROL: A REVIEW

ANSSAM HASSAN ALI[1] AND AMJAD ABD ALI[2*]

[1,2] Ministry of Education, General Directorate of Al-Qadisiyah Education, Diwaniyah 58001, Iraq.

***Corresponding Author**

Amjad Abd Ali

amjad.abdali@ec.edu.iq

Received: 24 09 2026 Revised: 19 10 2026 Accepted: 21 11 2026

Abstract

In many hot-arid cities the last step of the water supply is a small tank on the roof. Intermittent supply makes such tanks almost universal in Iraq and across much of the Middle East, yet their biology has received far less attention than that of treatment plants or distribution mains. This review gathers what is known about the regrowth of algae and cyanobacteria in household rooftop tanks, with a focus on summer, when stored water can exceed 40–50 °C. It first explains how tank material, colour, light transmission, stagnation and the fast loss of free chlorine in hot water create a niche for phototrophs. The field evidence is still thin, but it points one way. Domestic reservoirs in Egypt carried *Microcystis aeruginosa* with intracellular microcystins of 3.5–40 μg L^{-1}, and microcystin-LR exceeded 1 μg L^{-1} in 30% of urban water tanks surveyed in Qatar. Earthy and musty odorants such as geosmin and 2-methylisoborneol are noticed by consumers at a few ng L^{-1}, so even modest growth of cyanobacteria or actinomycetes on tank walls can spoil the water. The review then summarises the main cyanotoxins, the current WHO guideline values and the analytical tools suited to tank surveys, from phycocyanin probes and qPCR to ELISA, LC-MS/MS and HS-SPME-GC-MS. Control is mostly prevention: opaque, insulated and shaded tanks, tight lids, shorter storage, regular cleaning and a maintained chlorine residual. Copper algicides and boiling are poor choices against toxins. Research priorities for Iraq and similar regions close the review.

Keywords: *Rooftop storage tank; Intermittent water supply; Cyanobacteria; Microcystins; Geosmin; 2-Methylisoborneol; Hot-arid climate; Point-of-use treatment.*

Copyright:© 2026 The author(s). This article is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

1. INTRODUCTION

Not every residence gets piped water all day. At least 300 million people globally have intermittent supplies [1], and many homes manage by storing water in tanks above or below the house [2]. This is the usual configuration in Iraq. Water is pumped from the network (typically via a ground sump) into a tank on the roof and the house is then supplied by gravity [3]. The tank buys pressure. And some security. It also adds days of storage in a warm container, which is often sunlight.

Most work on household storage has looked at faecal indicators and heterotrophic bacteria [4,5], and standards for domestic tanks deal mainly with hygiene and residence time [6]. Algae and cyanobacteria are rarely measured, perhaps because a closed tank is assumed to be dark. Many tanks are not dark. Translucent plastic walls, cracked lids and open vents let light in, and in a hot-arid summer the water may become warmer than most lakes ever get.

This matters for three reasons. Cyanobacterial blooms are expanding with warming and nutrient enrichment [7,8], and the Middle East and North Africa are warming fastest in summer [9]. Phototrophs, and the microbes that live with them, release earthy and musty odorants that people notice at very low levels; this drives complaints and pushes families toward bottled or unregulated water. And some cyanobacteria make potent toxins, which have already been found in household storage in arid countries [10,11].

This review brings that scattered evidence together. It covers the thermal and hydraulic regime of rooftop tanks, the drivers of regrowth, what has actually been found in tanks, the taste-and-odour and toxin risks, the analytical tools, and practical control. Iraqi data are used where they exist, and the gaps are stated plainly where they do not.

2. ROOFTOP STORAGE IN HOT-ARID HOUSEHOLDS

2.1. Why Households Store Water on the Roof

Intermittent supply has many causes, among them scarcity, leaking networks, high demand and unreliable power [1]. Whatever the cause, households adapt in much the same way. The common Iraqi layout is drawn in Figure 1: a connection to the street main, a ground-level sump, a small electric pump and one or more tanks on the roof. Rooftop tanks are described as standard practice in Iraq [3,12]. In Koya, household storage was common because supply is intermittent, and rooftop tanks were cleaned only rarely [13]. In Irbid, Jordan, about two-thirds of households used plastic tanks and roughly half did not clean them at all [14]. Rooftop tanks are also the final storage step in Palestinian refugee camps [15] and in apartment buildings in Sharjah [16]. In the Arabian Gulf, desalinated water is held in dams, large reservoirs and secondary house tanks before use [10].

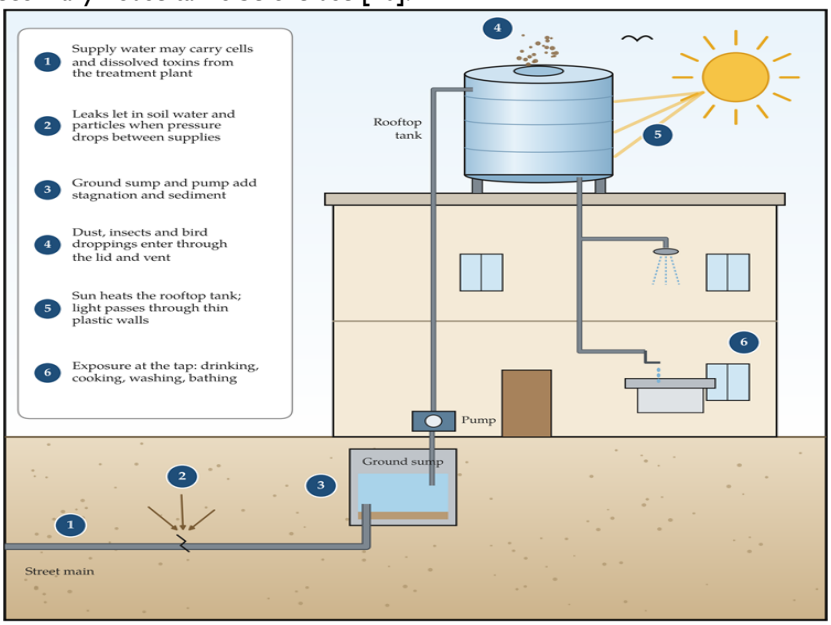

Figure 01: Typical household water path under intermittent supply in Iraqi cities and the points at which cells, nutrients and particles enter the rooftop tank (illustrative drawing, not to scale).

2.2. Materials, Colour and Design

Tanks are made of polyethylene, fibreglass, galvanised steel or concrete. Across 24 studies, tank material and retention time had the largest effect on stored water quality, followed by age, colour, design and location [5]. In Bolivia, polyethylene tanks carried more *E. coli* than fibre-cement and fibreglass tanks, and tanks cleaned three or more times a year had less *E. coli* and turbidity [17]. In Amman, by contrast, material did not change the total bacterial count; temperature did [4]. For phototrophs the important property is optical rather than chemical. Light-coloured, single-layer plastic lets some daylight through, while black or opaque walls do not, and light-permitting containers have been linked with cyanobacterial growth in stored water [18,19]. Lids and vents are the other weak point. A missing or cracked lid admits light, dust, insects and bird droppings.

2.3. The Thermal Regime of Rooftop Tanks

A rooftop tank functions as a solar collector that nobody ever planned as one. In Jeddah, substantial daily fluctuations and thermal stratification were seen in overhead galvanised-steel and fibreglass tanks, whereas a subterranean concrete tank stayed close to 34.6 °C [20]. The water temperature leaving domestic tanks in Saudi Arabia can be higher than 50 °C in summer [21]. Similar values are reported for Basrah and for central and southern Iraq [12,22]. In one Iraqi test, an uncooled tank reached roughly 43 °C at 2 p.m. with air at 45–50 °C [23]. These temperatures are far higher than those usually investigated in distribution networks, where some national regulations already limit tap water to 25 °C [24]. Heat accelerates chlorine degradation, microbial development, and chemical processes simultaneously [25]. The summer tank is really a different reactor than the winter.

3. DRIVERS OF ALGAL AND CYANOBACTERIAL REGROWTH

Five factors act together inside the tank (Figure 2): light, temperature, loss of disinfectant, nutrients with an inoculum, and surfaces for biofilm.

3.1. Light

Light is what separates a tank that grows bacteria from one that also grows algae. Heterotrophic bacteria in stored water often decline once nutrients run out. Cyanobacteria, however, make their own organic carbon from carbon dioxide, minerals and light, so they can persist in water that is too poor for heterotrophs [18]. In South African homes, cyanobacteria (mostly *Microcystis*) entered plastic containers with the source water and appeared to grow in the wall biofilm of light-permitting vessels [18]. In a rainwater tank exposed to the sun, attached heterotrophic bacteria were

more abundant than in a shaded tank, apparently because phototrophs supplied them with organic matter [26]. Covers that blocked light suppressed algal and cyanobacterial growth in experimental basins [27].

3.2. Temperature

Warmth favours cyanobacteria, but not in a simple way. In a controlled comparison of eight cyanobacteria and eight green algae, both groups had a mean optimum near 29 °C and most strains still grew well at 35 °C [28]. Among 26 freshwater species, cyanobacteria had the highest thermal optimum (30.6 ± 2.3 °C), above green algae and diatoms [29]. In another culture study, 35 °C was lethal to every species tested except *Aphanizomenon flos-aquae* [30]. Hence a tank around 45-50 °C may not favour but repress numerous planktonic algae. The likely winners are wall biofilms and thermotolerant cyanobacteria. Organisms such as these can accomplish such things, as was shown in the Saudi hot springs where mats had 468–512.5 μg g^{-1} of microcystins and Oscillatoria limosa and Synechococcus lividus were identified as producers [31]. Tanks are likewise stratified by day and cool down at nite [20] so that cells on the floor and walls experience milder circumstances than in the surface layer. Warming also has indirect effects, through stronger stratification and, in nitrogen-fixing species, faster fixation [7,32].

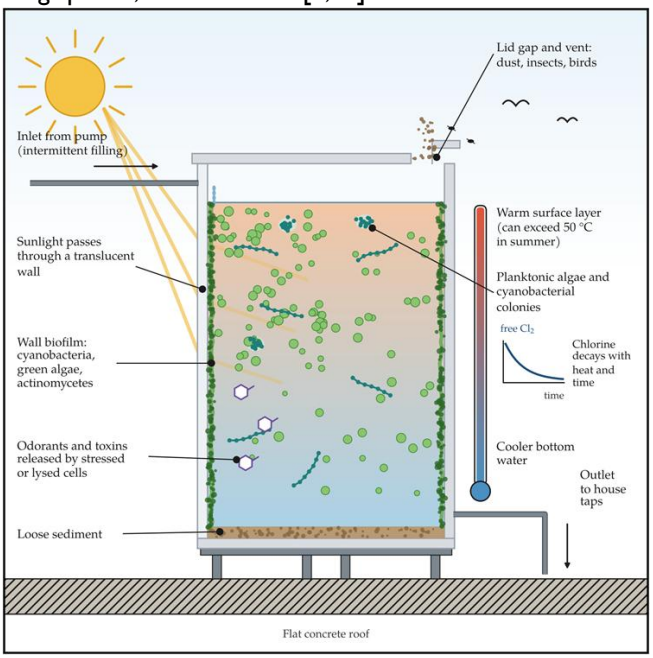

Figure 02: Drivers of algal and cyanobacterial regrowth inside a household rooftop tank on a summer day (illustrative drawing, not to scale).

3.3. Stagnation and Loss of Disinfectant

The sole barrier to the tank from the treatment plant is free chlorine and heat takes that out." Water temperature and organic content influence bulk decay rates [33].The decay constant grows with increasing water temperature [34]. Free chlorine was less than 0.2 mg L−1 in 30% of samples from Sharjah, mainly from storage tanks [16]. It dropped to 0.02 mg L−1 in Chinese roof tanks, and viable bacteria were roughly 10 times greater than in the inflow [35]. In Amman, heterotrophic counts increased from log 1.7 to log 5.2 and 5.7 cfu mL−1 after four and seven days of storage, respectively, and temperature was the main driver [4]. The rooftop tanks in a West Bank camp deteriorated following air temperature [15]. The construction of tanks is also a boon for opportunistic diseases such as Legionella and mycobacteria [36]. When the residue is finished there is no chemical resistance for algae and cyanobacteria that come with the water.

3.4. Nutrients and Inoculum

Phototrophs need a seed and some nutrients, and both arrive easily. Conventional treatment does not always remove cyanobacteria. At an Egyptian plant on the Nile, cells passed coagulation and filtration, and microcystins of 1.1–3.6 μg L^{-1} remained in the outflow tank water [37]. In seven other Egyptian plants, the filamentous *Oscillatoria limnetica* broke through treatment, and final water held 0.37–3.8 μg L^{-1} microcystins [38]. Groundwater is not always a safe alternative; Saudi wells contained cyanobacteria and 0.3–1.8 μg L^{-1} microcystins [39]. Under intermittent supply, low pressure and intrusion can carry particles and organic matter into the pipes [1]. A tank with a poor lid also receives dust, insects and bird droppings, as recorded for roof-fed rainwater tanks [40]. Dust is a particular burden in Iraq. Storms are frequent [41], and one 60-year analysis reported a rise from about 75 to 200 storms per year as temperatures increased [42]. Which nutrient limits growth in a given tank is simply not known. In natural waters it is the absolute concentration of the limiting nutrient, rather than the N:P ratio, that sets the maximum biomass [43].

3.5. Biofilms and Sediments

Most of the biomass in a tank is not in the water at all. It sits in biofilm on the walls and in loose sediment on the floor. A year-long metagenomic study of a working rooftop-tank system in Uruguay found distinct communities in bulk water,

biofilm and sediment, shaped by season and surface material [44]. Secondary supply tanks in China hold diverse eukaryotes as well as bacteria [45]. Benthic cyanobacteria produce microcystins, anatoxins, cylindrospermopsins and saxitoxins, and toxin content varies widely between and within mats [46,47]. Biofilm can be torn loose during filling, which happens often under intermittent supply [5]. A burst of colour, odour or particles after the pump runs is therefore not surprising.

4. OCCURRENCE IN TANKS AND HOUSEHOLD CONTAINERS

Direct surveys of algae and cyanobacteria in household tanks are few. Table 1 lists the relevant studies found for this review, together with some bacterial studies that show how fast stored water deteriorates. The clearest data come from Egypt. Domestic storage reservoirs held cyanobacteria, green algae and diatoms; *Microcystis aeruginosa* reached 4.2–5.92 × 10^6 cells L^{-1} in warm months and increased with time in storage [11]. Intracellular and extracellular microcystins were 3.5–40 and 1–7.6 µg L^{-1}, both above the WHO value of 1 µg L^{-1} [11]. In Qatar, where drinking water is largely desalinated, cyanobacteria were present in 80% of urban and 33% of rural impoundments, and microcystin-LR exceeded 1 µg L^{-1} in 30% of urban water tanks [10]. The authors pointed to storage practice, heat and light penetration as likely causes.

Table 01: Selected studies on the microbial, algal and cyanobacterial quality of water stored in household tanks and containers.

Location	Climate	Storage system	Main findings	Ref.
Amman, Jordan	Semi-arid, hot dry summer	Rooftop and basement tanks (polyethylene, fibreglass, cast iron)	Heterotrophic counts rose from log 1.7 to log 5.2–5.7 cfu mL^{-1} after 4–7 days; actinomycetes, *Pseudomonas* and *Moraxella* dominated; temperature, not tank material, was the main driver	[4]
West Bank, Palestine (two refugee camps)	Semi-arid	Community tanks feeding rooftop tanks under intermittent supply	Total coliforms in 10% and 5% of rooftop-tank samples in the two camps; residual chlorine lower in rooftop than in community tanks; deterioration followed air temperature	[15]
Sharjah, UAE	Hot desert	Lower and upper building tanks	Free chlorine < 0.2 mg L^{-1} in 30% of samples, mainly in tanks; temperature and chlorine changed significantly from mains to upper tanks	[16]
Irbid, Jordan	Semi-arid	Household tanks (67.2% plastic, 32.8% galvanised iron)	About half of households did not clean their tanks; impurities inside tanks were strongly linked to lack of cleaning	[14]
Koya, Iraq	Semi-arid, hot summer	Household containers and rooftop tanks	Storage widespread because of intermittent supply; rooftop tanks rarely cleaned; 22.9% of respondents reported recent gastrointestinal symptoms	[13]
Egypt	Hot desert	Domestic storage reservoirs of treated water	Cyanobacteria, green algae and diatoms; *M. aeruginosa* 4.2–5.92 × 10^6 cells L^{-1} in warm months; intracellular 3.5–40 and extracellular 1–7.6 µg L^{-1} microcystins	[11]
Qatar	Hot desert	Desalinated water in impoundments and house tanks; wells	Cyanobacteria in 80% of urban and 33% of rural impoundments; microcystin-LR > 1 µg L^{-1} in 30% of urban water tanks	[10]
Rural South Africa	Subtropical	20–25 L plastic household containers	Cyanobacteria, mainly *Microcystis*, carried in from the source and apparently growing in container biofilm; toxins not at health-significant levels	[18]
Hartbeespoort Dam area, South Africa	Subtropical highland	Household water containers	Microcystins present in stored water from all sources; light-penetrating containers implicated	[19]
South-eastern China (urban village)	Humid subtropical	Roof tanks	Chlorine as low as 0.02 mg L^{-1}; viable bacteria about one order of magnitude higher than in the inflow; *Legionella* and *Mycobacterium* markers frequent	[35]

Location	Climate	Storage system	Main findings	Ref.
Babil, Iraq	Hot desert	Household RO units and water-cooler tanks	Green algae (*Chlorella vulgaris*, *Scenedesmus*) and the diatom *Cyclotella* reported; microcystin-LR detected by HPLC (conference report, values unconfirmed)	[48]

The evidence from southern Africa indicates the same way. Cyanobacteria were transported to household containers and appeared to flourish in their biofilm, although toxins were still low [18]. Another investigation reported the presence of microcystins in stored water from all sources and labelled the containers as incubators [19]. The only report at household scale in Iraq is a conference paper from Babil, describing Chlorella vulgaris, Scenedesmus and diatoms in household reverse-osmosis units and water-cooler tanks, with microcystin-LR discovered by HPLC [48]. Concentration must be confirmed using a certified method. Iraqi source waters are better recorded. The generation of microcystin by a Westiellopsis isolate from the Tigris has been confirmed [49], and genes for cylindrospermopsin and saxitoxin synthesis were found in the river at Baghdad [50]. There's the inoculum. What is lacking is a survey of the tanks themselves.

Looking at the research in Table 1 together, there is a consistent pattern. In warm weather, stored water loses much of its chlorine within days, bacterial counts can increase by many orders of magnitude, and in Irbid around half of the homes did not clean their tanks at all. In a few of these studies phototrophs and toxins were searched for and when they were sought for they were generally detected. The lack of data from Iraqi rooftop tanks should therefore be seen as a sampling gap, not as evidence that the problem does not exist.

5. TASTE-AND-ODOUR RISKS

For most families the first sign of biological trouble in a tank is a smell. Taste and odour problems are rarely caused by pathogens or toxins, yet consumers use them as their main test of safety [51]. The commonest biological odorants are geosmin and 2-MIB, two terpenoid alcohols with an earthy-musty character (Table 2, Figure 3) [52]. Their odour thresholds are only a few ng L^{-1}: about 4 and 15 ng L^{-1} in one widely used compilation [51], and close to 10 ng L^{-1} for both in trained-panel tests [53]. Utilities start to receive complaints at about 10 ng L^{-1} [54]. Both compounds are made by cyanobacteria such as *Oscillatoria*, *Phormidium*, *Planktothrix*, *Pseudanabaena* and *Dolichospermum* (*Anabaena*), and by actinomycetes [52,55,56]. The actinomycete link matters for tanks, because actinomycetes were among the dominant regrowth bacteria in household tanks in Amman [4]. Benthic mats are an important source of both odorants and toxins in temperate, subtropical and tropical waters alike [57].

Table 02: Main biological taste-and-odour compounds relevant to water stored in household tanks.

Compound	Odour	Main producers	Odour threshold (ng L^{-1})	Remarks	Ref.
Geosmin	Earthy	*Dolichospermum* (*Anabaena*), *Oscillatoria*, *Phormidium* and other cyanobacteria; actinomycetes	≈ 4 to 10	Largely cell-bound in growing cells and released on lysis or stress; one *Anabaena* isolate made most geosmin per biomass at 20 °C	[51–53, 58]
2-Methylisoborneol (2-MIB)	Musty, camphor-like	*Planktothrix*, *Pseudanabaena*, *Oscillatoria*, *Phormidium*; actinomycetes	≈ 10 to 15	One *Pseudanabaena* strain made most MIB at 35 °C and released more under growth-limiting light and temperature	[51,53, 55,59]
β-Cyclocitral	Grassy, hay-like	*Microcystis* spp.	Not consistently reported	Formed rapidly by a carotene oxygenase after cell rupture	[60]

Temperature works on odour in more than one way. In culture, an *Anabaena* isolate made the most geosmin per unit biomass at 20 °C, and synthesis was repressed above that temperature [58]. A *Pseudanabaena* strain, on the other hand, produced the most MIB at 35 °C, where it grew slowest, and released a larger share of both odorants into the water under growth-limiting temperature and light [59]. Stress may thus raise the dissolved, perceptible fraction even when biomass falls. Perception also depends on water temperature and residual chlorine [61], and warm water at the tap gives off more of the volatile compound. *Microcystis* adds β-cyclocitral, which forms quickly when its cells break [60]. Shock-chlorinating a tank with a heavy wall biofilm may therefore make the odour worse before it improves. Odour complaints are, in a sense, free data. Utilities and health offices could log them by district and season and use them as an early warning of tank problems, keeping in mind that residual chlorine changes how people perceive these odours [61].

6. CYANOTOXIN RISKS

Cyanotoxins differ in chemistry and in the organs they attack (Table 03, Figure 03). Microcystins are cyclic heptapeptides that inhibit protein phosphatases and damage the liver. Cylindrospermopsin is a cytotoxic alkaloid, while anatoxin-a and the saxitoxins are neurotoxins [62]. WHO revised its values in 2020. For microcystins the provisional lifetime drinking-water value is 1 μg L^{-1} and the short-term value 12 μg L^{-1}; bottle-fed infants should be given another supply if concentrations exceed 3 μg L^{-1} [63]. Values were also set for cylindrospermopsins and saxitoxins, with a health-based reference value for anatoxin-a [64].

Table 03: Main cyanotoxin groups and the WHO drinking-water and recreational values adopted after the 2020 revision.

Toxin group	Chemical class	Main health effect	Example producers	WHO values (μg L^{-1})	Ref.
Microcystins	Cyclic heptapeptides; many variants	Liver damage; inhibition of protein phosphatases	*Microcystis*, *Planktothrix*, *Dolichospermum*, *Oscillatoria*; benthic mats	Lifetime 1; short-term 12; recreational 24	[62,63]
Cylindrospermopsins	Sulfated guanidine alkaloids	Liver and kidney injury; cytotoxicity	*Raphidiopsis* (*Cylindrospermopsis*), *Aphanizomenon*, *Chrysosporum*	Lifetime 0.7; short-term 3; recreational 6	[62,64]
Anatoxin-a	Bicyclic amine alkaloid	Neurotoxicity	*Dolichospermum*, *Aphanizomenon*; benthic *Phormidium* and *Microcoleus*	Health-based reference value 30 (short-term); recreational 60	[46,64]
Saxitoxins	Carbamate alkaloids	Neurotoxicity (paralytic)	*Dolichospermum circinalis*, *Aphanizomenon*, *Raphidiopsis*	Acute 3; recreational 30	[62,64]

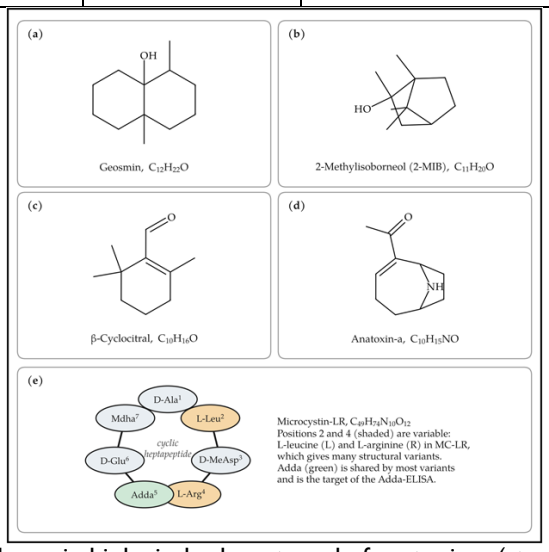

Figure 03: Structures of the main biological odorants and of anatoxin-a (stereochemistry not shown), with a schematic of the cyclic heptapeptide microcystin-LR. Adda, (2S,3S,8S,9S)-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid; MeAsp, 3-methylaspartic acid; Mdha, N-methyldehydroalanine.

Toxins can reach a rooftop tank by three routes. They may arrive dissolved in the supply, as in the Egyptian treatment plants [37,38] and the Saudi wells [39]. They may arrive inside cells that later die in the tank. Or they may be produced in the tank by cells that grow there, which is what the Egyptian reservoir data suggest [11]. The third route is the hardest to manage, because it turns a safe supply into an unsafe one after the last point of official control. The Iraqi data are worth a remark here. The Tigris carries genes for cylindrospermopsin and saxitoxin production as well as microcystin producers [49,50]. A program that screens exclusively for microcystins could miss part of the risk. The fate of a poison within the tank is a function of chlorine, pH, and time. Free chlorine oxidises microcystins, however the rate decreases as pH increases [65]. Chlorination of intact cells initially breaks their membranes and releases toxin that is eliminated only if there is adequate oxidant [66,67]. The balance can tip toward release in a warm tank with a small and dying residue. Microcystins are likewise very heat stable and hence boiling does not make the water safe [63].

Exposure is not restricted to drinking and the water stored is used for cooking, washing and bathing and some families have newborns, elderly people or patients to care for. A sensitive route can be quite hazardous (as evidenced by the worst known human outbreak. In 1996, microcystins were involved in the syndrome affecting patients undergoing haemodialysis in Caruaru, Brazil, which caused the death of 52 people [68]. The center involved had received water that was untreated, unfiltered or unchlorinated [69].

7. MONITORING AND ANALYTICAL APPROACHES

Few households will ever see a laboratory report, so monitoring has to be cheap at the screening stage and precise at the confirmation stage. Looking at the wall and lid, and testing free chlorine and temperature, is the first level. Field fluorometers that read chlorophyll-a and the cyanobacterial pigment phycocyanin give fast biomass estimates, but the readings shift with temperature, cell shape, light quenching and sensor make, so they need local calibration [70,71]. qPCR assays for toxin genes and for the geosmin and MIB synthase genes can flag potential producers before the compounds build up [56,57]. For toxins, the Adda-ELISA recognises most microcystin and nodularin variants with a quantitation limit of 0.02–0.07 μg L^{-1} [72], and LC-MS/MS confirms individual variants [73]. Geosmin and 2-MIB are best measured by headspace solid-phase microextraction with GC-MS, which can reach detection limits of 0.6–0.9 ng L^{-1} [74], below the odour thresholds. Sampling matters as much as the method. A tap sample reflects the bulk water, but the wall biofilm and the floor sediment hold most of the biomass, so a scraping or a sediment grab should be taken whenever a tank is cleaned. Toxins are best reported as intracellular and extracellular fractions, as in the Egyptian survey [11], because cell-bound toxin can be removed with the cells whereas dissolved toxin cannot [75]. Gene assays show potential, not actual, toxin production and need chemical confirmation. A practical design for Iraqi homes would pair a cheap screen of many tanks with a smaller confirmatory set analysed by ELISA and HS-SPME-GC-MS.

8. CONTROL AND MANAGEMENT

Control works best as a set of barriers (Figure 04, Table 04). Most of them are cheap, and most act before any growth starts.

8.1. Keeping Light and Heat Out

An opaque tank, or a multilayer polyethylene tank with a light-blocking inner layer, removes the energy source of phototrophs. A light outer colour, shade and insulation reduce heat gain. Saudi field and laboratory tests showed that insulation, colour, orientation, shading and cooling all change tank temperature, though to different degrees [21]. An air gap around a polyethylene tank cut summer heat transfer by about 10% [3]. Buried earth–water heat exchangers lowered the stored water temperature by about 15–16 °C in Basrah [12,22]. A tight lid and a screened vent keep out light, dust and birds, and covers alone suppressed algae in test basins [27].

8.2. Shorter Storage and Regular Cleaning

The user habits having the largest effect on stored water are cleaning and retention time [5]. Tanks cleaned three or more times per year had lower E. coli and turbidity [17]. Standards favour thorough mixing, high exchange rates and short residence times [6]. In practice this means a tank sized to meet the daily need rather than the longest supply gap, an inlet and exit positioned to minimise dead zones and a drain at the lowest point so that the sediment may be washed out. Cleaning should remove sediment and biofilm, followed by disinfection and rinsing before refilling. Evison and Sunna recommended at least yearly cleaning in warmer areas, with secondary chlorination [4]. The Iraqi summer circumstances require more regular cleaning, however the optimum interval has never been found [5].

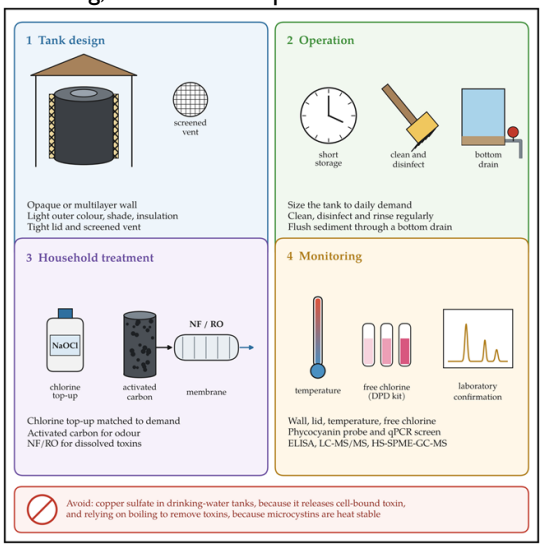

Figure 04: Multi-barrier control of algal and cyanobacterial regrowth in household rooftop tanks: tank design, operation, household treatment and monitoring.

8.3. Household Disinfection

Chlorine top-up reinstates a barrier. In residences in South Africa, the addition of sodium hypochlorite at the point of use reduced microcystins in stored water from ~1.1 µg L−1 to 0.07–0.18 µg L−1 after 30 min [76]. Dosage should be adjusted to the temperature and the organic requirement. Very high dosages lyse cells and generate disinfection by-products [67], and chlorine is more effective at near-neutral pH than at alkaline pH [65].

8.4. Practices to Avoid

Copper sulphate is still available for algae management, but should NOT be used in drinking water tanks. In a classical investigation, copper-treated cells released the majority of their microcystin-LR within three days and the half-life of the toxin after maximum release was approximately three days [77]. Both copper and peroxide therapy were followed by delayed release up to a week [78]. Boiling offers a false comfort against toxins but nevertheless kills microorganisms [63].

8.5. Point-of-Use Treatment

Activated carbon eliminates geosmin and MIB but its efficacy is reduced by natural organic matter, preloading and temperature [54,79]. Nanofiltration and reverse osmosis reject dissolved cyanotoxins; one nanofiltration membrane rejected > 96% of microcystins and anatoxin-a [75]. Household RO units need to be maintained, because algae can form in ignored units and transparent cooler reservoirs [48]. No single technique will remove all cyanotoxins, hence a multi-barrier approach is advocated even at small scale including household filters [80,81].

8.6. Measures beyond the Household

The lasting fix lies upstream. Moving from intermittent to continuous supply improved microbial water quality in Nagpur, India [82]. Water safety plans can treat the household tank as a control point [64]. Product standards for opacity, insulation and access, together with simple guidance for plumbers and householders, would cost little.

Table 04: Control options for algal and cyanobacterial regrowth in household rooftop tanks.

Measure	How it works	Main benefit	Limitations	Ref.
Opaque or multilayer tank, tight lid, screened vent	Blocks light, dust, insects and birds	Removes the energy source of phototrophs	Does not stop heterotrophs or toxins already in the supply	[18,19, 27]
Shade, light outer colour, insulation or air gap	Lowers solar heat gain	Slower chlorine decay and microbial growth	Partial effect (about 10% less heat transfer for an air gap); extra cost	[3,21]
Earth–water heat exchanger	Cools water in buried pipes	Water about 15–16 °C cooler	Cost, space and installation work	[12,22]
Right-sized tank, short storage, bottom drain	Lowers water age and allows sediment flushing	Less regrowth and sediment	Limited by the supply schedule	[5,6]
Regular cleaning with disinfection	Removes biofilm and sediment	Less *E. coli* and turbidity	Best cleaning interval not yet defined	[4,5,17]
Chlorine top-up (sodium hypochlorite)	Oxidises cells and dissolved toxins	Microcystins reduced to 0.07–0.18 µg L^{-1} at point of use	By-products; cell lysis at high dose; weaker at high pH	[65,67, 76]
Activated carbon at the tap	Adsorbs geosmin and MIB	Removes taste and odour	Competition from organic matter; saturation; temperature effects	[54,79]
Nanofiltration or reverse osmosis	Size and charge exclusion	> 96% rejection of microcystins and anatoxin-a by one nanofiltration membrane	Fouling and maintenance; neglected units can grow algae	[48,75]
Not recommended: copper sulfate; boiling to remove toxins	Copper lyses cells; microcystins are heat stable	None for toxins	Toxin release; false sense of safety	[63,77, 78]

9. RESEARCH GAPS AND OUTLOOK

The evidential foundation is limited, and for Iraq it is essentially non-existent. No systematic survey of algae, cyanobacteria, odorants or cyanotoxins in Iraqi rooftop tanks was found. Five gaps jump out. First, seasonal surveys

must be undertaken to quantify temperature profiles, chlorine, phycocyanin, odorants and toxins in the same tanks and across tank types. Secondly, the impact of severe heat is unknown. A 45°C tank may be safer than a 30°C tank since it kills most algae, or more dangerous because it favours thermotolerant producers and removes chlorine faster; only field data can resolve this. Third, the contribution of dust, birds, and network penetration to tank nutrient budgets is unknown. Fourth, affordable sensors and test kits need to be validated in hot, mineral-rich water. Fifth, there is little correlation between quality of tanks and health. The gastrointestinal complaints described by over a quarter of respondents in Koya [13] cannot be ascribed to any agent without coupled water and health data. These questions become more and more urgent. The warmest days in the Middle East and North Africa have averaged around 43 °C in the recent past, and could reach up to 50 °C by the end of the century with high emissions [9], with super- and ultra-extreme heatwaves becoming recurring [83].

10. CONCLUSION

In hot-arid cities, rooftop tanks are the last and least regulated stage of water provision. They are warm, often illuminated and badly disinfected, which is suitable for algae and cyanobacteria. The direct evidence is scant but constant. Phototrophs and their toxins have been identified in home storage in Egypt, Qatar and southern Africa, while toxigenic strains are present in source waters of Iraq. Geosmin and 2-MIB are detected at a few ng L−1 and may be derived by cyanobacteria or from actinomycetes on tank walls. Microcystins are resistant to heat and can survive boiling water. Simple controls are the most useful. Opaque, sealed tanks keep out light. Shade and insulation keep heat down. Keep storage short, clean tanks regularly. Maintain free chlorine residual. Do not use copper algicides. And carbon, membrane units at the tap help, if maintained. Iraq requires now field data, seasonal surveys that link tank temperature, chlorine, colours, odorants and poisons in the same households. This would turn the general suggestion into national guidance.

11. ACKNOWLEDGEMENT

Not Declared.

12. CONFLICT OF INTEREST STATEMENT

Not Applicable.

13. INFORM CONSENT AND ETHICAL STATMNET

Not Applicable

14. FUNDING

Nil

13. REFERENCES

1. Kumpel E, Nelson KL. Intermittent water supply: Prevalence, practice, and microbial water quality. Environmental Science & Technology. 2016;50(2):542–553. https://doi.org/10.1021/acs.est.5b03973
2. Salehi M. Global water shortage and potable water safety; Today's concern and tomorrow's crisis. Environment International. 2022;158:106936. https://doi.org/10.1016/j.envint.2021.106936
3. Mahdi JA, Juaifer HJA, Abdulrasool AA. Experimental and numerical analysis of air gap insulation for thermal performance enhancement in polyethylene water storage tanks. International Journal of Heat and Technology. 2025;43(2):449–455. https://doi.org/10.18280/ijht.430207
4. Evison L, Sunna N. Microbial regrowth in household water storage tanks. Journal AWWA. 2001;93(9):85–94. https://doi.org/10.1002/j.1551-8833.2001.tb09289.x
5. Manga M, Ngobi TG, Okeny L, Acheng P, Namakula H, Kyaterekera E, Nansubuga I, Kibwami N. The effect of household storage tanks/vessels and user practices on the quality of water: A systematic review of literature. Environmental Systems Research. 2021;10:18. https://doi.org/10.1186/s40068-021-00221-9
6. Slavik I, Oliveira KR, Cheung PB, Uhl W. Water quality aspects related to domestic drinking water storage tanks and consideration in current standards and guidelines throughout the world – a review. Journal of Water and Health. 2020;18(4):439–463. https://doi.org/10.2166/wh.2020.052
7. Paerl HW, Huisman J. Climate change: A catalyst for global expansion of harmful cyanobacterial blooms. Environmental Microbiology Reports. 2009;1(1):27–37. https://doi.org/10.1111/j.1758-2229.2008.00004.x
8. Huisman J, Codd GA, Paerl HW, Ibelings BW, Verspagen JMH, Visser PM. Cyanobacterial blooms. Nature Reviews Microbiology. 2018;16(8):471–483. https://doi.org/10.1038/s41579-018-0040-1
9. Lelieveld J, Proestos Y, Hadjinicolaou P, Tanarhte M, Tyrlis E, Zittis G. Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. Climatic Change. 2016;137(1–2):245–260. https://doi.org/10.1007/s10584-016-1665-6

10. Chatziefthimiou AD, Metcalf JS, Glover WB, Banack SA, Dargham SR, Richer RA. Cyanobacteria and cyanotoxins are present in drinking water impoundments and groundwater wells in desert environments. Toxicon. 2016;114:75–84. https://doi.org/10.1016/j.toxicon.2016.02.016
11. Mohamed ZA, Deyab MA, Abou-Dobara MI, El-Raghi WM. Occurrence of toxic cyanobacteria and microcystin toxin in domestic water storage reservoirs, Egypt. Journal of Water Supply: Research and Technology—AQUA. 2016;65(5):431–440. https://doi.org/10.2166/aqua.2016.115
12. Dakhil AA, Hammadi SH. Theoretical and experimental study of water storage tank with earth water heat exchanger in hot climates regions. Basrah Journal of Engineering Sciences. 2022;22(1):29–35. https://doi.org/10.33971/bjes.22.1.4
13. Muhammad HA, Albarzinji IM, Abdulrahman SO, Abdullah HK. Influence of storage practices, container type, and handling on overall safety of household drinking water quality. Frontiers in Water. 2026;8:1794632. https://doi.org/10.3389/frwa.2026.1794632
14. Al-Zboon KK. Management of household water tanks in Irbid Governorate of Jordan. Jordanian Journal of Engineering and Chemical Industries. 2025:28–36. https://doi.org/10.48103/jjeci832024
15. Alazzeh S, Galaitsi SE, Bishara A, Al-Azraq N, Durant JL. Impacts of intermittent water supply on water quality in two Palestinian refugee camps. Water. 2019;11(4):670. https://doi.org/10.3390/w11040670
16. Semerjian L, Al-Bardan M, Kassar MGA. Assessment of water quality variations from mains to building storage tanks in Sharjah, United Arab Emirates. Environmental Monitoring and Assessment. 2021;193(10):629. https://doi.org/10.1007/s10661-021-09409-z
17. Schafer CA, Mihelcic JR. Effect of storage tank material and maintenance on household water quality. Journal AWWA. 2012;104(9):E521–E529. https://doi.org/10.5942/jawwa.2012.104.0125
18. Fosso-Kankeu E, Jagals P, Du Preez H. Exposure of rural households to toxic cyanobacteria in container-stored water. Water SA. 2008;34(5):631–636. https://doi.org/10.4314/wsa.v34i5.180660
19. Mokoena MM, Mukhola MS. Current effects of cyanobacteria toxin in water sources and containers in the Hartbeespoort Dam area, South Africa. International Journal of Environmental Research and Public Health. 2019;16(22):4468. https://doi.org/10.3390/ijerph16224468
20. Al-Ghamdi AS. Water conservation in hot climate buildings by temperature control. Asian Journal of Water, Environment and Pollution. 2010;7(4). https://doi.org/10.3233/AJW-2010-7_4_02
21. Almuhanna EA. Effectiveness of some methods used to reduce water temperature from residential water tanks under hot and humid climatic conditions. Misr Journal of Agricultural Engineering. 2016;33(2):603–634. https://doi.org/10.21608/mjae.2016.98010
22. Hammadi SH. Tempering of water storage tank temperature in hot climates regions using earth water heat exchanger. Thermal Science and Engineering Progress. 2018;6:157–163. https://doi.org/10.1016/j.tsep.2018.03.009
23. Majdi HS, Ali FAMA, Habeeb LJ. The rooms air conditioning by cooling the conventional water tank using hot summer air and solar energy. International Journal of Heat and Technology. 2020;38(2):472–478. https://doi.org/10.18280/ijht.380224
24. Agudelo-Vera C, Avvedimento S, Boxall J, Creaco E, de Kater H, Di Nardo A, Djukic A, Douterelo I, Fish KE, Iglesias Rey PL, Jacimovic N, Jacobs HE, Kapelan Z, Martinez Solano J, Montoya Pachongo C, Piller O, Quintiliani C, Ručka J, Tuhovčák L, Blokker M. Drinking water temperature around the globe: Understanding, policies, challenges and opportunities. Water. 2020;12(4):1049. https://doi.org/10.3390/w12041049
25. Furst KE, Graham KE, Weisman RJ, Adusei KB. It's getting hot in here: Effects of heat on temperature, disinfection, and opportunistic pathogens in drinking water distribution systems. Water Research. 2024;260:121913. https://doi.org/10.1016/j.watres.2024.121913
26. Andriamanantena RV, Kim M, Han M. Effect of visible light on surface-attached and suspended heterotrophic bacteria in a typical household rainwater harvesting tank. Sustainability. 2021;13(10):5410. https://doi.org/10.3390/su13105410
27. Box J, Otto J, Kent W, Higgins BT. Investigation of covers and chemical treatment for the suppression of cyanobacteria in water treatment systems. Water and Environment Journal. 2021;35(2):463–472. https://doi.org/10.1111/wej.12643
28. Lürling M, Eshetu F, Faassen EJ, Kosten S, Huszar VLM. Comparison of cyanobacterial and green algal growth rates at different temperatures. Freshwater Biology. 2013;58(3):552–559. https://doi.org/10.1111/j.1365-2427.2012.02866.x
29. Nalley JO, O'Donnell DR, Litchman E. Temperature effects on growth rates and fatty acid content in freshwater algae and cyanobacteria. Algal Research. 2018;35:500–507. https://doi.org/10.1016/j.algal.2018.09.018
30. Butterwick C, Heaney SI, Talling JF. Diversity in the influence of temperature on the growth rates of freshwater algae, and its ecological relevance. Freshwater Biology. 2005;50(2):291–300. https://doi.org/10.1111/j.1365-2427.2004.01317.x
31. Mohamed ZA. Toxic cyanobacteria and cyanotoxins in public hot springs in Saudi Arabia. Toxicon. 2008;51(1):17–27. https://doi.org/10.1016/j.toxicon.2007.07.007

32. Visser PM, Verspagen JMH, Sandrini G, Stal LJ, Matthijs HCP, Davis TW, Paerl HW, Huisman J. How rising CO_2 and global warming may stimulate harmful cyanobacterial blooms. Harmful Algae. 2016;54:145–159. https://doi.org/10.1016/j.hal.2015.12.006
33. Powell JC, Hallam NB, West JR, Forster CF, Simms J. Factors which control bulk chlorine decay rates. Water Research. 2000;34(1):117–126. https://doi.org/10.1016/S0043-1354(99)00097-4
34. García-Ávila F, Sánchez-Alvarracín C, Cadme-Galabay M, Conchado-Martínez J, García-Mera G, Zhindón-Arévalo C. Relationship between chlorine decay and temperature in the drinking water. MethodsX. 2020;7:101002. https://doi.org/10.1016/j.mex.2020.101002
35. Hu D, Zeng J, Chen J, Lin W, Xiao X, Feng M, Yu X. Microbiological quality of roof tank water in an urban village in southeastern China. Journal of Environmental Sciences. 2023;125:148–159. https://doi.org/10.1016/j.jes.2022.01.036
36. Li H, Li S, Tang W, Yang Y, Zhao J, Xia S, Zhang W, Wang H. Influence of secondary water supply systems on microbial community structure and opportunistic pathogen gene markers. Water Research. 2018;136:160–168. https://doi.org/10.1016/j.watres.2018.02.031
37. Mohamed ZA, Deyab MA, Abou-Dobara MI, El-Sayed AK, El-Raghi WM. Occurrence of cyanobacteria and microcystin toxins in raw and treated waters of the Nile River, Egypt: Implication for water treatment and human health. Environmental Science and Pollution Research. 2015;22(15):11716–11727. https://doi.org/10.1007/s11356-015-4420-z
38. Mohamed ZA. Breakthrough of *Oscillatoria limnetica* and microcystin toxins into drinking water treatment plants – examples from the Nile River, Egypt. Water SA. 2016;42(1):161. https://doi.org/10.4314/wsa.v42i1.16
39. Mohamed ZA, Al Shehri AM. Microcystins in groundwater wells and their accumulation in vegetable plants irrigated with contaminated waters in Saudi Arabia. Journal of Hazardous Materials. 2009;172(1):310–315. https://doi.org/10.1016/j.jhazmat.2009.07.010
40. Hamilton K, Reyneke B, Waso M, Clements T, Ndlovu T, Khan W, DiGiovanni K, Rakestraw E, Montalto F, Haas CN, Ahmed W. A global review of the microbiological quality and potential health risks associated with roof-harvested rainwater tanks. npj Clean Water. 2019;2:7. https://doi.org/10.1038/s41545-019-0030-5
41. Sissakian VK, Al-Ansari N, Knutsson S. Sand and dust storm events in Iraq. Natural Science. 2013;5(10):1084–1094. https://doi.org/10.4236/ns.2013.510133
42. Awadh SM. Impact of North African sand and dust storms on the Middle East using Iraq as an example: Causes, sources, and mitigation. Atmosphere. 2023;14(1):180. https://doi.org/10.3390/atmos14010180
43. Chorus I, Fastner J, Welker M. Cyanobacteria and cyanotoxins in a changing environment: Concepts, controversies, challenges. Water. 2021;13(18):2463. https://doi.org/10.3390/w13182463
44. Martínez S, Cerdeiras MP, Douterelo I, Ijaz UZ. Biofilm and sediment phases as key components of microbial community dynamics within secondary drinking water distribution systems. BMC Microbiology. 2026;26:605. https://doi.org/10.1186/s12866-026-05149-7
45. Cai X, Hu Y, Zhou S, Meng D, Xia S, Wang H. Unraveling bacterial and eukaryotic communities in secondary water supply systems: Dynamics, assembly, and health implications. Water Research. 2023;245:120597. https://doi.org/10.1016/j.watres.2023.120597
46. Quiblier C, Wood S, Echenique-Subiabre I, Heath M, Villeneuve A, Humbert JF. A review of current knowledge on toxic benthic freshwater cyanobacteria – Ecology, toxin production and risk management. Water Research. 2013;47(15):5464–5479. https://doi.org/10.1016/j.watres.2013.06.042
47. Wood SA, Kelly LT, Bouma-Gregson K, Humbert JF, Laughinghouse HD IV, Lazorchak J, McAllister TG, McQueen A, Pokrzywinski K, Puddick J, Quiblier C, Reitz LA, Ryan KG, Vadeboncoeur Y, Zastepa A, Davis TW. Toxic benthic freshwater cyanobacterial proliferations: Challenges and solutions for enhancing knowledge and improving monitoring and mitigation. Freshwater Biology. 2020;65(10):1824–1842. https://doi.org/10.1111/fwb.13532
48. Hadi SH, Raheema RH, et al. Cyanobacteria and microalgae microcystin-LR of the reverse osmosis house filter drinking water in Babel Province, Iraq. In: MINAR International Multidisciplinary Congress (conference proceedings); 2023. p. 209–218. https://doi.org/10.47832/minarcong9-18
49. Abed IJ, Abdulhasan GA, Moushib LI. Molecular and immunological methods to confirm toxiginicity (microcystin production) of *Westiellopsis prolifica* isolated from Tigris River – Iraq. Baghdad Science Journal. 2019;16(4 Suppl.):978. https://doi.org/10.21123/bsj.2019.16.4(suppl.).0978
50. Gummaa NR, Dwaish AS, Hamzah IH. Molecular detection of some toxogenic cyanobacteria in Tigris River in Baghdad–Iraq. Molecular Biology Reports. 2021;48(7):5393–5397. https://doi.org/10.1007/s11033-021-06538-z
51. Watson SB. Aquatic taste and odor: A primary signal of drinking-water integrity. Journal of Toxicology and Environmental Health, Part A. 2004;67(20–22):1779–1795. https://doi.org/10.1080/15287390490492377
52. Jüttner F, Watson SB. Biochemical and ecological control of geosmin and 2-methylisoborneol in source waters. Applied and Environmental Microbiology. 2007;73(14):4395–4406. https://doi.org/10.1128/AEM.02250-06
53. Young WF, Horth H, Crane R, Ogden T, Arnott M. Taste and odour threshold concentrations of potential potable water contaminants. Water Research. 1996;30(2):331–340. https://doi.org/10.1016/0043-1354(95)00173-5
54. Zamyadi A, Henderson R, Stuetz R, Hofmann R, Ho L, Newcombe G. Fate of geosmin and 2-methylisoborneol in full-scale water treatment plants. Water Research. 2015;83:171–183. https://doi.org/10.1016/j.watres.2015.06.038

55. Izaguirre G, Hwang CJ, Krasner SW, McGuire MJ. Geosmin and 2-methylisoborneol from cyanobacteria in three water supply systems. Applied and Environmental Microbiology. 1982;43(3):708–714. https://doi.org/10.1128/aem.43.3.708-714.1982
56. Suurnäkki S, Gomez-Saez GV, Rantala-Ylinen A, Jokela J, Fewer DP, Sivonen K. Identification of geosmin and 2-methylisoborneol in cyanobacteria and molecular detection methods for the producers of these compounds. Water Research. 2015;68:56–66. https://doi.org/10.1016/j.watres.2014.09.037
57. Gaget V, Almuhtaram H, Kibuye F, Hobson P, Zamyadi A, Wert E, Brookes JD. Benthic cyanobacteria: A utility-centred field study. Harmful Algae. 2022;113:102185. https://doi.org/10.1016/j.hal.2022.102185
58. Saadoun IMK, Schrader KK, Blevins WT. Environmental and nutritional factors affecting geosmin synthesis by *Anabaena* sp. Water Research. 2001;35(5):1209–1218. https://doi.org/10.1016/S0043-1354(00)00381-X
59. Wang Z, Li R. Effects of light and temperature on the odor production of 2-methylisoborneol-producing *Pseudanabaena* sp. and geosmin-producing *Anabaena ucrainica* (cyanobacteria). Biochemical Systematics and Ecology. 2015;58:219–226. https://doi.org/10.1016/j.bse.2014.12.013
60. Jüttner F, Watson SB, von Elert E, Köster O. β-Cyclocitral, a grazer defence signal unique to the cyanobacterium *Microcystis*. Journal of Chemical Ecology. 2010;36(12):1387–1397. https://doi.org/10.1007/s10886-010-9877-0
61. Ito T, Okumura T, Yamamoto M. The relationship between concentration and sensory properties of 2-methylisoborneol and geosmin in drinking water. Water Science and Technology. 1988;20(8–9):11–17. https://doi.org/10.2166/wst.1988.0218
62. Chorus I, Welker M, editors. *Toxic Cyanobacteria in Water: A Guide to Their Public Health Consequences, Monitoring and Management*. 2nd ed. Boca Raton (FL): CRC Press, on behalf of the World Health Organization; 2021. https://doi.org/10.1201/9781003081449
63. World Health Organization. Cyanobacterial toxins: Microcystins. Background document for development of WHO Guidelines for drinking-water quality and Guidelines for safe recreational water environments. Geneva: World Health Organization; 2020 (WHO/HEP/ECH/WSH/2020.6).
64. World Health Organization. Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First and Second Addenda. Geneva: World Health Organization; 2022 (ISBN 978-92-4-004506-4).
65. Acero JL, Rodriguez E, Meriluoto J. Kinetics of reactions between chlorine and the cyanobacterial toxins microcystins. Water Research. 2005;39(8):1628–1638. https://doi.org/10.1016/j.watres.2005.01.022
66. Daly RI, Ho L, Brookes JD. Effect of chlorination on *Microcystis aeruginosa* cell integrity and subsequent microcystin release and degradation. Environmental Science & Technology. 2007;41(12):4447–4453. https://doi.org/10.1021/es070318s
67. Zamyadi A, Ho L, Newcombe G, Bustamante H, Prévost M. Fate of toxic cyanobacterial cells and disinfection by-products formation after chlorination. Water Research. 2012;46(5):1524–1535. https://doi.org/10.1016/j.watres.2011.06.029
68. Azevedo SMFO, Carmichael WW, Jochimsen EM, Rinehart KL, Lau S, Shaw GR, Eaglesham GK. Human intoxication by microcystins during renal dialysis treatment in Caruaru—Brazil. Toxicology. 2002;181–182:441–446. https://doi.org/10.1016/S0300-483X(02)00491-2
69. Jochimsen EM, Carmichael WW, An J, Cardo DM, Cookson ST, Holmes CEM, Antunes MB, de Melo Filho DA, Lyra TM, Barreto VST, Azevedo SMFO, Jarvis WR. Liver failure and death after exposure to microcystins at a hemodialysis center in Brazil. New England Journal of Medicine. 1998;338(13):873–878. https://doi.org/10.1056/NEJM199803263381304
70. Zamyadi A, Choo F, Newcombe G, Stuetz R, Henderson RK. A review of monitoring technologies for real-time management of cyanobacteria: Recent advances and future direction. TrAC Trends in Analytical Chemistry. 2016;85:83–96. https://doi.org/10.1016/j.trac.2016.06.023
71. Bertone E, Burford MA, Hamilton DP. Fluorescence probes for real-time remote cyanobacteria monitoring: A review of challenges and opportunities. Water Research. 2018;141:152–162. https://doi.org/10.1016/j.watres.2018.05.001
72. Fischer WJ, Garthwaite I, Miles CO, Ross KM, Aggen JB, Chamberlin AR, Towers NR, Dietrich DR. Congener-independent immunoassay for microcystins and nodularins. Environmental Science & Technology. 2001;35(24):4849–4856. https://doi.org/10.1021/es011182f
73. Van Hassel WHR, Huybrechts B, Masquelier J, Wilmotte A, Andjelkovic M. Development, validation and application of a targeted LC-MS method for quantification of microcystins and nodularin: Towards a better characterization of drinking water. Water. 2022;14(8):1195. https://doi.org/10.3390/w14081195
74. Saito K, Okamura K, Kataoka H. Determination of musty odorants, 2-methylisoborneol and geosmin, in environmental water by headspace solid-phase microextraction and gas chromatography–mass spectrometry. Journal of Chromatography A. 2008;1186(1–2):434–437. https://doi.org/10.1016/j.chroma.2007.12.078
75. Gijsbertsen-Abrahamse AJ, Schmidt W, Chorus I, Heijman SGJ. Removal of cyanotoxins by ultrafiltration and nanofiltration. Journal of Membrane Science. 2006;276(1–2):252–259. https://doi.org/10.1016/j.memsci.2005.09.053
76. Mokoena MM, Mudau LS, Mokgobu MI, Mukhola MS. The use of sodium hypochlorite at point-of-use to remove microcystins from water containers. Toxins. 2021;13(3):207. https://doi.org/10.3390/toxins13030207

77. Kenefick SL, Hrudey SE, Peterson HG, Prepas EE. Toxin release from *Microcystis aeruginosa* after chemical treatment. Water Science and Technology. 1993;27(3–4):433–440. https://doi.org/10.2166/wst.1993.0387
78. Zamyadi A, Greenstein KE, Glover CM, Adams C, Rosenfeldt E, Wert EC. Impact of hydrogen peroxide and copper sulfate on the delayed release of microcystin. Water. 2020;12(4):1105. https://doi.org/10.3390/w12041105
79. Yuan J, Huang Y, Nie Z, Hofmann R. The effect of water temperature on the removal of 2-methylisoborneol and geosmin by preloaded granular activated carbon. Water Research. 2020;183:116065. https://doi.org/10.1016/j.watres.2020.116065
80. Westrick JA, Szlag DC, Southwell BJ, Sinclair J. A review of cyanobacteria and cyanotoxins removal/inactivation in drinking water treatment. Analytical and Bioanalytical Chemistry. 2010;397(5):1705–1714. https://doi.org/10.1007/s00216-010-3709-5
81. Merel S, Walker D, Chicana R, Snyder S, Baurès E, Thomas O. State of knowledge and concerns on cyanobacterial blooms and cyanotoxins. Environment International. 2013;59:303–327. https://doi.org/10.1016/j.envint.2013.06.013
82. Bivins A, Lowry S, Wankhede S, Hajare R, Murphy HM, Borchardt M, Labhasetwar P, Brown J. Microbial water quality improvement associated with transitioning from intermittent to continuous water supply in Nagpur, India. Water Research. 2021;201:117301. https://doi.org/10.1016/j.watres.2021.117301
83. Zittis G, Hadjinicolaou P, Almazroui M, Bucchignani E, Driouech F, El Rhaz K, Kurnaz L, Nikulin G, Ntoumos A, Ozturk T, Proestos Y, Stenchikov G, Zaaboul R, Lelieveld J. Business-as-usual will lead to super and ultra-extreme heatwaves in the Middle East and North Africa. npj Climate and Atmospheric Science. 2021;4:20. https://doi.org/10.1038/s41612-021-00178-7