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Risk assessment to groundwater of pit latrine rural sanitation policy in developing country settings

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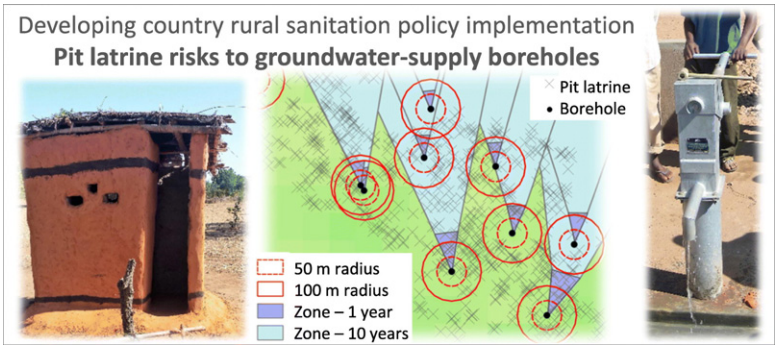
HIGHLIGHTS

- Global rise in both pit latrine sanitation and groundwater supply poses concern.
- Groundwater risk due to typical developing-country pit latrine sanitation policies
- Developed risk assessment framework approach pragmatic to regulatory management.
- Significance of establishing baseline groundwater quality data shown; a global need
- Low Malawian contamination to date: attenuation effectiveness or emergent problem?

GRAPHICAL ABSTRACT



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ABSTRACT

Parallel global rise in pit-latrine sanitation and groundwater-supply provision is of concern due to the frequent spatial proximity of these activities. Study of such an area in Malawi has allowed understanding of risks posed to groundwater from the recent implementation of a typical developing-country pit-latrine sanitation policy to be gained. This has assisted the development of a risk-assessment framework approach pragmatic to regulatory-practitioner management of this issue. The framework involves water-supply and pit-latrine mapping, monitoring of key groundwater contamination indicators and surveys of possible environmental site-condition factors and culminates in an integrated statistical evaluation of these datasets to identify the significant factors controlling risks posed. Our approach usefully establishes groundwater-quality baseline conditions of a potentially emergent issue for the study area. Such baselines are foundational to future trend discernment and contaminant natural attenuation verification critical to policies globally. Attribution of borehole contamination to pit-latrine loading should involve, as illustrated, the use of the range of contamination (chemical, microbiological) tracers available recognising none are ideal and several radial and capture-zone metrics that together may provide a weight of evidence. Elevated, albeit low-concentration, nitrate correlated with some radial metrics and

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was tentatively suggestive of emerging latrine influences. Longer term monitoring is, however, necessary to verify that the commonly observed latrine-borehole separation distances (29–58 m), alongside statutory guidelines, do not constitute significant risk. Borehole contamination was limited and correlation with various environmental-site condition factors also limited. This was potentially ascribed to effectiveness of attenuation to date, monitoring of an emergent problem yet to manifest, or else contamination from other sources. High borehole usage and protective wall absence correlated with observed microbiological contamination incidence, but could relate to increased human/animal activity close to these poorly protected boreholes. Additional to factors assessed, a groundwater-vulnerability factor is recommended that critically relies upon improved proactive securing of underpinning data during borehole/latrine installations. On-going concerns are wide ranging, including poorly constrained pit-latrine input, difficulties in assessing in-situ plume natural attenuation and possible disposal of used motor oils to latrines.

1. Introduction

A poorly understood threat to the chemical and microbiological quality of groundwater supplies in developing countries is the risk posed by the dramatically increased use of pit latrines for improved sanitation (Graham and Polizzotto, 2013). In response to the Millennium Development Goal on sanitation which targeted improved access levels by 2015 (UN, 2015a), the number of pit latrines is rising globally as populations gain access to improved sanitation under a plethora of water sanitation and hygiene (WASH) programmes (Jain, 2011; UNICEF – WHO, 2015). Pit latrines are the most common low-cost sanitation solution in developing countries and are used by an estimated 1.77 billion people (Graham and Polizzotto, 2013). Sanitation policies in rural areas, alongside some rapidly growing peri-urban areas, are primarily pit latrine based. Such policies may allow districts to cost effectively reach, much sought after, open defecation free (ODF) status and lower exposure risks to fecal-related, acutely toxic, microorganisms (Cho et al., 2016).

Alongside improved sanitation, improved access to drinking water is also rising globally under WASH programmes. Indeed, the recently developed Sustainable Development Goals (SDGs) unifies sanitation and sustainable water management under SDG 6 (UN, 2015b). Critically, improved access to water invariably relies upon groundwater sources (Rosa and Clasen, 2010). The twin growth hence arising is of most concern where groundwater use and pit latrine disposal are located in close proximity. The absence of a physical barrier between latrine-stored excreta and the underlying soil and groundwater (van Ryneveld and Fourie, 1997), and the fact that abstracted groundwater is often untreated and infrequently monitored prior to drinking add credence to this concern. There is hence a pressing need to better understand the connectivity between latrine sources and groundwater supply points and health risks posed at typical rural development scales (BGS, 2002; Bain et al., 2014; Graham and Polizzotto, 2013).

Pit latrine fecal sludge, although produced at low volumetric rates of around 1.5 l per capita per day, contains not only microbiological pathogens of human-health concern (Bain et al., 2014; Cho et al., 2016; Pedley et al., 2006), but also elevated nitrogenous and carbonaceous organic matter that is persistent due to the confined nature of pit latrines. Pit latrines largely hold, rather than treat, the disposed mass (Coetzee et al., 2011). Some mass loss as liquid leachate infiltration is nevertheless expected to occur and enter the underlying soil and groundwater and forms the migration pathway of concern herein (BGS, 2002). To reduce risks posed, guidelines exist for the minimum separation distance between latrines and groundwater supply points. However, these vary internationally, from around 10 to 75 m. Also, national statutory guidelines may not be set (Parker and Carlier, 2009; Section 3.4.2) and, when set, can sometimes be ignored or inadequately regulated. Good underpinning case data can also be sparse and often lack the high spatial resolution ideally required. Furthermore, the associated process-based science is challenging to undertake, has perhaps become dated, or lacks the nuance detail required (Banerjee, 2011; Caldwell and Parr, 1937; Franceys et al., 1992; Graham and Polizzotto, 2013; Howard et al., 2003; Still and Nash, 2002; WaterAid, 2013).

Various African studies have examined soil – groundwater contamination ascribed to pit latrine disposal. These include Verheyen et al. (2009) in Benin, Jacks et al. (1999), Lewis et al. (1980) and Mafa and Vogel (2004) in Botswana, Mzuga et al. (2001) and Okotto-Okotto et al. (2015) in Kenya, Tandia et al. (1999) in Senegal, Still and Nash (2002) and Vinger et al. (2012) in South Africa, Howard et al. (2003) and Nyenje et al. (2014) in Uganda, Chidavaenzi et al. (1997), Dzwairo et al. (2006) and Zingoni et al. (2005) in Zimbabwe and Palamuleni (2002) in Southern Malawi, specifically peri-urban Blantyre. Groundwater contamination - typically discerned from increased total/fecal coliforms, nitrogen species (nitrate, ammonium), chloride and occasionally virus detections when analysed - appears to largely remain quite close to latrine pits. Distances appear to be typically restricted to 5 to 50 m or so, although it is recognised that case studies may lack spatial resolution to allow confident assessment of distances and discernment of attenuation processes that may limit migration (Banks et al., 2002; Escamilla et al., 2013; Graham and Polizzotto, 2013; Howard et al., 2003; Nichols et al., 1983; Nyenje et al., 2014; Schijven and Hassanizadeh, 2000; Tandia et al., 1999; Wright et al., 2013). Graham and Polizzotto (2013) conclude from their review that the number of field studies investigating links between groundwater pollution and pit latrine contamination is limited and advocate the need for improved measurement approaches, development of better criteria for locating pit latrines and the examination of a larger set of contextual variables.

Our goal is hence to further the understanding of risks posed to groundwater by pit latrine based sanitation policies typically implemented in developing country, rural, settings. From this position, we aim to develop and demonstrate a pragmatic risk assessment framework approach that may provide for practitioner (regulatory) management of this issue. This has been achieved through study of the Mwanza Valley in Southern Malawi, where development of both groundwater supply and pit latrine sanitation provision has occurred over recent decades and continues apace (Back, 2015; Hinz, 2015; Mackay, 2015). Specific aims were:

- to investigate the potential contamination of supply boreholes from pit latrines within an area subject to continued and recent development of pit latrine and supply borehole infrastructure;
- recognising the study area represents a relatively young problem scenario for the most part, to assess whether the collected data constitute a reasonable baseline against which future influences may be monitored;
- to evaluate the contributing factors to supply contamination incidence, including the statistical evaluation of contextual parameters such as surrounding pit latrine density, borehole infrastructure condition and modelled borehole - groundwater capture characteristics;
- to identify future management concerns and research needs arising from pit latrine based sanitation policy implementation.