Reviewing the potential anthropogenic sources of groundwater contamination - Case study of the expanding urban area of Taleza in Algeria

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ABSTRACT
Located in north-east Algerian, the coastal aquifer of Taleza constitutes a significant source of groundwater. It contains hundreds of private wells installed by the population for several purposes including drinking water. Recently, the groundwater has become quite salinized. Furthermore, some people have noted the presence of a bad odor, as rotten eggs, in the groundwater pumped from their wells. The groundwater quality is mostly controlled by two factors: 1) natural processes related to aquifer lithology, and soil/rock interactions with groundwater, and 2) anthropogenic activities. However, the later activities can be considered as the most serious sources of groundwater contamination. This paper describes a review of potential anthropogenic sources of groundwater contamination over the Taleza territory. Several different potential anthropogenic sources were identified, such as cultivated fields, private sanitation systems, random urbanisation, over-exploitation of groundwater, solid waste dumpsites, and cemeteries. Consequently, efficient and durable groundwater protection planning is urgently required, to limit and possibly remediate groundwater contamination related to anthropogenic activities.

RÉSUMÉ
Localisé dans le Nord-Est de l'Algérie, l'aquifère côtier de Taleza constitue une source d'eau souterraine potentiellement importante. Il contient des centaines de puits privés installés par la population à plusieurs fins incluant l'approvisionnement en eau potable. Récemment, les eaux souterraines sont devenues très salines. De plus, certaines personnes ont noté la présence d'une mauvaise odeur d'œufs pourris dans les eaux souterraines pompées dans leurs puits. La qualité des eaux souterraines est principalement contrôlée par deux facteurs: 1) les processus naturels liés à la lithologie de l'aquifère et aux interactions sol/roc avec les eaux souterraines, et 2) les activités anthropiques. Cependant, les activités anthropiques peuvent être considérées comme les sources sérieuses de contamination des eaux souterraines. Cet article décrit les sources anthropiques potentielles de contamination des eaux souterraines relevées sur le territoire de Taleza, telles que l'agriculture, les systèmes privés d'assainissement d'eaux usées, l'urbanisation aléatoire, la surexploitation des eaux souterraines, les décharges de déchets solides et les cimetières. Par conséquent, une planification efficace et durable s'avère urgente pour la protection des eaux souterraines, afin de limiter et potentiellement inverser les effets des sources anthropiques sur la qualité des eaux souterraines.

1 INTRODUCTION

Groundwater requires to be protected from any potential source of contamination in order to be beneficial to natural ecosystems and to remain available in good quality for human use. Groundwater quality is mostly controlled by two factors: 1) natural processes related to aquifer lithology, the quality of recharge water, and soil/rock interactions with water (Walter et al. 2017); and 2) anthropogenic activities like agricultural production, industrial growth, urbanization with increasing exploitation of water resources, and private sanitation systems (Jeong 2001, Garewal and Vasudeo 2018). Many anthropogenic activities can be considered as very serious sources of groundwater contamination. Indeed, numerous cases of serious groundwater contamination problems in urban areas are identified in the world (Jangam et al. 2015, Zeng et al. 2016, Lapworth et al. 2017). For some of these cases, groundwater contamination results from the absence of any groundwater protection plan applied to industries such as that using chlorinated solvents (Takizawa 2008), or from expanding urban areas, especially in rural regions of some less-developed countries, without any strategic development plan and any consideration of the nocuous repercussion on human health. The lack of adequate development plan in many expanding urban areas is a growing concern given that the groundwater resources, under these expanding urban areas, are being put under considerable pressure from contamination loading with clear implications for groundwater quality and public health (McMichael et al. 2006, Xu and Usher 2006, Wang et al. 2012, Howard et al. 2016, Lapworth et al. 2017). In certain hydrogeological conditions, very small amounts of a hazardous substance can contaminate an important quantity of groundwater over large areas (Ashton and Turton 2009).

This paper describes a case study of an expanding urban area, over a wide range of diverse hydrogeological settings, by reviewing the potential anthropogenic groundwater contamination sources identified both inside and on trans-boundary territories outside of that urban area, as well as their causes and consequences.

2 STUDY AREA

The expanding urban area of the Plain of Taleza is considered as a District of the City of Collo (W. Skikda) located in the north-east of Algeria (Figure 1). The Plain of Taleza is a flat valley bottom covering about 7 km^2, constituted of Quaternary granular alluvium deposits, varying in thickness between 5 and 40 m, and resting on Mio-Pliocene marl substratum. The alluvium deposits can be divided into two main lithofacies. The southern part of the study area is mostly dominated by silt sandy clay, as well as clay; while the northern part is mostly composed by sand, gravel, and pebbles (CGG 1965, Minmeliovodkhoz 1968, ANRH 1974). Under natural conditions before significant human activities had been developed in the Taleza region (1960's and 1970's), the estimated effective volume of the groundwater reservoir of the unconfined Taleza aquifer was approximately 75 million cubic meters (CGG 1965). De-Camps (1974) had estimated to 120 l/sec the potential extraction flow rate from this aquifer. The alluvial deposits of the unconfined part of the Taleza aquifer correspond to a zone of high water flowing. In fact, the hydraulic conductivity estimated from pumping tests data according to Jacob's method (Jacob 1947), in two municipal wells (Benoto and Safor) located in the southeast part of the Plain, is varied between 8.29×10^{-4} m/s and 2.07×10^{-3} m/s (Beloulou 1987). The Plain of Taleza is fed by direct rainfall precipitation (estimated to be 800 to 1000 mm/year), runoff from surrounding metamorphic mountains (2000 mm/year), and infiltration from the Guebli River which drains a large sub-watershed covering an area of 993 km^2 (ANRH 1974, Mecibah 2008). The Cherka River, which drains a smaller watershed localised in the western part of the Plain of Taleza, constitutes another source of water infiltration into the aquifer.

The Plain of Taleza is selected as a study area because it contains hundreds of private wells installed by the population for several purposes including drinking water. However, most local people seem unaware of possible anthropogenic groundwater contamination (Boumaiza et al. 2019). The aquifer of the Plain of Taleza was also used as the principal source of water supply for surrounding communities (Collo, Ain-Aghbel and Kerkra), where a total of 9 municipal wells were then installed, before surface water became available from the Beni-Zid Dam in 1993 (Chabour 2004a). On the other hand, the Plain of Taleza constitutes an important source of agricultural garden products for almost all Eastern Algeria. It also includes an important touristic area along the Mediterranean Sea, where resorts, hotels and other touristic buildings are operating. Recently, the Plain of Taleza has become an estate development area where several important construction projects are developing in areas with agricultural and touristic vocations, without any strategic plan to protect the aquifer (Chabour et al. 2009).

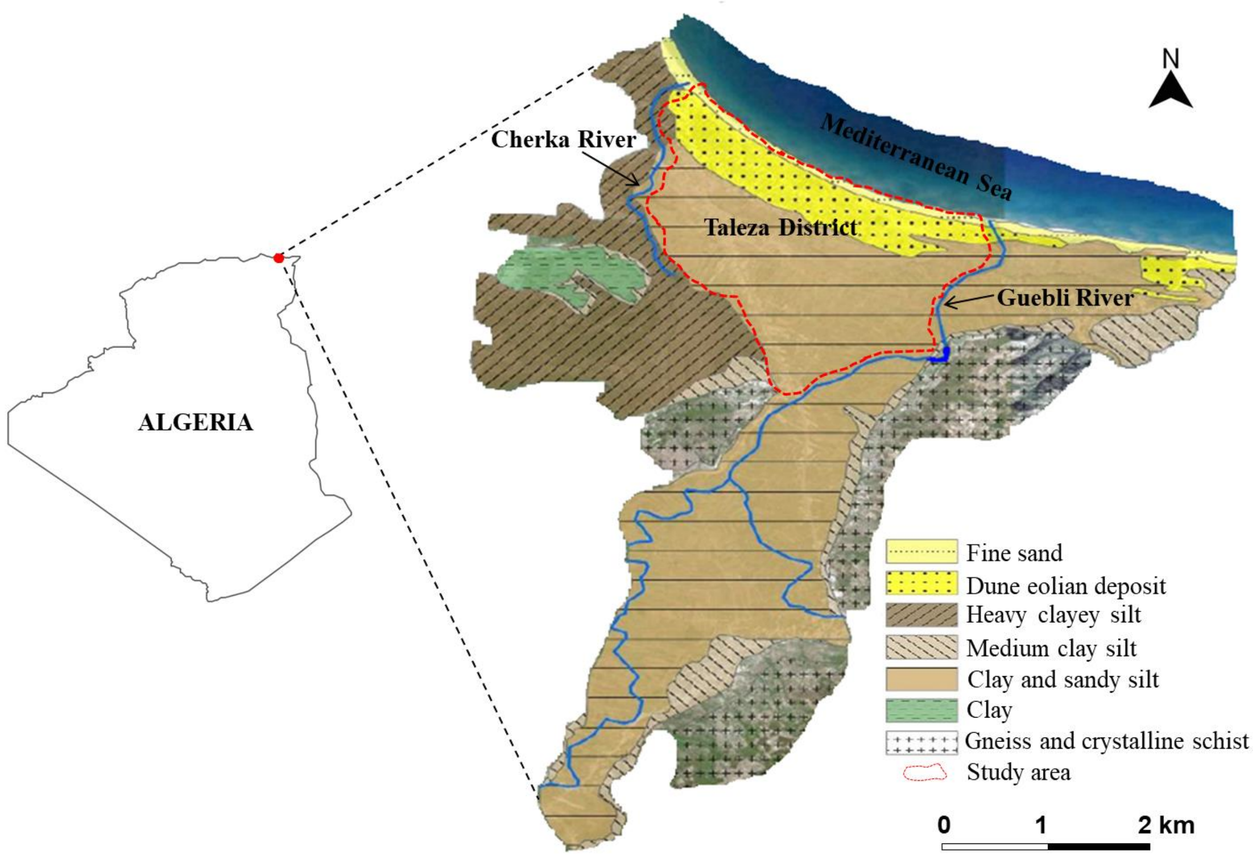

Figure 1. Localisation and surface geological deposits of the Taleza region (Minmeliovodkhoz 1968).

3 POTENTIAL ANTHROPOGENIC SOURCES OF GROUNDWATER CONTAMINATION

It should be mentioned that no physical characterisation or chemical analysis have been performed as part of this study. The potential anthropogenic sources of groundwater contamination in the Plain of Taleza are discussed in this paper based on the previous investigations performed in the Plain of Taleza and from some other similar case studies carried out in the world.

3.1 Contamination from cultivated fields

Agriculture has had profound effects on the rate and composition of groundwater recharge. In many areas of the world, the major-element chemical loads of water infiltrating into unconfined aquifers are dominated by constituents derived in part from agricultural practices and used additives (Hudak 2000, Nolan 2001, Böhlke 2002), where the consequence of irrigation and intense fertilization of cultivated fields could usually result in: 1) salinization of the soil and groundwater (Stigter et al. 1998), and 2) increase of nitrate (NO_3^-) concentrations in groundwater (Singh et al. 1995). Groundwater can also be seriously affected by other agricultural contaminants with potential health or ecological impacts such as pesticides (Kladivko et al. 2001) and phosphorus (Sharpley et al. 2000). All these elements involve a long-term risk of groundwater contamination when an excess of fertilizers, salts, and pesticides are used in cultivated fields (Hadas et al. 1999). Agricultural contaminant loads in recharging groundwater have resulted in well-known societal problems related to drinking-water quality (Fan and Steinberg 1996) and ecological effects of groundwater discharge to surface-water bodies (Howarth et al. 2000).

The development of agriculture in the Plain of Taleza is highly dependent on irrigation; for instance, an area of about 1600 ha of irrigated fields has resulted in an intense activity of groundwater extraction (Chabour et al. 2009). The impact of agricultural contamination has motivated a number of studies conducted on the Plain of Taleza focusing in part on this problem, with nitrate concentrations in groundwater were used as an indicator of agricultural contamination (e.g. Hamani 1998, Boulabeiz 2006, Chekroud 2007). During the 90s, the use of certain fertilizers was prohibited, while the agricultural activity on the Plain of Taleza was not much developed. That practice did not lead to nitrate contamination of the aquifer (Chabour 2004a). Since the late 90s, however, the agricultural sector has experienced as expansion as part of a governmental program, in which several types of fertilizer have been used in agriculture. As a result, chemical analyses performed in 2003 on groundwater samples from the Plain of Taleza revealed nitrate concentrations in exceedance of the maximum admissible concentration of 50 mg/l (EC 1980, WHO 2011). The high concentration values are localised in the central part of the Plain of Taleza, coinciding with areas of intense agricultural activity (Chabour 2004a). These findings were confirmed in 2005 by further groundwater sampling and chemical analysis campaign. Indeed, the nitrate concentrations distribution map (Figure 2) established by Boulabeiz (2006) shows that the area zone with intense agricultural activity, localised in the central part of the Plain of Taleza, is the most affected by high nitrate concentration. Chekroud (2007) stated that this situation is explained by the intense use of fertilizers and poor management of cultivated fields.

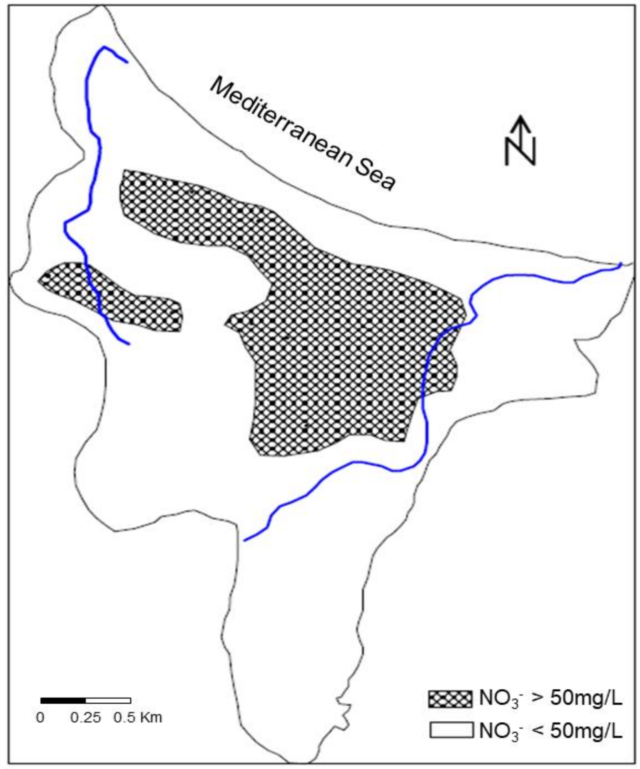

Figure 2. Nitrate distribution in groundwater in the Plain of Taleza (Boulabeiz 2006).

3.2 Contamination from private sanitation systems

The contamination due to the use of private sanitation systems is one of the most discussed groundwater contamination problem in the world. Cases of inappropriate wastewater treatment are numerous in developed and less developed countries (Heng et al. 2010, Pujari et al. 2011). For instance, private sanitation systems, which are a means of wastewater disposal for approximately 25% of all housing units in the USA, have been reported to be a source of groundwater contamination in that country (Bunnell et al. 1999).

In many countries, a recommended practice is to use a septic tank associated with a seepage field (e.g. MDDELCC 2015). In the Plain of Taleza however, many home owners have built sewage storage systems with open-bottom so that the wastewater can seep directly into the subsurface, resulting in groundwater contamination. Also, all the developed areas for residential housing lots are connected to local collective sewage storage with open-bottom. Studies have shown that the expansion of poor private sanitation systems in urban and rural areas has a major effect on groundwater contamination (Lu et al. 2008, Shivendra and Ramaraju 2015). The groundwater contamination associated to private sanitation systems in the Plain of Taleza is confirmed by the recorded concentrations of NO_3^-. This contamination has been commonly linked to agricultural activities and the use of fertilizers. However, septic systems also contribute important quantity of nitrates to aquifers, especially in urban areas (Wakida and Lerner 2005). The effluent from septic tanks is usually charged by ammonium (NH_4^+) and organic nitrogen, that could be transformed to NO_3^-, which may be transported into groundwater (Starr and Sawhney 1980). According to Chabour (2004a), the intense use of poor private sanitation systems, due to the absence of collected sanitation network, contributes to the high nitrate concentrations that are recorded in the central part of Plain of Taleza (Figure 2), where most of the people are living. In this central part, high NH_4^+ concentrations are also recorded according to groundwater analysis campaigns of 2005 (Boulabeiz 2006), and 2006 (Chekroud 2007). On the other hand, sulfides (H_2S) can be produced during the anaerobic degradation of organic substances present in septic tanks (Gujer and Zehnder 1983), and generate a very toxic gas smelling as rotten eggs. Some municipal and private drinking water wells installed in the Plain of Taleza were abandoned due to the presence of this strong odor, which can be explained by the presence of H_2S (Chabour 2004a).

3.3 Contamination from urbanisation

Historically, the first established houses on the Plain of Taleza were located in the north-west area (named previously Ouled-Mazouz), and to a lesser extent, in central area (named El-Tahra territory). Subsequently, the Plain of Taleza has been intensively urbanised since the late 1990s, where many private houses are built from the north-west area to north-east. Other uncontrolled expanding housing area appeared on the sides of the national road (N-85) crossing the Plain. More recently, many large developed residential housing areas are built by the Algerian's Government in different parts of the Plain, without realizing any sanitation network. The northern sector also includes a touristic development zone along the Mediterranean Sea, where resorts, hotels and other touristic facilities are constructed (Figure 3). This uncontrolled expanding urbanisation, without any plan to protect the underlying aquifer, contributes to irreversible degradation of water resources, particularly groundwater.

The rapid growth of urban area has negative effects on natural recharge of aquifer due to ground surface sealing by concrete and asphalt cover (Baier et al. 2014), and also by introducing new sources of contamination (Foster et al. 1994, Morris et al. 1994). The waterproofing due to ground sealing could affect also the spatial and deep distribution of groundwater recharge, while the precipitation could eventually be converted into runoff, rather than to be infiltrated into aquifer (Wakode et al. 2018). This process has not yet happened in the Plain of Taleza as its urbanisation is still expanding. However, an eventual scenario is a piezometric decrease in the aquifer, resulting in a reduced groundwater supply potential and an increasing intrusion of marine saltwater from the north (see next sub-section).

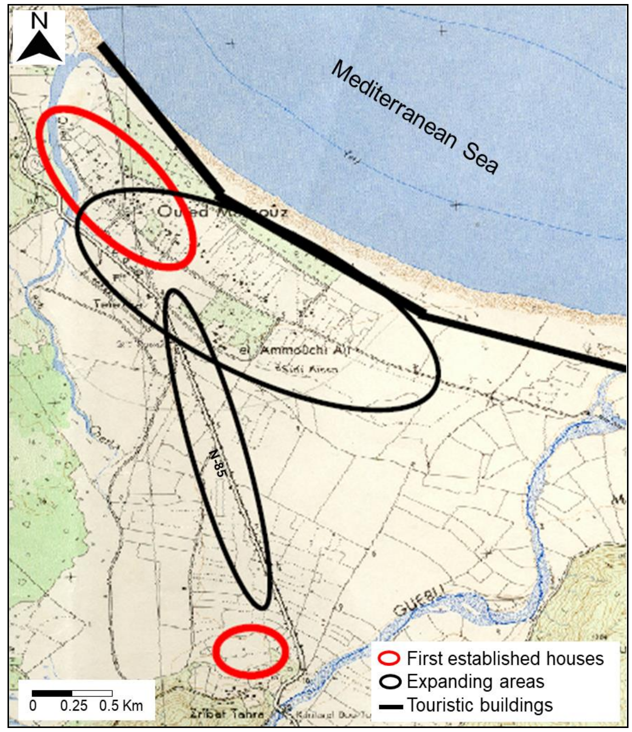

Figure 3. Expanding urbanization in the Plain of Taleza (Chabour et al. 2009).

3.4 Contamination from over-exploitation

Groundwater overdraft, a form of « over-exploitation », occurs when extraction exceeds both natural and induced aquifer recharge over a long period (Pophare et al. 2014). The global scenario of groundwater overdraft indicates that over-exploitation of groundwater from the shallow aquifers has deteriorated its quality (Khayat et al. 2006). In fact, the most intensive contamination occurs in rapidly urbanized areas, where intensive exploitation of groundwater takes place, ultimately leading to a high downward gradient. This hydrogeological condition may accelerate the migration of contaminants from the surface into aquifer (Jeong 2001). Also, as the majority of urban areas are located in coastal regions, the aquifers may be impacted by saline intrusion (Steyl and Dennis 2010), which could be compounded by changes in sea level and/or over-abstraction of vulnerable coastal aquifer systems (Comte et al. 2016).

The electrical conductivity of groundwater in the Plain of Taleza was characterized by values generally ranging between 300 and 1400 µS/cm (ANRH 1974). Considering the low exploitation of groundwater in the Plain of Taleza at that time, no interpretation was made relative to probable saline water intrusion. However, groundwater monitoring conducted in 2003 (Chabour 2004a) showed a clear evolution of the electrical conductivity values in the well pumping area in the north-east part of Plain of Taleza. Groundwater samples, from wells that had shown electrical conductivity values below 1100 µS/cm in 1974, have shown values in excess of 3000 µS/cm in 2003. The intensive pumping (close to shore) involves the lowering of the water table that causes an advancing saline water wedge toward the interior of the Plain of Taleza, and this contributes to a higher salinity of fresh water (Chabour 2004a, 2004b, 2017, Mebarki et al. 2017, Boulabeiz et al. 2018). Also, the lowering of water table due to over-exploitation influences the vertical hydraulic gradient, and could potentially activate geochemical interaction of the deeper saline water with shallower freshwater. On the other hand, aquifer systems that contain freshwater and saline water are usually stratified, with the more dense saltwater underlying the freshwater. A groundwater well discharging from the freshwater zone causes the saltwater to move upwards towards the well. This phenomenon, known as saltwater upconing, is used to describe the movement of saltwater from a deeper saltwater zone upward into the fresh groundwater in response to pumping at a single well (Reilly and Goodman 1987, Ma et al. 1997). In the aquifer of the Plain of Taleza, a layer of marine saltwater, which was deposited after the Quaternary-era marine transgressions, lies at the bottom of the paleo-channels (Chabour 2004a). This marine saltwater layer could affect the freshwater layer of the Taleza aquifer. In fact, an excessive pumping in deep wells localised inland far from the shore has caused raise saltwater moving inland (CGG 1965).

3.5 Contamination from dumpsites

Landfills and/or open dumpsites have been common practice for municipal solid waste disposal all over the world (Nagendran et al. 2006). In less-developed countries, these areas could receive a large variety of municipal solid wastes (without any prior sorting), including commercial and industrial hazardous wastes such as electronic goods, leftover paint, dyes and inks in paper, pesticides and fertilizers in yard waste, and used batteries. The immediate nocuous repercussions of these areas are fires and explosions, vegetation damage, unpleasant odors, and air contamination (Calvo et al. 2005). On the other hand, rainwater percolating through the waste layers in a landfill or dumpsite, generates a highly contaminated leachate under and downstream from the dumpsite, that may be categorized as a water-based solution of four groups of contaminants: 1) dissolved organic matter, 2) inorganic macro-components, 3) heavy metals, and 4) xenobiotic organic compounds (Maiti et al. 2016). This very toxic leachate would contaminates groundwater that migrates through aquifers and potentially contaminate surface water as well (Patil et al. 2013).

Two large dumpsites are localised on the borders of the Plain of Taleza: 1) the Boumhadjer dumpsite ($\simeq$ 15 000 m^2) is still receiving solid waste from many communities of the Collo region since 1970, and 2) the Rise dumpsite ($\simeq$ 1 500 m^2) receives solid waste from the municipality of Kerkra and the community of Hadjeria since 1984. The Boumhadjer dumpsite is located to the west of the Plain of Taleza (Figure 4) at an elevation of about twenty meters higher than the Plain of Taleza level. This high elevation favors a surface runoff toward the Plain of Taleza, which could be seriously charged in different contaminants. Also, the groundwater in this area is presumably flowing toward the Plain of Taleza, also due to the high elevation of the Boumhadjer area. In this case, potential contaminated leachate, resulting from the Boumhadjer dumpsite, could migrate with groundwater and reaches the aquifer of the Plain of Taleza. The environmental association El-Manara which fights for the environmental preservation in the region of Collo has placed multiple calls to concerned authorities about this problem. In fact, one of the requests addressed by this association mentions the danger of this wild dumpsite and the ambiguity which characterises the authorities to determine an acceptable area for locating a safer landfill site. On the other hand, the regional piezometric map shows that groundwater at Rise dumpsite located to east (Figure 4) is also flowing toward the Plain of Taleza. In this case, contaminated leachate from the Rise dumpsite could migrate with groundwater and reaches the aquifer of Plain of Taleza. For the two affected border areas, either the Cherka River to the west or the Guebli River to the east (Figure 4) could receive the groundwater transported leachate, and may transport it further downstream, particularly during the high water period when the rivers drain the aquifer.

3.6 Contamination from cemeteries

In the process of decomposition of a buried body, 0.4 to 0.6 litres of leachate is produced per 1 kg of body weight. The leachate contains 60% water and 30% salts (in the form of ions containing nitrogen, phosphorus, and compounds of various metals), and 10% of organic substances (Silva 1998). Other contaminants could be derived from the buried body including chemical substances applied in chemotherapy and embalming processes (e.g., arsenic, formaldehyde and methanol), makeup (e.g., cosmetics and pigments), as well as various additional items, such as cardiac and metal hardware elements. Accordingly, closer cemeteries are considered among the anthropogenic sources of groundwater contamination in urban areas (Silva and Filho 2012). This topic has been investigated in some regions of the world such as Brazil, Australia, South Africa, Portugal, United Kingdom and Poland. However, recently more and more attention has been focused on this issue (e.g. Zychowski and Bryndal 2015) given the impact of this contamination source.

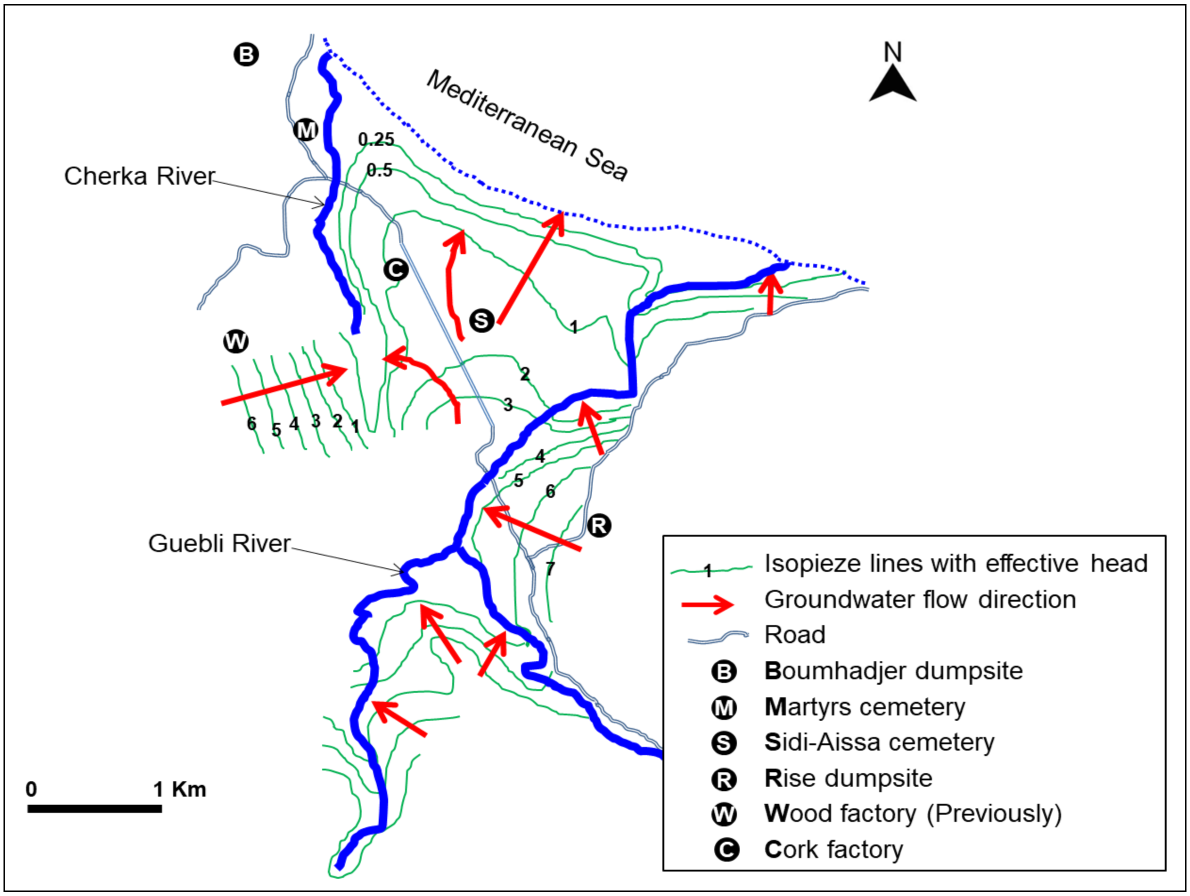

Figure 4. Regional piezometric map of Plain of Taleza (CGG 1965, info-graphed by Lamine Boumaiza) and approximate localisation of some potential anthropogenic sources of groundwater contamination.

Two large cemeteries are localised on the Plain of Taleza: 1) the Sidi-Aissa cemetery where the body of deceased people of the Taleza District are buried since a very long-time ago, and 2) the Martyrs cemetery established since 1964 for reburied over than 1300 martyrs. There is no specific study performed to investigate the potential contamination generated from the cemeteries in the Plain of Taleza. However, given the localisation of these two cemeteries (Figure 4), part of the contamination by nitrates and phosphors (and other related contaminants) identified in the central part of Plain of Taleza (Boulabeiz 2006, Chekroud 2007) could originate from decomposition process of buried bodies.

3.7 Contamination from rivers

Rivers generally interact with groundwater in three basic ways: 1) rivers gain water from inflow of groundwater through the streambed (gaining stream); 2) rivers lose water to groundwater by outflow through the streambed (losing stream); or 3) rivers do both, gaining in some reaches and losing in other reaches, or both gain and lose in the same reach at different times. In order for groundwater to discharge into a stream channel, the elevation of the groundwater table or the piezometric surface adjacent to the stream must be higher than the elevation of the river stage. Conversely, for surface water to seep to groundwater, the elevation of the river stage must be higher than the adjacent near stream groundwater elevation (Woessner 2000, Ivkovic 2009). Accordingly, eventual contamination could be transported during losing stream from river to aquifer.

The Plain of Taleza is crossed by two principal rivers (Figure 4). The Cherka River, which drains local watershed localised in the Western part of the Plain of Taleza, is linked to important wetlands, where, trees such as poplar, brambles and other species, make this ecosystem very rich in biodiversity. However, the actual environmental situation of this river is degraded because the wild spills of various wastes. In fact, this river has become a large receptor for various wastes, such as used oils, garbage, concrete and rubble. Also, the sanitation network of City of Ramoul-Abdelazize (a population of more than 8000 persons), drains in this river without any prior treatment. During losing stream periods, the contaminated river water resulting from wild spills, does infiltrate toward the aquifer and contaminates groundwater. Industrial facilities like a wood product industry (converted in 2015 as military barrack) and a cork factory established on the Plain of Taleza (Figure 4) generate liquid waste from their processes. These liquids could reach the Cherka River as the groundwater in this area is flowing toward this river. Analysis performed on surface water samples collected from this river has revealed a value of electrical conductivity that exceeds 16000 µs/cm (Boulabeiz 2006). For its part, the Guebli River, 154 km long, is suffering from various wild spills including industrial and commercial spills. This river also constitutes the outlet of the sanitation systems from many cities, the waste water being poured into this river without any prior treatment. Value of electrical conductivity that exceeds 4 000 µs/cm has been observed in surface water samples from this river during a 2005 campaign (Boulabeiz 2006).

4 CONCLUSION

This study identifies potential anthropogenic sources of groundwater contamination in the aquifer of Taleza, such as cultivated fields, private sanitation systems, urbanisation, over-exploitation of groundwater, dumpsites, cemeteries and crossing rivers. Also, the manure produced by a number of chicken farms present in the study area is considered as another potential source of nitrate contamination. The hydrogeo-environmental disturbances affecting the aquifer of Taleza, by several different factors, have led to the degradation of the groundwater quality. The unconsciousness and irresponsibility of local authorities contributes to an irreversible degradation of the hydro-system that can result in health problems due to groundwater contamination. Consequently, urgent, efficient and durable planning is required over the Plain of Taleza, instead of temporary untested solutions. At this stage, courageous and judicious decisions could save the aquifer of Taleza, in particular an optimization strategy of groundwater extraction, the introduction of environmentally safe agricultural practices and the installation of a reliable sanitation network for the existing urbanised sectors. Moreover, the sustainable development of the Plain of Taleza must be realized by an implication of the scientific community. For instance, determining the origin of saline components in aquifer of Taleza would provide to a better understanding of the salinization process; this knowledge is required to develop useful solutions for ensuring the long-term protection of water resources. Accordingly, it is recommended to perform a multi-tracer study, combining isotopic and hydro-geochemical analysis, to identify the origin and fate of groundwater salinization.

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