International Journal of Disaster Risk Reduction 31 (2018) 489–497

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

A field study on the construction of a flood-proof riverbank filtration well in India – Challenges and opportunities

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ARTICLE INFO

Keywords:
Riverbank filtration
Flood
Flood-proof well
Watertight well headworks
Annular seal
Industrial competence

ABSTRACT

In light of the direct entry of surface water by inundation during floods and extreme rainfall events into riverbank filtration (RBF) wells and the consequent risk of contamination, this study discusses the state of the art of sealing the borehole annulus and well headworks in some developing countries exemplified by northern India in context to established guidelines and standards. Accordingly a market survey was conducted and a concept was developed to construct watertight wellhead elements and a flood-proof well chamber. The concept was implemented through the fabrication of the major components of a watertight wellhead in India and the subsequent construction of watertight headworks and a flood-proof chamber for a RBF well in Srinagar (Uttarakhand, India). The study showed that water wells at risk of flooding in general can be made flood-proof. A novel concept of deliberately flooding the well chamber was tested and proved successful. Although the fabrication enterprises and suppliers of well construction material in India currently do not produce non-standardised or special purpose well components, experience from the current study shows that local small-medium enterprises engaged in the unorganized metal working sector possess the technical competence to fabricate some of the major components but in limited numbers. The familiarisation of water supply practitioners and the well construction industry in India on the need and measures to flood-proof wells must be continued through information and education campaigns.

1. Introduction

Riverbank filtration (RBF) has been used in Europe for more than 140 years and has great potential for drinking water production in India [32], Egypt [16], Thailand and other countries [29], especially to remove pathogens and turbidity [23,6,8]. However due to their location near rivers, RBF wells risk contamination during floods and extreme rainfall events [17,2,28,30,33,34,9]. Risks associated with flooding of production wells have been recognized by several water supply companies in Europe and actions have been taken to reduce these risks ([18,22,28]). According to Rambags et al. [28], the microbiological infection of drinking water forms the largest and most direct risk for human health, and direct intrusion of surface flood water into a well is considered the "worst case" contaminant event. In this context, the first and most direct pathway is the short-circuiting of flood water into the well (e.g. through the well head or observation wells) and the second pathway is when surface water enters the well via the annular space between the well casing and the aquifer (borehole wall) or via cracks or joints in the well casing and sanitary sealing (Fig. 1; [1,20,24,25,28,39]). The third pathway of contamination is the infiltration of surface flood water into the aquifer and movement of the water towards the production well. A study to elucidate the nexus between surface flooding, groundwater contamination and human gastroenteric outcomes in developed countries, found that the main causes for groundwater contamination were rainfall related events followed by fluvial events, with the predominant impacts being (rapid) exposure to contaminated surface/flood waters and damage to water chlorination systems [1].

On the other hand, the phenomena of groundwater flooding, which has been given due consideration only in the last two decades can be associated with the third pathway of contamination and causes damage to subsurface parts of buildings and infrastructure ([3,7,14,21,26]). According to Ascott et al. [3], groundwater flooding is the emergence of groundwater at the ground surface away from perennial river channels

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https://doi.org/10.1016/j.ijdrr.2018.06.003
Received 11 January 2018; Received in revised form 4 June 2018; Accepted 5 June 2018
Available online 07 June 2018
2212-4209/

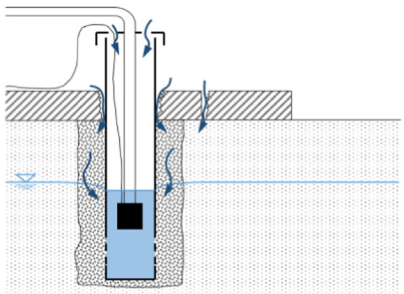

Fig. 1. Vulnerable locations allowing the direct entry of flood water into RBF wells as typically constructed (without flood-proof measures) in India.

or the rising of groundwater into man-made ground, under conditions where the "normal" ranges of groundwater level and groundwater flow are exceeded. Rising groundwater and high groundwater levels are accompanying phenomena of river floods, mainly caused by infiltration of inundation water into the aquifer but also by a multitude of other factors that complicate the characterisation of groundwater floods, e.g. accumulation of groundwater from the hinterland, long or extreme rainfall on pre-wetted soils causing high groundwater recharge, infiltration into the underground by subterranean infrastructure such as a sewerage system [21]. Resulting damage to buildings and infrastructure can be due to water contact and capillary rise, but also due to buoyancy or lateral pressure that can result in structural damage of a base-plate or even destruction or destabilisation of a building [21,26]. Due to the direct and rapid ingress of flood water in limestone and karst aquifers, groundwater flooding poses a greater health risk to the groundwater resources intended for drinking [1,14,27]. Consequently, while a direct risk of flooding is damage to the well infrastructure (electrical and chlorination systems, pumps) that is usually noticed by a sudden shutdown of the well, the contamination of the abstracted raw water is a greater concern due to the associated health hazard [1,28].

Findings from risk assessments and monitoring campaigns in Northern India have repeatedly shown the presence of total coliforms and E. coli in RBF wells even at greater distances (48–190 m) to the river bank and were partly related to local faecal contamination in the vicinity of the wells [5]. However, water quality analysis of well water soon after the extreme flood of June 2013, whereby the RBF site in Srinagar was completely inundated, showed total coliform and E. coli counts of 959–2613 most probable number / 100 mL (MPN / 100 mL) and 107–495 MPN / 100 mL respectively [33,34]. A visual inspection of the affected RBF wells indicated a non-watertight wellhead through which the floodwater directly entered the well. On the other hand, field tests conducted to check the watertightness of the sealing around the caissons of large-diameter RBF wells by infiltrating a NaCl tracer showed a breakthrough of the tracer in the abstracted water after a very short time of few minutes up to five hours indicating contamination via preferential flow paths. Consequently the contamination pathways are attributed to non-watertight well heads and well chamber covers, cracks and fissures in well chambers and caissons, insufficient sealing of the well at ground level and below in the annular space of the well bore that result in preferential flow paths and eventually "short circuiting" (Fig. 1).

In general and as a minimum precaution against the entry of water from any source other than the aquifer, most water well and monitoring (observation) well construction guidelines, standards or codes of best practise in developed and developing countries recommend (albeit with varying degree of details) a sanitary seal that consists of filling the annular space between the casing and borehole with a substance that forms an impermeable seal ([4,12,15,31,36,37,41]). Accordingly these documents state that the well head or casing head should generally be as high as possible within the headworks to minimise the risk of inundation from surface water (ponding due to extreme rainfall, floods, accidental spills or other anthropogenic activities). From a review of the general state of art of the sanitary sealing of the borehole annulus (2.1.1) and headworks (2.1.2) of water wells, the following can be inferred:

- Specific technical details (in guidelines, standards or recommendations) and practical experiences to flood-proof water wells (waterproofing of headworks and protection against infra-/ structural damage) in general and RBF wells in particular, especially to prevent the direct entry of surface water (Fig. 1) resulting from severe inundation of the well headworks (overtopping), is limited for developed countries (other than as described for some European countries in [11,18,22,28] and to a lesser degree of detail in ([4,15,35,36,38]).
- For India and some other developing countries (e.g. Bangladesh and African countries), guidelines and recommendations do not provide technical specifications to make well headworks watertight (let alone flood-proof), other than a general statement that headworks should prevent the ingress of surface water [31,41].
- All guidelines and procedures for the construction of drilled water wells generally lay substantial emphasis on the annular sealing to prevent vertical flow of surface water between the borehole and well casing into the aquifer. But the need for the application of an enhanced horizontal sealing at the interface between the annular sealing at ground level and the concrete collar of the well headworks, has only been elucidated relatively recently [39].

A market survey and first-hand field experience of the authors (Section 2.1 and subsequent sections) has revealed that the practical implementation of flood-proof measures focussed on the prevention of direct surface water entry into the well through inundation of the headworks is a major challenge comprising technical, institutional and industrial aspects. Thus, a project was started in 2015 to develop and test the application of measures to flood-proof RBF wells in India using locally available materials. The aim of this article is to present the current state of the art of constructing wells in general in India with a focus on direct entry of surface water (from a flood resulting in inundation of the headworks) and to discuss these in relation to existing guidelines and standards. In light of the existing difficulties encountered in implementing such mitigation measures, the article presents the construction and subsequent testing of the watertightness of a pilot flood-proof well at a RBF site in Srinagar.

2. Conceptual development of a flood-proof well for India

2.1. State of the art and market survey

2.1.1. Sanitary sealing of borehole annulus

Although specific details about the composition (consistency), thickness (depth) and methods of application (placement) of the sanitary seal vary amongst the cited references, it is usually achieved by typically placing bentonite (in the form of pellets, granules or slurry) immediately above the filter zone and then backfilling the remainder of