Groundwater Quality: Cambodia

This is one of a series of information sheets prepared for each country in which WaterAid works. The sheets aim to identify inorganic constituents of significant risk to health that may occur in groundwater in the country in question. The purpose of the sheets is to provide guidance to WaterAid Country Office staff on targeting efforts on water-quality testing and to encourage further thinking in the organisation on water-quality issues.

Background

The Kingdom of Cambodia (estimated population 15.8 million) is located in south-east Asia, bordered to the west, north, east and south by Thailand, Laos and Vietnam, and by the Gulf of Thailand to the south-west (Figure 1a). Cambodia has an area of 181,000 square kilometres and is divided into 24 provinces (Figure 1b). The capital is Phnom Penh (population 1 million).

Topography can be divided into three main terrains: mountains and plateaux of the border areas (Cardamom Mountains in the west, Dangrek Mountains in the north, the Annamite Mountains in the north-east, the Eastern Plateau, and Elephant Mountains in the south); the central plains which cover about 75% of the land area; and the south-western coastal plain, occupied by mangrove marsh, sandy beaches and headlands (Figure 1a). Highest elevation is at Phnom Aural (1,810 m) in the eastern Cardamom Mountains. The central plains have an elevation of around 10–30 m above sea level. These are drained by the Mekong River and the Tonle Sap-Bassac River systems. The central plains represent the most fertile and populous land of Cambodia.

The Mekong River rises on the Tibetan Plateau and flows through four countries upstream of Cambodia before extending over some 500 km within the country. Below Phnom Penh, the river divides into the Lower Mekong River and the Bassac River which each flow via Vietnam and discharge to the South China Sea. At Phnom Penh, the Mekong River is connected to the Tonle Sap via the Tonle Sap River (Figure 1a). The volume of the Tonle Sap Lake varies significantly annually in response to rainfall and flooding from the Mekong River; the connecting Tonle Sap River reverses flow direction accordingly. During the peak monsoon season, the swelling Mekong River floods and flows northwards along the Tonle Sap River. The flow reverses after the rainy season as the swollen Tonle Sap Lake drains. The Tonle Sap is the largest freshwater lake in South East Asia.

Climate is tropical and dominated by the alternating south-west and north-east monsoon air masses, May-November being associated with the south-west monsoon which contributes 90% of the annual rainfall. The remaining months are associated with the north-east monsoon, which brings dry and cooler air. Annual rainfall varies from some

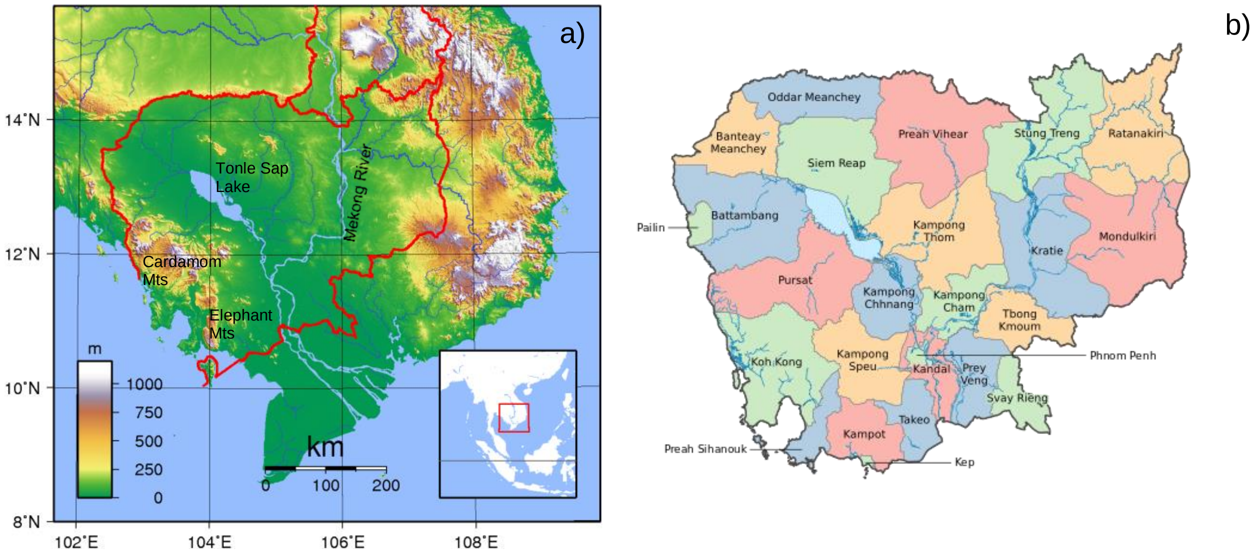

Figure 1. a) Topographic map; b) Province map of Cambodia (Creative Commons Licence).

2,700 mm in the coastal area, through 2,400 mm in the Cardamom and Elephant Mountains, to around 600–800 mm in the Tonle Sap. Average annual nationally is some 1000–1500 mm. Average monthly temperatures vary from 22°C in January to 36°C in April (ADB, 2014). Average annual temperature is around 25°C.

Land cover is dominated by forestry (58%) and agriculture (22%). Agriculture is the most significant economic activity. This is dominated by rice, but includes corn and cassava; as well as cattle and poultry. Of additional importance are textiles, construction, garments and tourism. 80% of the population lives in rural areas and 70% of livelihoods rely on agriculture. The industrial sector is nascent but increasing in significance.

Although Cambodia has one of the most rapid rates of economic growth in Asia, poverty remains a major problem. Environmental issues include recent deforestation and pollution from urban, industrial and agricultural sources. Flooding is an annual occurrence in the main floodplains though the country has also experienced occasional droughts.

Geology

Cambodia forms part of a stable continental block with a basement of Palaeozoic and older rocks. These form numerous isolated outcrops in the uplands surrounding the central plains, but in lower-lying areas are largely covered by Mesozoic deposits of the Khorat Basin which extends over a large part of Cambodia and Thailand (McDougall, 2009; Figure 2). The overlying Mesozoic (Triassic–Cretaceous) sediments are mainly fluvial and shallow marine sandstones, with less significant conglomerate, shale, evaporite and coal. The Triassic strata at the base of the sequence are folded and overlain unconformably by flat-lying, unfolded Jurassic and Cretaceous sediments. Some volcanic units of approximate Jurassic age occur in the Khorat Basin sequence. Granitic rocks also intrude into some of the Khorat sediments with an inferred Triassic or Jurassic age (McDougall, 2009). Mesozoic rocks occupy a large part of the peripheral areas of the country (Figure 2). Offshore islands are also composed of Jurassic and Cretaceous sandstones.

Cenozoic flood basalts occur in parts of eastern Cambodia.

Much of Cambodia's central plain is covered by alluvial deposits of Quaternary to Recent age, thickest in the Tonle Sap Lake area and Mekong Delta. The central plains consist mainly of sands, silts and clays of Plio-Pleistocene, Pleistocene and Holocene age. In the Mekong floodplain, Holocene deposits are of the order of 50 m thick, though can reach thicknesses of some 200 m in the south of Cambodia (Feldman and Rosenboom, 2001).

Resources of copper, gold, zinc, lead, tin and iron ore occur (EU, 2012) in association with some of the Palaeozoic basement rocks and igneous intrusions. Deposits of gold exist in the north-eastern highlands, exploitation being small-scale and artisanal. Copper/gold resources, hosted in diorite, also occur at Porphyry Creek in Preah Vihear Province. Gold occurs at the nearby Senator and Angkor Wat exploration projects, the former associated with the Phnum Lung historic gold mine (McDougall, 2009). Both alluvial and vein-hosted

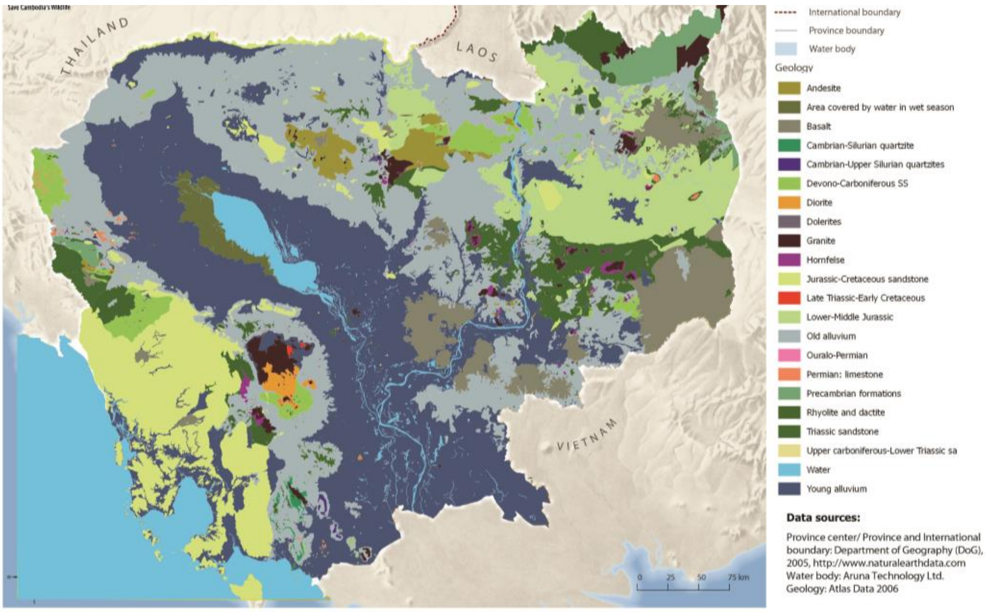

Figure 2. Simplified geological map of Cambodia. Source http://www.opendevelopmentcambodia.net (Creative Commons Licence).

gold occur at these sites, though exploitation is small-scale. The gold mineralisation is associated with sulphide minerals, dominated by pyrite, pyrrhotite, chalcopyrite, sphalerite, galena and arsenopyrite, as well as haematite.

Deposits of phosphorite occur at Phnom Totung and Tuk Meas in Kampot Province, as well as in Battambang Province. Oil and gas reserves have been discovered 200 km offshore though these are not exploited.

Soils are mainly sandy and nutrient-poor in the upland areas, reflecting dominance of underlying sandstone and granitic basement rocks. More fertile alluvium and lacustrine deposits occur along the floodplain of the Mekong and other major rivers and around the Tonle Sap.

Groundwater Availability

The climate ensures that Cambodia has abundant resources of both surface water and groundwater. By far the largest water use in Cambodia is for agriculture, whether by irrigation or rain-fed. Water for agriculture has traditionally been supplied almost exclusively from surface water, although the country has experienced recently a rapid rise in the use of groundwater for rice irrigation. Increases in groundwater abstraction of some 10% per year have been estimated for irrigation in the Mekong delta in the last few years (Erban and Gorelick, 2016). Unchecked, such a large rate of expansion of shallow groundwater abstraction would result in rapidly declining groundwater levels with the potential loss of capability to abstract using shallow suction pumps, and possible increases in land subsidence (Erban and Gorelick, 2016).

Drinking water is supplied substantially from groundwater resources: this supplies some 58% of the population's drinking water in the dry season and the proportion increases in rural areas (ADB, 2013). Groundwater is abstracted mainly from boreholes at shallow depths, typically less than 50 m deep in rural areas but deeper in urban areas. Groundwater is also abstracted from traditional dug wells (ADB, 2014). In the central lowlands, water levels are usually shallow (5–10 m below surface; EU, 2012) and water is abstracted with hand pumps (with a capacity to pump at depths down to 7 m). Though providing generally good yields, problems can occur from falling water levels in the dry season due to groundwater over-pumping. Deeper aquifers have been investigated in Kampong Thom Province though have not been exploited more widely (ADB, 2013).

The dominant aquifers are alluvial. Triassic sedimentary rocks and bedrock (e.g. basalts) also provide groundwater. However, a high proportion of wells in basalt have failed (ADB, 2014). The numbers of wells and boreholes in Cambodia is unknown but estimated at around 500,000. Of the wells recorded on national databases, the vast majority are in the alluvial aquifers, and most of these are present in the Mekong delta (ADB, 2014).

Groundwater Quality

Overview

Limited data are available to assess the quality of groundwater across all the aquifers in Cambodia although monitoring of the most significant aquifers is carried out (Ministry of Rural Development, MRD, for rural water supply and Ministry of Industry and Handicrafts (MIH), for urban water) (ADB, 2013). The largest volume of accessible data by far is for the alluvial aquifers of the Mekong river/delta system, which has been a response to the discovery more than a decade ago of high concentrations of arsenic in the groundwater (Feldman and Rosenboom, 2001). Arsenic constitutes the most significant water-quality problem in the aquifers of Cambodia, though additional and related problems occur with high (often very high) concentrations of iron, manganese and ammonium. Problems also occur from agricultural, industrial and urban wastewater pollution (Clausen, 2009), including bacterial contamination (ADB, 2013; Thomas et al., 2013). Access to adequate sanitation in 2002 was just 50% in urban areas and <10% in rural areas (Irvine et al., 2006). Aquifers in the south-east are also vulnerable to saline intrusion if over-pumped. Occasional exceedances of a number of other elements above drinking-water standards or guidelines have been recorded, though these are of likely lower health impact and water-supply significance.

Nitrogen species

Nitrogen species can contribute to the nitrogen load of groundwaters through contamination by nitrogenous fertilisers or domestic/urban waste. They can also derive naturally by natural soil/aquifer reactions.

The main alluvial aquifers of Cambodia necessarily have a range of redox conditions which will greatly influence the observed nitrogen species present in the groundwater. Under oxic conditions more typical of shallow groundwater (e.g. from dug wells) and from sandy aquifers, concentrations of nitrate (NO_3) can be high, in places exceeding the WHO guideline value of 11.3 mg/L as N. Under anoxic (reducing) conditions however, concentrations will be much lower and non-detects can be more usual. In three zones of Kandal Province south of Phnom Penh, Buschmann et al. (2007) reported nitrate concentrations (as N) of <0.25–22 mg/L, <0.25–1.9 mg/L and <0.25–<0.25 mg/L for groundwaters respectively from west Kandal (west of Bassac River), Kandal/Takeo (between Bassac and Mekong Rivers) and Prey Veng Provinces. Concentrations in the west Kandal area indicate the presence of more oxic conditions, in contrast to the central Kandal/Takeo and Prey Veng areas investigated. A high proportion of the groundwaters in the alluvial aquifers of the Mekong-Bassas-Tonle Sap system have low concentrations of nitrate in response to prevalence of reducing conditions. Elsewhere in sandstone and bedrock aquifers, concentrations could be higher, especially at shallow depths.

The dominance of anoxic alluvial aquifers in the central lowlands is also consistent with the occurrence of naturally-occurring ammonium, related to bacterial decomposition of organic matter in the aquifers. Some of the observed concentrations of ammonium are very high. Buschmann et al. (2007) reported NH_4-N concentrations in the range <0.01–5.4 mg/L, <0.01–52 mg/L and <0.01–0.5 mg/L in the three study areas listed above respectively. Berg et al. (2007) reported NH_4-N concentrations in the range <0.08–40 mg/L. Rowland et al. (2008) found ammonium at concentrations up to 26 mg/L (as N) in Kandal Province. The WHO guideline value for ammonium-N in drinking water is 0.39 mg/L. Highest concentrations are associated with the most strongly reducing aquifer conditions in central Kandal Province.

High concentrations of ammonium could also be present in some groundwaters as a response to local pollution sources (e.g. domestic, agricultural) though observations for this are lacking.

A range of nitrite concentrations is observed in the alluvial groundwaters, with occasional exceedances above the WHO guideline value of 0.91 mg/L as N. Feldman et al. (2007) reported concentrations of NO_2-N in the range <0.003–4.11 mg/L (mean 0.12 mg/L, n=57).

Salinity

Saline intrusion has been noted around the south-eastern provinces of Prey Veng, Takeo and Kampot. Saline groundwater in these is in the depth range of around 40–50 m. Deeper groundwater abstraction for irrigation in Takeo Province has failed due to intrusion of saline groundwater (ADB, 2013). Limits to abstraction are therefore needed in this area to prevent salinization of groundwater and soil, rendering both unusable for water supply and crop production.

Buschmann et al. (2007) reported relatively high concentrations of sodium and chloride in the shallow alluvial groundwaters in Kandal, Takeo and Prey Veng Provinces. Highest values were up to 700 mg/L and 1180 mg/L respectively. Similarly high concentrations of sulphate (up to 1000 mg/L) were found in some, though these are redox-dependent and concentrations are lower under strongly reducing conditions where sulphate can be reduced to sulphide. Such conditions are observed in central Kandal Province.

A general complaint of hard water has been made of several areas in Cambodia (Feldman et al., 2007); this appears to be true especially for groundwater proximal to the Tonle Sap Lake (ADB, 2013).

Fluoride

The Cambodian drinking-water limit for fluoride is 1 mg/L while the WHO guideline value is 1.5 mg/L. Chronic use of drinking water with high concentrations of fluoride, much above these values, is known to cause an increased risk of fluorosis (dental, possibly skeletal). Feldman et al. (2007) reported groundwater fluoride concentrations above 1 mg/L at four locations across Cambodia. Values in the range <0.01–2.9 mg/L were determined. These authors also quoted results from studies dating back to the 1990s which found concentrations of between 1–3 mg/L in 18% of wells tested from five central and south-eastern provinces (Kampong Cham, Kampong Chhnang, Kampong Speu, Takeo and Svay Rieng Provinces). In the Quaternary alluvial groundwaters, concentrations are mostly low though Kocar et al. (2008) reported a range of <0.3–1.5 mg/L in groundwaters from central Kandal (between the Bassac and Mekong Rivers, south of Phnom Penh). Concentrations of fluoride in groundwater above 1.5 mg/L have been reported in Pursat Province (ADB, 2013), although the geological associations there are unclear.

Other possible risk areas for fluoride could also potentially include occurrences of granitic rocks in the highlands and deposits of phosphorite, for example in Kampot Province. No data are available to clarify this however. Regionally, high concentrations of fluoride are not expected because of a combination or geology and climatic conditions.

Iron and manganese

High concentrations of iron and manganese in groundwater are most commonly seen in anaerobic conditions where the solutes are released via dissolution of iron and manganese oxides. As such, concentrations of both elements are a common feature of the anoxic groundwaters within the Quaternary alluvial aquifers of central Cambodia. Buschmann et al. (2007, 2008) reported concentrations of both iron and manganese in groundwater from the Mekong floodplain up to 32 mg/L and 3.2 mg/L respectively. Elevated iron was found in many groundwater samples from Kandal, Takeo and Prey Veng Provinces. Rowland et al. (2008) reported concentrations up to 26.5 mg/L for iron and 4.8 mg/L for manganese in Kandal Province. These can give rise to complaints from consumers through adverse taste and staining following oxidation. Highest concentrations of manganese are observed in mildly reducing conditions in the alluvial aquifer of west Kandal Province (west of Bassac River). High concentrations of iron and manganese are also found in boreholes within the alluvial/lacustrine aquifer around the Tonle Sap Lake (ADB, 2013). Potential health problems associated with high manganese have been highlighted by a number of these studies, but the WHO guidance has since removed the formal guideline value of 0.5 mg/L for manganese on review of its health implications.

Localised high concentrations of iron and manganese could also occur in areas of metalliferous mineralisation where released by mineral weathering, for example in the mineralised areas in Preah Vihear Province described above. Rapid precipitation of iron oxide is expected in oxic shallow groundwater conditions.

Arsenic

High concentrations of arsenic were first discovered in groundwater from boreholes in the alluvial aquifers of the Mekong delta in 2000 (Feldman and Rosenboom, 2001). The investigation of 88 groundwater samples found 9% having arsenic concentrations greater than the WHO guideline value of 10 μg/L. Since then, a large number of surveys and publications have sought to clarify the extent and distribution of groundwaters with concentrations greater than the national drinking-water limit for arsenic of 50 μg/L or the WHO guideline value. The Ministry of Rural Development, Ministry of Industry, Mines & Energy (now MIH) and UNICEF conducted field tests of over 10,000 wells across Cambodia and mapped areas of arsenic risk (Fredericks, 2004; Figure 3a). The investigation identified Holocene, Pleistocene, and Plio-Pleistocene aquifers in the basin. Arsenic concentrations above 50 μg/L were only identified in young (Holocene) lowland alluvial deposits.

More recent maps have combined evidence from arsenic analyses, geology and land features and provided smoothed distributions (e.g. Lado and Polya, 2008; Lado et al., 2008; Sovann and Polya, 2014; Figure 3b). The maps all highlight the greatest arsenic risk within the Holocene alluvial aquifer of the lower Mekong River. Some maps have indicated probable risks (>10 μg/L) in the Tonle Sap floodplain (e.g. Winkel et al., 2008), though the recent mapping of Sovann and Polya (2014) suggests a lower overall risk there, albeit with sporadic high observed concentrations. Some (not all) maps have indicated a slightly raised potential risk in groundwater from Preah Vihear in north-central Cambodia. Borehole locations there appear to derive from Mesozoic or older bedrock (Polya et al., 2005) and if arsenic is present in the

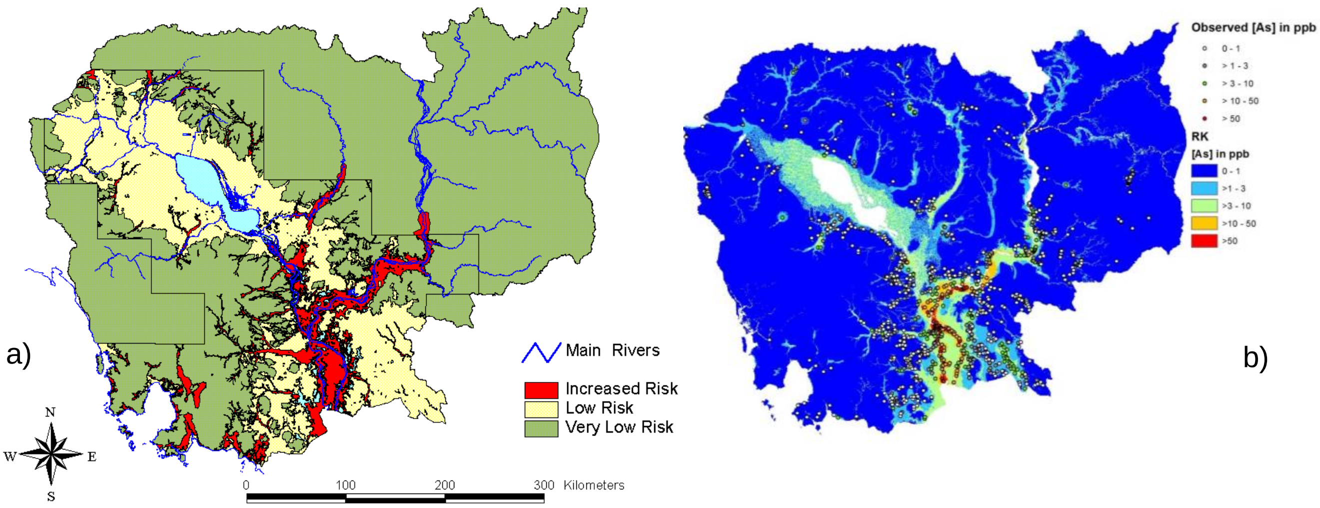

Figure 3. Arsenic risk in Cambodian groundwater: a) classified on the basis of Holocene/Pleistocene/pre-Pleistocene stratigraphy (D. Fredericks, pers. comm. (2003); Fredericks (2004); b) using geostatistical modelling (regression kriging of boreholes 16–120 m depth); reproduced from Sovann and Polya (2014), with permission from CSIRO Publishing.

groundwater, it likely has a different origin from that in the Mekong floodplain (e.g. from sulphide mineral weathering).

Lado et al. (2008) quoted a range for arsenic in Cambodia nationally of 0.1–1340 μg/L, with 41% of observations above 50 μg/L (1329 samples). The worst-affected Province is Kandal (Fredericks, 2004; Berg et al., 2007; Buschmann et al., 2007, 2008; Rowland et al., 2008), although problems have also been recognised in Kampong Chhnang, Prey Veng, Kampong Cham Kratie and Kampong Thom (Feldman et al., 2007; Uy et al., 2010; Polya et al., 2005; Sovann and Polya, 2014). Of 494 groundwater samples tested from Kean Svay District of Kandal Province, 29% had arsenic concentrations greater than 500 μg/L (Milton, 2003). Buschmann et al. (2007) found highest concentrations of arsenic in groundwater from land between the Bassac and Mekong Rivers of central Kandal Province. Buschmann et al. (2008) mapped arsenic occurrence along the lower Mekong valley down to the Vietnamese border and demonstrated the high values between the Mekong and Bassac Rivers south of the distributary at Phnom Penh. They also marked high concentrations (>50 μg/L) along the Mekong floodplain to the north of it.

The highest concentrations occur in the most strongly reducing groundwater. These are associated with low-lying wetlands and ox-bow lakes within fine, organic-rich sediments in the Mekong floodplain (Kocar et al., 2008). High concentrations of arsenic are commonly associated with high concentrations of ammonium (NH_4) as a consequence of the strongly reducing conditions. Presence of arsenic in groundwater may also be broadly associated with the presence of dissolved iron and manganese, although correlations between these may be weak due to differing redox equilibria, sorption reactions and mineral precipitation.

Shallow groundwater from dug wells (<15 m deep) has lower arsenic concentrations than deeper dug-well waters or borehole waters, owing to the presence of more oxic conditions near ground surface. Shallow dug-well waters are more prone to bacterial contamination, however (Sampson et al., 2008; Uy et al., 2010).

The population of Kandal Province likely to be at risk of arsenic exposure has been estimated at 100,000 people (Sampson et al., 2008).

It has been suggested that the recent trend of increasing groundwater abstraction for rice irrigation poses a potential risk of exacerbating arsenic problems in the alluvial aquifers of Cambodia (Erban and Gorelick, 2016). This could be the case if drawdown of groundwater into the deeper pre-Holocene aquifers occurs, as has been observed in neighbouring Vietnam (Winkel et al. 2011; Erban et al., 2013).

Iodine

No data could be found for iodine in Cambodian groundwater. Climate and proximity to the Gulf of Thailand however suggest that concentrations should not be anomalously low. Relatively high salinity in some of the groundwaters in the southern alluvial aquifers is also consistent with elevated iodine concentrations. The inferences give no cause for undue health concerns from iodine ranges though confirmation is suggested.

Other trace elements

A number of other trace elements in the alluvial aquifers of central Cambodia have concentrations above WHO guideline values for drinking water, albeit with much lower exceedances and likely impacts than arsenic. Concentrations of barium in excess of 700 μg/L (the WHO guideline) were reported, especially in central Kandal Province, by Buschmann et al. (2007, 2008), and in two samples by Feldman et al. (2007). These high concentrations are presumably also indirectly associated with the strongly reducing conditions in this aquifer (barite precipitation inhibited). Buschmann et al. (2007) found one sample out of 131 with a concentration of uranium greater than the WHO guideline value of 30 μg/L (value 32 μg/L). Buschmann et al. (2008) found concentrations up to 59 μg/L in alluvial groundwater north of Phnom Penh. Concentrations of uranium are usually low in the strongly reducing groundwater associated with high arsenic concentrations, but the occasional highs indicate that the alluvial aquifer is vulnerable to contamination under more oxic conditions (e.g. those with higher nitrate concentrations). Selenium concentrations up to 15 μg/L (WHO guideline value 10 μg/L) were also found north of Phnom Penh (Buschmann et al., 2008). Feldman et al. (2007) also reported molybdenum concentrations in the range <0.5–70.8 μg/L, one sample being slightly above the WHO health-based value for molybdenum in drinking water of 70 μg/L. The strongly reducing groundwaters in the Mekong river/delta system (e.g. those enriched in arsenic) might also contain detectable dissolved methane, which would be worthy of further investigation.

Metals including copper, zinc, lead, and molybdenum as well as arsenic can be expected in mineral veins associated with the Porphyry Creek, Senator and Angkor Wat prospects in Preah Vihear Province. The WHO guideline value for copper in drinking water is 2000 μg/L but that for lead is much lower (10 μg/L). Molybdenum is also known to be associated with porphyry copper deposits and so areas such as Porphyry Creek may have locally higher groundwater molybdenum concentrations. Although molybdenum is no longer an analyte formally listed in the WHO guidelines for drinking-water quality, surveillance in respect of the health-based value of 70 µg/L is still recommended. Testing for these trace metals is recommended in groundwaters abstracting from basement rocks, and in the mineralised areas mentioned above in particular.

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