

Do natural spring waters in Australia and New Zealand affect health? A systematic review

Jessica Stanhope, Philip Weinstein and Angus Cook

ABSTRACT

Therapeutic use of spring waters has a recorded history dating back to at least 1550 BC and includes both bathing in and drinking such waters for their healing properties. In Australia and New Zealand the use of therapeutic spring waters is a much more recent phenomenon, becoming a source of health tourism from the late 1800s. We conducted a systematic review aimed at determining the potential health outcomes relating to exposure to Australian or New Zealand natural spring water. We found only low-level evidence of adverse health outcomes relating to this spring water exposure, including fatalities from hydrogen sulphide poisoning, drowning and primary amoebic meningoencephalitis. We found no studies that investigated the therapeutic use of these waters, compared with similar treatment with other types of water. From the broader literature, recommendations have been made, including fencing potentially harmful spring water, and having signage and media messages to highlight the potential harms from spring water exposure and how to mitigate the risks (e.g. not putting your head under water from geothermal springs). Sound research into the potential health benefits of Australian and New Zealand spring waters could provide an evidence base for the growing wellness tourism industry.

Key words | Australia, health, New Zealand, spring water, systematic review

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INTRODUCTION

In historical and current times, natural spring waters have gained much attention for their putative therapeutic benefits. Natural spring water is generally understood to be water from an aquifer that has flowed naturally to the surface and remains unaltered by additional water treatment. This water may contain a number of minerals, which are assumed to increase the therapeutic value of the water, and the warmth of geothermal waters may also provide health-enhancing effects through bathing.

Therapeutic applications and proposed benefits of spring water therapies

Spring water therapies encompass a complex range of activities. Spring water therapies may involve use of waters for

bathing (Faull 2005; Bálint *et al.* 2007; Merial-Kieny *et al.* 2011), showering (Faull 2005), drinking (Merial-Kieny *et al.* 2011) and inhalation (Keller *et al.* 2014), as well as use for nasal irrigation (Keller *et al.* 2014) and dermal sprays (Merial-Kieny *et al.* 2011). While bathing in spring water, patients may receive other therapies such as exercises (Altan *et al.* 2004), massage (Konrad *et al.* 1992; Faull 2005; Merial-Kieny *et al.* 2011) and traction (Konrad *et al.* 1992). Shower therapies may also involve massage (Faull 2005).

The use of spring water as a therapy is thought to have started by at least 1550 BC (Moss 2010). One of the early proponents of balneology was Hippocrates of Kos (Fytikas *et al.* 2005) who stated ‘... that cold water warms, ... whilst warm water cools the body; ... that warm shower baths induce sleep, ... and that cold water stimulates; ... he recommended

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cold water to assuage fever and pain' (Calthrop 1928). However, formal research into the therapeutic value of spring water did not occur until the 1700s (Calthrop 1928).

International evidence from a number of systematic reviews suggests that spring water therapies may be beneficial for a range of disorders. These reviews have reported improvements for upper respiratory tract diseases (Keller *et al.* 2014) and a range of musculoskeletal disorders, including chronic low back pain (Falagas *et al.* 2009; Bender *et al.* 2014), osteoarthritis (Falagas *et al.* 2009; Harzy *et al.* 2009; Bender *et al.* 2014), rheumatoid arthritis (Falagas *et al.* 2009), ankylosing spondylitis (Falagas *et al.* 2009) and fibromyalgia (Falagas *et al.* 2009). Many of these reviews failed to exclude studies which did not have a comparison group utilising different types of water (e.g. tap water), and it is therefore difficult to determine whether the spring water itself provided the benefit, or whether any other type of water applied in the same manner may have been just as effective. Some trials have formally evaluated spring water therapies versus the same treatment using other types of water (e.g. tap water), and have reported beneficial effects for conditions such as lower back pain (Tefner *et al.* 2012), osteoarthritis (Szucs *et al.* 1989; Yurtkuran *et al.* 2006; Kovács *et al.* 2012), chronic inflammatory gynaecological disorders (Zámbó *et al.* 2008) and upper respiratory tract infections (Salami *et al.* 2008).

Unlike many other therapies, the potential benefits of spring water therapies may be specific to the water quality of an individual spring, and may vary over time. In prescribing a treatment involving spring water, there are a number of considerations which may influence the effectiveness. These include the route of exposure (e.g. bathing, drinking, inhalation), the duration and frequency of exposure, the level of immersion for bathing, the amount of water consumed for drinking therapies, the minerals present in the water, the flow rate, amount of effervescence, the temperature, the atmosphere and the setting (e.g. natural or clinical). For instance, there is evidence to suggest that increased hydrostatic pressure, buoyancy, temperature, and water composition may play a role in the treatment of rheumatic diseases (Fioravanti *et al.* 2011), all of which may vary depending on the spring. Given the complexity of the potential exposures to spring waters, the potential health benefits

of local exposure must be considered before accurate claims can be made.

Spring water in Australia and New Zealand

Spring water has been promoted for medicinal use in both Australia and New Zealand (NZ) (Johnson 1990; White 2012). In New Zealand, Māori have used hot springs for healing since 1300 AD (Erfurt-Cooper & Cooper 2009). Arthur Stanley Wohlmann, NZ's first official Government Balneologist, recommended spa treatments such as mineral water treatment, but also involved other physical treatments (e.g. massage, exercises, electrotherapy), change in environment, diet and regulation of habits (Wohlmann 1914). Wohlmann (1914) studied his patients to determine the effects of the spa treatment on their ailments, reporting a case series of 593 inpatients (three and a half year period, 1908–1911) seen by him in Rotorua for a wide range of conditions, including those of the musculoskeletal, nervous, digestive, respiratory, cardiovascular, urinary and integumentary systems. He reported that 525 patients improved (127 better, 117 much better and 281 very much better) and only two got worse, although the diagnostic criteria, characteristics of the treatments and outcome measures used were not fully reported. Wohlmann (1914) also highlighted the importance of psychological suggestion in the treatment. The contribution of the natural spring water itself to these therapeutic improvements is therefore difficult to determine.

Spring water was also promoted for tourism in Australia and NZ from the late 1800s and early 1900s (Bruck 1888; Johnson 1990). The spa industry declined from the 1950s but then underwent a resurgence in the 1980s (Johnson 1990; Erfurt-Cooper & Cooper 2009). Since then the industry has continued to grow, with recent investment in Hepburn Springs, Moree, and Peninsula Springs (Johnson 1990; Erfurt-Cooper & Cooper 2009), and plans to explore opportunities to establish new facilities in Victoria (Tourism Victoria n.d.). In 2010, it was estimated that 1.4 million domestic day-trippers visited the Central Victorian Mineral Springs Region in Australia (Tourism Victoria 2011). Throughout this region there are springs for drinking water which feature signs outlining the chemical analysis, and proposed health benefits (Tourism Victoria 2011) (see examples in Figure 1). Furthermore, the spas in Australia

and New Zealand discuss various health benefits of spring water therapies. QE Health, in NZ, reports that water at their Rachel springs reduces aches and pains, increases flexibility, increases circulation, promotes relaxation and reduces stress, and that it may assist with some skin conditions, such as eczema (QE Health n.d.). The Peninsula Hot Springs in Victoria, Australia outline the benefits of spring water therapies in terms of aiding with cardiovascular disease, liver, respiratory, gastrointestinal, central nervous system, orthopaedic, rheumatic gynaecological, post-

traumatic, post-operative and skin conditions (Peninsula Hot Springs n.d.). It is suggested that these improvements are achieved by such mechanisms as opening peripheral blood vessels and improving circulation, reducing hypertension and mild atherosclerosis, strengthening bones, building muscle mass, eliminating toxins, increasing cell oxygenation, and stimulating metabolism (Peninsula Hot Springs n.d.). The Peninsula Hot Springs (Peninsula Hot Springs n.d.) website does not explicitly state that their water results in these benefits, although it is implied to the consumer by stating the benefits of particular minerals or water temperature, then reporting the characteristics of their water without reference to what concentrations are required to bring about these beneficial changes. These spas do not provide guidance on their websites regarding the required dosage (e.g. immersion time, frequency of exposure) to achieve these beneficial health outcomes. Furthermore, no research is cited on their websites.

With the uncertainties around these proposed health effects, there is a need to systematically review the health benefits of natural spring water in Australia and NZ to provide high level evidence of any health benefits, which may support public health, in addition to wellness tourism. This review will also seek to identify gaps in the current literature that may provide opportunities for future research in this area.

Adverse health effects of spring water

Natural spring water used for hydration and therapeutic purposes is often promoted as a safe alternative to drinking tap water, or to utilising more conventional treatments, such as medications. However, the adverse health effects of spring water also need to be considered. The potential risks associated with natural spring water exposure may vary depending on the route of exposure and the location of the spring.

The promotion of springs through websites and signage may refer to the chemical components of the water (e.g. Figure 1), with statements regarding the health benefits of these minerals. There may be an assumption that the higher the concentration of these minerals, the better these proposed health benefits, but this is not always the case. Even those minerals which are important for good health may be toxic if consumption is excessive, and this exposure

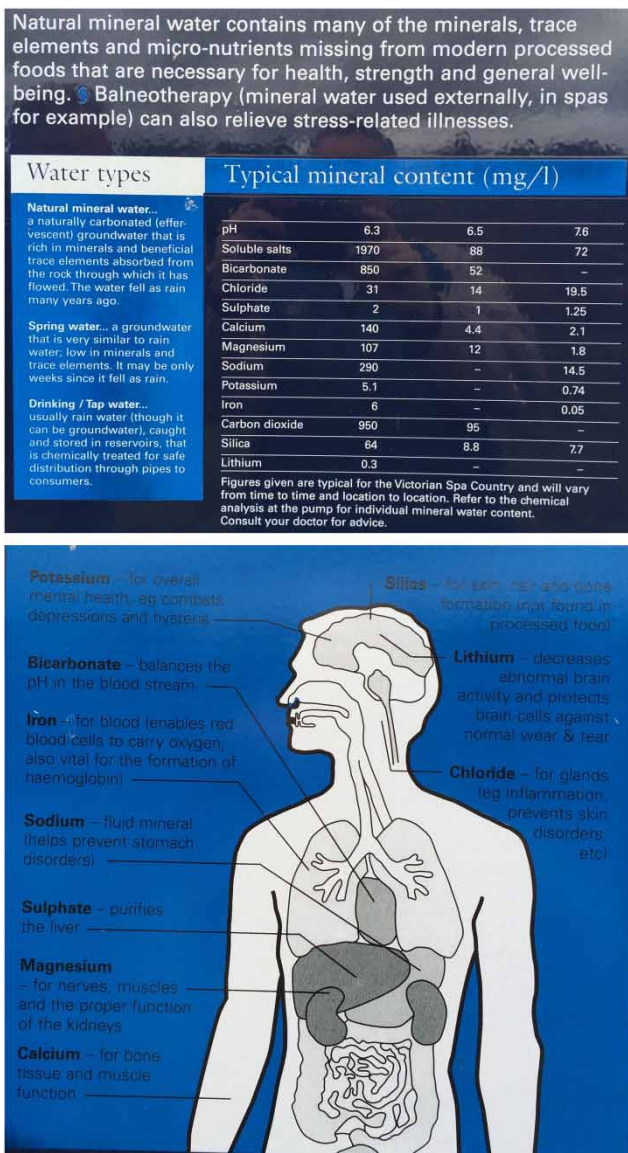


Figure 1 | Signs from Central Springs Reserve, Victoria.

may in some cases be fatal (Lindh 2007). The health claims, such as reducing blood pressure, may pose subtle dangers where people choose to discontinue conventional treatments, choosing instead to utilise these spring water therapies which claim to be effective; or people may choose to self-diagnose and treat, thus delaying or avoiding conventional, evidence-based diagnosis and treatment. Without an understanding of the therapeutic dosage of these minerals, intake may be insufficient for any health benefit, or excessive to the point of toxicity (particularly in the absence of full chemical analysis, including potentially toxic constituents) (Martin & Dowling 2013). Toxicity may also arise from exposure to some non-essential elements present in some spring waters (Lindh 2007; Martin & Dowling 2013).

The potential health risk of spring water use in both Australia and NZ has recently been raised. A recent study (Martin & Dowling 2013) of water from 11 springs in the Central Victorian Mineral Springs Region of Australia identified that levels of arsenic, antimony, and lead in these springs were higher than the Australian Drinking Water Guideline values (National Health and Medical Research Council & Natural Resource Management Ministerial Council 2016). This is a region where springs often have signs reporting the health benefits of their water, as well as water analyses, but the harmful elements and potential adverse health outcomes are not reported (Martin & Dowling 2013). Similarly, spring water used in pools for bathing in the Taupo Volcanic Zone in NZ have high levels of arsenic, with over 94% of total arsenic level in some of these springs being from arsenite, one of the more toxic species of arsenic (Lord *et al.* 2012). Spring water may therefore pose a range of health risks for those exposed to it.

As with any water body, we would expect microbes to be present in the spring water of New Zealand and Australia, which may pose a risk to human health. The characteristics of the specific spring, including temperature, water flow, minerals and acidity, would be expected to influence which microbes are present. The presence of these microbes, even if pathogenic, will not necessarily pose a human health risk, depending on the type and dosage of exposure. As such, there needs to be an investigation into the adverse health events resulting from exposure to Australian and New Zealand natural spring water.

Aim and research questions

The aim of this systematic review was to determine the human health effects of Australian and NZ spring water. The main research questions were: (1) what are the established beneficial human health outcomes associated with exposure to Australian and NZ spring waters?; (2) what are the potentially adverse human health outcomes associated with exposure to Australian and NZ spring waters?; and (3) does the benefit of exposure to natural spring waters of Australia and New Zealand outweigh the risks?

METHODS

The published review protocol (Stanhope *et al.* 2015a) was registered with PROSPERO (June 28, 2015; PROSPERO registration number: CRD42015023713 (Stanhope *et al.* 2015b)). Prior to commencing searching in November 2015, minor amendments were made to this protocol (see Appendix 1, available with the online version of this paper). In short, studies were obtained through a systematic search of eight library databases, Google Scholar search specific to three local journals (*New Zealand Medical Journal*, *Medical Journal of Australia*, and *Australian and New Zealand Journal of Public Health*), and reference and citation list (Web of Science and Google Scholar) screening of included studies. Details of these searches are reported in the protocol (Stanhope *et al.* 2015a, 2015b).

To be eligible for inclusion, studies had to be peer-reviewed, published in full text, in English language and report any health effects of Australian or NZ natural spring water on humans. Spring water which had been treated or had added supplements was not considered natural spring water; hence these studies were excluded. Studies investigating interventions where natural spring water exposure was combined with another intervention (e.g. exercises) were only included if they compared different types of water while keeping the additional intervention the same, so that any beneficial health effect could be attributed to the spring water exposure, or if these studies reported whether there were any adverse events. Non-systematic reviews (e.g. narrative reviews) were not eligible for inclusion.

Data were extracted manually, and included the age, gender and health condition of the population, the spring

location, temperature, setting and composition, the spring water application and dosage, the year of the study, type of research question and study design. All outcomes, in addition to the outcome measures used, were extracted. Where interventions included a second intervention (e.g. exercises performed whilst bathing in spring water), the outcomes were only extracted if the water used was compared with another type of water (e.g. tap water, or water from another spring). Adverse events (including the finding of no adverse events) reported in these studies were extracted. Where there were uncertainties regarding data extraction, another author was consulted.

Studies were allocated, according to their designs, to the National Health and Medical Research Council (NHMRC) Levels of Evidence (National Health and Medical Research Council 2009), with the aetiological and experimental hierarchies considered. Critical appraisal was conducted for experimental studies (using the Downs and Black critical appraisal tool (Downs & Black 1998)) and cohort, case-control and cross-sectional studies (using Shamliyan *et al.*'s (2011) quality criteria). Case series and case studies were not formally appraised given the inherent biases in their designs. Similarly, for experimental studies which were included only on the basis of reporting adverse events, critical appraisal was not conducted as these did not compare different types of spring water exposure, and were therefore considered low-level evidence. This was conducted independently by two of the authors (JS & AC). The two authors discussed any difference in appraisal, until a consensus was reached. Where this was not possible, another author (PW) was consulted.

Given the breadth of the systematic review, it was unlikely that a meta-analysis could be conducted owing to the heterogeneity of the studies. As such, findings were reported descriptively. The Grading of Recommendations Assessment, Development and Evaluation (GRADE) criteria (Guyatt *et al.* 2008) was used to provide an overall summary of the strength of the evidence. This was determined independently by two of the authors (JS & PW), using the same process as critical appraisal to resolve any differences.

RESULTS

Of 186 papers identified for full-text screening, only 11 met the inclusion criteria (see Appendix 2 for the flowchart of

study inclusion/exclusion, available with the online version of this paper), and these reported only adverse health outcomes of spring water exposure. Only one paper included the study of spring water used in a clinical setting (Day *et al.* 2010).

There were no beneficial health outcomes reported, with adverse health outcomes associated with drinking and bathing in spring water. The reported adverse health outcomes were diarrhea (Day *et al.* 2010), in-water fatal hydrogen sulphide (H₂S) poisoning (Bassindale & Hosking 2011), drowning (Gardiner *et al.* 1985; Hassall 1989), and fatal primary amoebic meningoencephalitis (PAM) (Anonymous 1969; Mandal *et al.* 1970; Nicoll 1973; Cursons & Brown 1975; Cursons *et al.* 1976a, 1976b, 2003). Weinstein *et al.* (1993) investigated drinking spring water as a risk factor for *Cryptosporidium* infection, and one case of fatal H₂S poisoning was reported for an individual located within an enclosed room adjacent to geothermal water, but who had not entered the water (Bassindale & Hosking 2011).

Seven fatal cases (NHMRC Level IV evidence) of PAM have been reported following bathing in geothermal waters in the North Island of NZ (Anonymous 1969; Mandal *et al.* 1970; Nicoll 1973; Cursons & Brown 1975; Cursons *et al.* 1976a, 1976b, 2003). (Cursons *et al.* (2003) also reported on an additional two cases of PAM occurring in this region. Based on a review of the cited sources, both were excluded as in one the water was 'apparently chlorinated' (Cursons *et al.* 1979) and the other was a letter to the editor (Cursons *et al.* 1976a, 1976b).) Cases were aged 7–21 years (Anonymous 1969; Mandal *et al.* 1970; Nicoll 1973; Cursons & Brown 1975; Cursons *et al.* 1976a, 1976b, 2003). The location of these springs was not explicitly reported in all studies, although Cursons *et al.*'s (2003) report indicates that all occurred in the Waikato area of NZ, along the Waikato River from Matamata to Taupo; specifically at Crystal Springs, Golden Springs, Opal Springs and the Orumuheke stream, a natural thermal stream, where it meets the Waikato River at Taupo.

Two fatal cases (NHMRC Level IV) of H₂S poisoning were reported in an enclosed spa in Rotorua, NZ in 1997 and 1998 (Bassindale & Hosking 2011). Both were male, one aged 77 years and the other 88 years (Bassindale & Hosking 2011). One was bathing and was found in the water, whilst the other did not enter the water (Bassindale

& Hosking 2011). The pathologist concluded they had died of H₂S poisoning, and there were no other contributing factors, including age (Bassindale & Hosking 2011).

Three cases (NHMRC Level IV) of children drowning in thermal pools have been reported in two case series (Gardiner *et al.* 1985; Hassall 1989). One case series (Gardiner *et al.* 1985) reported on 60 children who drowned in Auckland, NZ between 1977 and 1984, with two drownings occurring in the same thermal swimming pool. The other case series included 36 children aged five years or younger who drowned in NZ between 1982 and 1986, one of which occurred in a thermal pool (Hassall 1989). No specific details were reported for these fatalities.

One study investigated spring water as a risk factor for cryptosporidiosis (Weinstein *et al.* 1993). This was a case-control study (NHMRC Level III₃), with a number of issues with poor reporting, as well as methodological flaws (see Appendix 3, available with the online version of this paper). The only major flaw was not validating the method used to assess exposures. This study was conducted in Adelaide, South Australia (1990–1991) and investigated the relationship between contracting cryptosporidiosis and drinking water (Weinstein *et al.* 1993). A total of 51 cases and 51 controls were included, of which 55% were female, and 69% were aged ≤5 years, with a mean age of 8 years (range 0–41 years) (Weinstein *et al.* 1993). Weinstein *et al.* (1993) reported that cases were more likely to have consumed spring water than controls although these results were not statistically significant (spring water only, $p = 0.06$, spring water with other water, $p = 0.08$). Controls were significantly more likely to have consumed rain water (rain water only, $p < 0.005$, rain water with other water, $p < 0.001$) than cases (Weinstein *et al.* 1993).

A randomised controlled trial investigated spring water supplemented with magnesium bicarbonate in postmenopausal women, with cardiovascular risk factors, bone metabolism and acid/base balance assessed as therapeutic outcomes (Day *et al.* 2010). Because the water was artificially supplemented, only the adverse events reported for those in the placebo group who consumed spring water without supplementation was included within our review. Those in the control group consumed 1,500–1,800 mL of spring water without supplementation for 84 days (Day *et al.* 2010). This spring water naturally contained <5 mg/L of magnesium

and no bicarbonate (Day *et al.* 2010). Within this control group, 15.2% of participants reported experiencing diarrhea, which was the most frequently reported adverse event. No serious adverse events were reported (Day *et al.* 2010). As this study was conducted in Australia, and the location of the spring was not reported, it is assumed that only Australian spring water was used. Whilst this is Level II evidence, we only extracted data regarding adverse events in the control group and therefore no critical appraisal was conducted for this study.

Overall, the evidence was considered very low quality according to each aspect of the GRADE system (Guyatt *et al.* 2008).

DISCUSSION

This systematic review is the first to investigate the health outcomes associated with exposure to spring water, specific to Australia and NZ. We identified 11 studies and 10 reported fatalities from H₂S poisoning (Bassindale & Hosking 2011), PAM (Anonymous 1969; Mandal *et al.* 1970; Nicoll 1973; Cursons & Brown 1975; Cursons *et al.* 1976a, 1976b, 1979; Cursons *et al.* 2003) and drowning (Gardiner *et al.* 1985; Hassall 1989). The final study investigated the association between drinking spring water and cryptosporidiosis ($p = 0.06$ and $p = 0.08$, respectively) (Weinstein *et al.* 1993). No studies reported the beneficial health effects of Australian and NZ spring water use.

Exposures in clinical contexts

Benefits

Only one clinical study regarding spring water exposure was included in this review (Day *et al.* 2010), although this was only included for information regarding adverse events as natural spring water was used as a comparison intervention, with no within-group analysis performed. This study therefore cannot be used to determine the health benefits of consuming natural spring water. Another clinical trial using spring water from NZ was identified in the search, however this was excluded as two techniques involving spring water were compared for people with fibromyalgia (Faull 2005). Watsu and

Aix massage were compared, with significant changes in bodily pain, physical function, social function and vitality, according to the 36-Item Short Form Survey (SF-36), reported with Watsu treatment, whilst there was not a significant change for Aix therapy (Faull 2005). While this shows that Watsu may be an appropriate therapy for people with fibromyalgia, it does not indicate that the spring water used contributed a therapeutic component. A randomised-controlled trial should be conducted comparing Watsu utilising this spring water as well as tap water of the same temperature to determine the therapeutic value of spring water.

Adverse events

Day *et al.* (2010) reported that 15.2% of participants in the spring water group of their study experienced diarrhea during the study period (84 days). This may indicate that spring water is associated with diarrhea. Two international systematic reviews (Bender *et al.* 2014; Keller *et al.* 2014) reported adverse effects associated with spring water exposure in clinical contexts. In Bender *et al.*'s (2014) systematic review (1,199 participants) one adverse event was reported, which was an allergic reaction to sulphur. With regards to nasal irrigation and inhalation in patients with upper respiratory tract diseases, 19 of the 840 participants reported adverse effects, reflecting an adverse event rate of 11.9% (assumed rate 7.8–17.6%) (Keller *et al.* 2014). One participant reported an aggravation of symptoms, one dermatological hypersensitivity, five very limited epistaxis, and 13 a burning sensation after application, as well as mild nasal irritation (Keller *et al.* 2014). All related only to sulphurous water, and the overall adverse event rate for sulphurous water was 9.8% (assumed rate 6.6–14.4%) (Keller *et al.* 2014). More adverse outcomes may have occurred and Falagas *et al.* (2009) noted that many studies in their review did not report such effects.

Summary

Despite a number of health claims being made regarding therapies using spring water from Australia and NZ, we found no published studies which have reported studies investigating whether treatment with Australian or NZ spring water is effective, when compared with other types

of water treatments. This may reflect publication bias, or that studies involving formal comparisons have yet to be conducted. Based on this evidence, within an evidence-based practice framework, these therapies should not be recommended by health and medical professionals, particularly given the potential for adverse events, especially for sulphurous water. Furthermore, claims regarding the health benefits of spring water from Australia and NZ are at this stage substantiated, and should be revised to reflect the current evidence base.

Non-clinical exposures

In terms of non-clinical exposures to spring water, adverse health effects associated with pathogens were identified, as well as the potential for H₂S poisoning and drowning.

Exposure to pathogens

PAM is a rare but serious condition, and is almost always fatal (Ellis-Pegler 2003). Reported incubation times vary, with the majority of cases around 2–5 days (Ellis-Pegler 2003). Patients present with similar clinical features to bacterial meningitis, including fever, headache and vomiting, followed by reduced consciousness (Cursons *et al.* 2003), with death occurring within 6 days (Ellis-Pegler 2003). Seven cases occurring after swimming in spring water in the Waikato area of NZ were reported (Anonymous 1969; Mandal *et al.* 1970; Nicoll 1973; Cursons & Brown 1975; Cursons *et al.* 1976a, 1976b, 2003). Infection occurs when the amoebae enter the nasal cavity, invade the nasal mucosa, penetrate the nasal epithelium, infect the olfactory nerves via the cribriform plate, then the meninges and brain (Carter 1978; Moussa *et al.* 2015). The first four cases, occurring in 1968, were originally attributed to *Myxomycetale* (Mandal *et al.* 1970), with further examinations later concluding the pathogen involved to be *Naegleria gruberi* (Cursons & Brown 1975). Ultimately, *N. fowleri* was concluded to be the cause of PAM in these cases (Cursons *et al.* 1976a, 1976b). The additional three cases were also attributed to *N. fowleri* (Nicoll 1973; Cursons *et al.* 1976a, 1976b, 2003).

Although all cases occurred in one region of NZ, the risk is present in any environment where these amoebae thrive. The optimal environment for *N. fowleri* is fresh

water of 40–45°C, and is therefore associated with geothermal waters (Ellis-Pegler 2003). In at least one of the cases signage at the pool informed swimmers not to immerse their heads, but tragically this advice was not followed (Cursons *et al.* 2003). This incident resulted in heightened media coverage of the risk factors and greater promotion of safe behaviour, such as advising bathers not to dive or jump into the water and not to submerge their faces (Cursons *et al.* 2003). Strategies which may decrease the risk in terms of pool operation include filtration, high water turnover, appropriate chlorination and assiduous exclusion of soil from the water source and pool (Cursons *et al.* 2003).

There were no adverse health effects reported associated with drinking spring water, although only one Australasian study investigated this aspect. Weinstein *et al.* (1993) showed no conclusive statistical association between drinking spring water, either exclusively or with other water sources, and cryptosporidiosis ($p = 0.06$ and $p = 0.08$, respectively). Broader analyses have been conducted internationally on exposure to untreated waters in general as opposed to spring water specifically. A recent systematic review reported that there was an increase in risk associated with drinking surface or tap water with no further treatment (such as spring water) (OR 1.40 [1.15, 1.72]), when compared with other water sources (Gualberto & Heller 2006). Furthermore, a case-control study from New South Wales, Australia identified that swimming in untreated water, again including natural spring water, was significantly associated with cryptosporidiosis (adjusted OR 4.8 [1.1–20.3], $p = 0.03$) (Puech *et al.* 2001). These reports indicate the potential risks of spring water exposure from both swimming and drinking. With regards to using water for drinking, the contamination may occur as part of the bottling process, whereas surface water for swimming may become infected through fecal exposure from those swimming in the water, from animals or run-off of contaminated water into the spring.

A study of the microbiological quality of bottled water available in NZ was conducted in 2010 (Svagzdiene 2010). A total of 38 brands were sampled, and tested for compliance with the New Zealand Microbiological Reference Criteria for Food and the Australia and New Zealand Food Standards Code in terms of *Escherichia coli*, coliforms, *Enterococci*, *Pseudomonas aeruginosa*, and total viable

counts, as well as testing for yeast and moulds, and *Campylobacter* spp. (not part of the New Zealand Microbiological Reference Criteria for Food and the Australia and New Zealand Food Standards Code) (Svagzdiene 2010). The authors stated that no major public health issues were identified, although some brands of NZ spring and natural mineral water did not comply with the Australia and New Zealand Food Standards Code for the total viable pathogen count (Svagzdiene 2010). As bottled water is subject to these standards, it is unlikely to pose a public health issue. Unregulated water obtained directly from natural springs, however, may pose potential risks.

The pathogens present in spring water may change over time, with changes in the temperature, flow and minerals present, but also changes in local ecology. For instance, the recent establishment of populations of the thiarid snail, *Melanoides tuberculata*, at Golden Springs, a geothermal stream in NZ, may pose a risk to human health (Derraik 2008). The potential health risks are not due to the *M. tuberculata* directly, but rather as an intermediate host of trematode parasites (Derraik 2008). Derraik (2008) has discussed the conditions required for human infections related to parasites associated with *M. tuberculata* to occur, including the need for a second intermediate host and the parasites to be introduced to these springs. Despite *M. tuberculata* first being discovered at Golden Springs in 2001 (Duggan 2002), we identified no studies reporting adverse health outcomes associated with such parasites at this time.

Exposure to minerals

The two reported cases of fatal H₂S poisoning occurred while bathing and in the vicinity of enclosed spas (Bassindale & Hosking 2011), highlighting the potential for unsafe levels of H₂S to be present around geothermal waters. On the day of one death the background level of H₂S was 1–17 ppm (and 44 ppm over the outlet), and 5–9 ppm on the day of the second death. During the month following the deaths, the levels were reported as ranging from 3 to 57 ppm (Bassindale & Hosking 2011). According to the World Health Organisation (2000), acute exposure to H₂S concentrations of 10–20 ppm results in eye irritation, levels of 50–100 ppm may result in serious eye damage, with an increased risk of death only if the H₂S concentration reaches at least 320 ppm. In

addition to such irritant and toxic effects, it is important to note that this heavier-than-air gas can also impact on health through asphyxiation. The coroner who reviewed these cases recommended monitoring H₂S levels in each spa pool area before each use, preferably agitating the water before taking the reading, and it was also noted that bathers should avoid being alone in enclosed geothermal pools (Basindale & Hosking 2011).

Despite excessive levels of arsenic, antimony and lead being identified in springs in the Central Victorian Mineral Springs Region of Australia (Martin & Dowling 2013), there has been no published study investigating the potential adverse health effects of consuming water from these springs. Similarly, there have been no published reports regarding the health effects of bathing in spring water from the Taupo Volcanic Zone (Mokena Geyser, Top Inlet Spring, Parekiri, Takarea Pools #5 and #6, and Taumatapuhipuhi Spring) where high levels of arsenite have been reported in some of the spring waters (Lord *et al.* 2012). With an increase in spa and eco-tourism encouraging visitors to these regions, there is an urgent need for the health effects of these spring waters to be investigated, particularly with respect to arsenic exposure.

Exposure to different water pH

Another variable to consider with regards to natural spring water is the water pH. In the Taupo Volcanic Zone of New Zealand, the pH of springs used for bathing has been reported as low as 3.2 (Lord *et al.* 2012), which may be a skin irritant, particularly for those with sensitive skin.

General exposure to water bodies

The details of the three drownings at thermal pools were not reported (Gardiner *et al.* 1985; Hassall 1989), and therefore it is difficult to assess the context of these fatalities and whether pre-existing medical conditions were a factor. For instance, seizures may be triggered by hot water in some individuals with epilepsy (Roos & van Dijk 1988; Bebek *et al.* 2001), which may increase the risk of drowning.

There are a range of other potential health risks associated with water in natural settings, including injury, and

bites and stings from insects and reptiles that are also present in the area. This is of particular importance in northern Australia where crocodiles may inhabit springs and their surrounds. For instance, at Lorella Springs, both bathing in spring water and crocodile spotting are promoted as tourist activities (Lorella Springs Wilderness Park 2016). In 2014–2015, 37 estuarine crocodiles were removed from Berry Creek, which is spring-fed, in addition to smaller capture numbers in Howard Springs and Wangi Creek (spring-fed) (Parks and Wildlife Commission of the Northern Territory 2016a). Having designated swimming areas appears effective in preventing such attacks, with no crocodile attacks in the Northern Territory occurring in these areas over the last 20 years (Parks and Wildlife Commission of the Northern Territory 2016b).

Thermal waters may pose a risk of burns. Geothermal water in the Waikato region and Taupo Volcanic Zone in NZ have water temperatures ranging from 11.0 to 98.0°C (Lord *et al.* 2012). It has been reported that at temperatures above 54.4°C, exposure of 30 seconds or less will result in full thickness epidermal burns (Katcher 1981), a temperature threshold exceeded by a number of springs in this region, five of which are used for bathing, albeit cooled (Lord *et al.* 2012). In 2010, a 10 year-old boy experienced full thickness burns to 95% of his body, and ultimately died, after falling into a thermal pool (74.8°C) at Kuirau Park in Rotorua, NZ (Macfarlane 2013). The pool was surrounded by a rockery on which the child was playing when he fell in (Macfarlane 2013). This highlights the potential risk of burns from geothermal waters.

Thermal waters may also pose risks for those with certain health conditions, associated with abnormal thermoregulation which may place them at risk of hyperthermia. These issues are associated with multiple sclerosis, epilepsy, central nervous system damage, some types of headaches, sleep deprivation, stress, and anxiety, as well as those taking or withdrawing from some medications (Gullup & Gullup 2008; Gullup & Eldakar 2012). There have been reports of fatal hyperthermia associated with taking hot baths in people with multiple sclerosis (Kohlmeier *et al.* 2000), seizures for people with epilepsy (Roos & van Dijk 1988; Bebek *et al.* 2001) and headaches (Blau & Engel 1999; Negoro *et al.* 2000; Müngen & Bulut 2005).

Recommendations to improve safety

Various strategies may improve the safety of exposure to spring water, including fencing, monitoring, signage and the media. Fencing has been suggested as a strategy to minimise drowning in swimming pools (Wallis *et al.* 2015), especially for children aged less than three years (Nixon *et al.* 1979). Fencing was a factor considered in the case of the child with fatal burns after entering geothermal water in Rotorua (Macfarlane 2013). Signage may also be used to advise of danger and the intended behaviour, for instance for bathers to keep their heads above water when swimming in thermal springs (Cursons *et al.* 2003) and to avoid the use of dangerously hot springs (Macfarlane 2013). Signs were in place for one case of PAM advising swimmers not to immerse their heads in the thermal waters, but tragically this advice was not followed (Cursons *et al.* 2003). Pictorial representations and possibly signs written in different languages should be considered, particularly in tourist areas.

It has been reported that in the Central Victorian Mineral Springs Region of Australia many springs do have signs regarding water quality and health (e.g. Figure 1), however these tend to report only the potentially beneficial elements and how these may benefit the consumer. Information regarding any potential dangers is largely omitted (Martin & Dowling 2013). Signs may also take the simplistic view that elevated concentrations of 'beneficial' minerals are always beneficial, although as noted high levels of these minerals may also pose health risks.

Other methods of disseminating information, such as the media, may be used to advise people of dangers and how to minimise them. Cases relating to fatal burns (Macfarlane 2013), hydrogen sulphide toxicity (Bassindale & Hosking 2011), and PAM all received a high level of media attention (Cursons *et al.* 2003). Following the 2000 case of PAM, a pamphlet on the risks of the disorder and how to limit exposure was produced by the New Zealand Ministry of Health (2014). Regional websites have also been used to outline the hazards of spring water exposure in the area (e.g. the Waikato Region's website (Waikato Region n.d.)).

Monitoring of the water quality, as well as air quality in the case of geothermal waters, should be regularly conducted to ensure that the waters are safe, especially as

spring water quality can vary significantly with time and place. Monitoring may include the levels of various elements, for instance arsenic, in the water, as well as H₂S in the air, and closing these sites as appropriate. However, there remain uncertainties over the levels at which the area should be closed, or whether there should be time limits imposed for various levels of hydrogen sulphide. Monitoring of elements in the waters should be conducted regularly. For example, the levels of arsenic have been found to fluctuate in both Victorian and NZ springs (Lord *et al.* 2012; Martin & Dowling 2013), and hence older readings may not be sufficient to protect the health of users of these waters. It has been recommended that people should not use geothermal spa pools when alone in order to avoid H₂S poisoning (Bassindale & Hosking 2011). This warning should be extended to users of thermal pools who have abnormal thermoregulation which may place them at risk of hyperthermia.

There are other generic sources of advice to minimise the risks of bathing in spring water, such as the New Zealand Standard Pool Water Quality (NZS 5826: 2010) (Standards New Zealand 2010), which includes guidelines for geothermal pools. Physiotherapy standards for hydrotherapy outline a number of contraindications for hydrotherapy for those who have compromised health (Aquatic Physiotherapy Group 2015), which are applicable to all shared swimming environments including geothermal pools.

Review limitations and future research

This systematic review involved a comprehensive search strategy, utilising database searches, targeted Google Scholar searching, and reference and citation list screening; it is therefore unlikely that relevant studies published in peer-reviewed journals were missed. The review recommendations are limited by the lack of research in this area, with no studies investigating the health benefits of spring water exposure, and limited evidence regarding the adverse health effects.

By registering and publishing the review protocol (Stanhope *et al.* 2015a, 2015b) prior to starting this process, the transparency of the review is increased. Although slight changes were made to the protocol prior to commencing the searches (as outlined in Appendix 1), these changes

were made to improve the breadth of the review, and were unlikely to result in bias.

Despite the body of international evidence regarding the benefits of spring water exposure, a major finding of this review was that there have been no studies regarding the health benefits of exposure to natural spring water from Australia and New Zealand. Given the differences in individual springs, with regard to the temperature and mineral content, this international evidence is not directly applicable to Australian and New Zealand spring water. By investigating the health benefits of Australian and New Zealand natural spring water exposure in randomised controlled trials, with appropriate comparison treatments (i.e. other types of water), medical and health professionals may be able to provide an evidence base for use of these therapies. Evidence of health benefits will also support the growing wellness tourism industry, particularly in Victoria. Ensuring the safety of the public should be a priority. The safety of natural spring water exposure should be investigated, particularly for people with ongoing exposure to the water, or those with compromised health who may be utilising natural spring water for its perceived or advertised health benefits. Only with additional research can the risk-benefit of natural spring water exposure in this region be assessed.

CONCLUSION

To date there has been no research investigating the health benefits of Australian or NZ natural spring water, revealing an opportunity for future research in this area. There has also been insufficient research into the potential adverse health effects of exposure to these waters. The safety of Australian and NZ spring water exposure requires investigation to protect the health of the public and provide a stronger evidence base for the therapeutic applications of spring water. Only with such an evidence base can the potential health and regional economic benefits of the spring water industry be capitalised.

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