Waste Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Determination of trigger levels for groundwater quality in landfills located in historically human-impacted areas

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ARTICLE INFO

Article history:
Received 8 September 2017
Revised 10 January 2018
Accepted 29 January 2018
Available online xxxx

Keywords:
Groundwater monitoring
Landfill monitoring
Leachate
Landfill Directive
Threshold values
Landfill management

ABSTRACT

Landfills are one of the most recurrent sources of groundwater contamination worldwide. In order to limit their impacts on groundwater resources, current environmental regulations impose the adoption of proper measures for the protection of groundwater quality. For instance, in the EU member countries, the calculation of trigger levels for identifying significant adverse environmental effects on groundwater generated by landfills is required by the Landfill Directive 99/31/EC. Although the derivation of trigger levels could be relatively easy when groundwater quality data prior to the construction of a landfill are available, it becomes challenging when these data are missing and landfills are located in areas that are already impacted by historical contamination.

This work presents a methodology for calculating trigger levels for groundwater quality in landfills located in areas where historical contaminations have deteriorated groundwater quality prior to their construction. This method is based on multivariate statistical analysis and involves 4 steps: (a) implementation of the conceptual model, (b) landfill monitoring data collection, (c) hydrochemical data clustering and (d) calculation of the trigger levels.

The proposed methodology was applied on a case study in northern Italy, where a currently used lined landfill is located downstream of an old unlined landfill and others old unmapped waste deposits. The developed conceptual model stated that groundwater quality deterioration observed downstream of the lined landfill is due to a degrading leachate plume fed by the upgradient unlined landfill. The methodology led to the determination of two trigger levels for COD and NH_4-N, the former for a zone representing the background hydrochemistry (28 and 9 mg/L for COD and NH_4-N, respectively), the latter for the zone impacted by the degrading leachate plume from the upgradient unlined landfill (89 and 83 mg/L for COD and NH_4-N, respectively).

1. Introduction

Groundwater often constitutes the main fresh water reservoir which is widely used for drinking, domestic, irrigation and industrial purposes. Its protection is important to ensure the fulfillment of human needs and, at the same time, to preserve its environmental values. In many countries worldwide, current national and supranational regulations try to protect groundwater resources in this perspective. For instance, the EU Water Framework Directive (EC, 2000) and Groundwater Directive (EC, 2006) aim to ensure a sustainable use of groundwater resources and to guarantee a good status of groundwater ecosystems by establishing specific measures to prevent pollution and quality deterioration.

One of the most relevant source of groundwater contamination around the world is constituted by landfills (Bjerg et al., 1995; Christensen et al., 1998, 2000, 2001; Han et al., 2016; Kjeldsen, 1993; Looser et al., 1999; MacFarlane et al., 1983; Rapti-Caputo and Vaccaro, 2006, Talalaj, 2014). Both unlined and lined landfills can impact groundwater by hazardous chemicals: the former due to direct leaks of leachate, the latter due to the failure of the liners (Han et al., 2014, 2016; Reyes-López et al., 2008). The EU Landfill Directive (EC, 1999) aims to prevent or reduce the negative effects of landfills on soils, surface water and groundwater. It establishes a list of requirements for a proper groundwater monitoring network in landfill sites, addressing the identification of sampling points, sampling frequency and parameters to be analyzed. Furthermore, it specifically imposes the definition of trigger levels for identifying significant adverse environmental effects on groundwater generated by the landfill. The trigger levels must be determined taking into account the specific hydrogeological and hydrochemical features of the site where the landfill is located. When a trigger level is reached and confirmed by repeating samplings, the landfill contingency plan and remediation actions should be adopted. The

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https://doi.org/10.1016/j.wasman.2018.01.043
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determination of trigger levels in landfills follows other research efforts aimed at providing groundwater quality threshold values for the management and protection of water resources, such as natural background levels and threshold values (Dalla Libera et al., 2017; Ducci et al., 2016; Hinsby et al., 2008; Rotiroti et al., 2015b) or environmental quality standards (Valsecchi et al., 2017).

The EU Landfill Directive does not specify how to calculate the trigger levels, however for newly constructed landfills, they could be easily derived from groundwater quality data of the area before the filling operations, if available. Conversely, the derivation of trigger levels becomes challenging when groundwater quality data prior to the construction of the landfill are missing and in the case of historically human-impacted areas, such as many urban environments (e.g. brownfield sites). Here, the baseline groundwater chemistry could be the product of existing and different (in space and time) anthropogenic influences on groundwater quality instead of natural processes. Therefore in these cases, high concentrations of pollution indicators measured downstream of a landfill could be the effect of historical groundwater pollution rather than leachate spills from the landfill itself and distinguishing between them is a key aspect.

The aim of this work is to present a methodology for determining trigger levels for groundwater quality in landfills located in areas where historical contaminations have already deteriorated groundwater quality and when groundwater quality data of the area before landfill construction are missing. The purpose is not only to meet the requirements of the EU Landfill Directive but also, in general, to provide a tool of wider and worldwide applicability for distinguishing between background existing contaminations and any contamination coming from a landfill, in order to better support landfill management and groundwater resources protection.

This methodology is based on multivariate statistical analysis of data measured from the existing network of wells/piezometers for monitoring the groundwater quality nearby the landfill. Several studies suggested the use of data-driven procedure in order to identify groups of well with similar hydrochemical features (Cloutier et al., 2008; Singh et al., 2005). Cloutier et al. (2008) and Devic et al. (2014) successfully applied hierarchical clustering methods for the evaluation, interpretation and grouping of groundwater quality data since multivariate statistics are independent and quantitative methods. In particular, Güler et al. (2002) compared the performance of graphical and statistical methods for classifying water samples: the most efficient result was achieved by statistical clustering techniques, demonstrating that graphical techniques have limitations compared to multivariate statistics in the case of large data sets.

The presented methodology is applied to a case study in northern Italy. Here, a more recently constructed and currently used landfill is located in an area that was used in the past decades (before the implementation of environmental regulations) as an unregulated disposal site (no other possible historical contaminations of a different type affected the area). Therefore, the correct identification of the proper source of groundwater pollution that lowered the groundwater quality in the area (i.e. the more recent landfill or the older unregulated waste deposits) is challenging and requires specific tools of investigation and analysis.

2. Materials and methods

2.1. Study area

The area under examination is located in an Alpine region in northern Italy. The study area corresponds to a dumping area (Fig. 1) that covers about 0.55 km^2 and hosts: (a) a lined landfill constructed in the 1989 that is still to be filled (b) an old unlined landfill closed in the 90s and (c) other old smallest waste deposits whose the correct number and locations are unknown. The lined landfill is filled with municipal solid waste and sludge of wastewater treatment plants. It covers an area of ~6 ha in which ~1,800,000 t of waste are stored. The annual quantity of stored waste is about 70,000 t. The liner is formed by a 1 m thick impermeable clay layer. The bottom of the lined landfill is at a depth of 2–3 m bgl, above the groundwater table. The old unlined landfill and the other smallest deposits were filled with inert, plastic and urban wastes of different and unknown composition. This was done during the 60–80s, before the implementation of environmental regulations. In the 90s, the unlined landfill was capped with a clay layer in order to prevent rain infiltration.

The aquifer beneath the dumping area is composed of alluvial sediments of medium and coarse textures (i.e. sands and gravels) and it is unconfined. The bottom of this aquifer is placed at 25–30 m bgl where a silty layer with an average thickness of about 5 m is found. Groundwater table beneath the dumping area has an average depth of 4.5 m bgl with seasonal fluctuations in the range of 1.5–2 m. Groundwater mainly flows from NW to SE, controlled by the gaining behaviour of the river that flows along the southern border of the lined landfill (Stefania et al., 2017). The local hydraulic gradient is between 0.4 and 0.3% (Bonomi et al., 2015).

2.2. Available data

The data used in this study are the results of the hydrochemical monitoring performed on the monitoring network of the lined landfill (36 piezometers with an average depth of 15 m bgl; Fig. 1) during the period 2006–2010. No data on groundwater quality before the construction of the lined landfill are available. The available data were provided by local Authorities. The monitoring points were averagely sampled every two months. The total number of samples is 1004. The monitored parameters were chemical oxygen demand (COD), ammonium-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total phosphorus (P-tot), SO_4, F, As, Cr, Fe, Mn, Ni, Pb, and Cu. Sampling operations

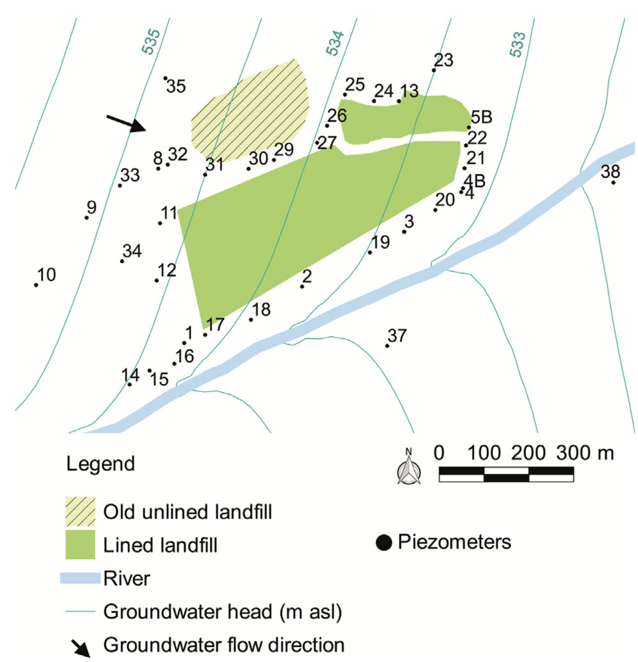

Fig. 1. Location of landfills and monitoring points and contour map of groundwater heads in the study area; labels are monitoring points IDs.

Please cite this article in press as: Stefania, G.A., et al. Determination of trigger levels for groundwater quality in landfills located in historically human-impacted areas. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.01.043