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Identification and cartography of potential groundwater polluters in Tlemcen urban area (northwest of Algeria)

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ABSTRACT

This paper presents the hazard mapping of groundwater in the Tlemcen urban area (TUA). First, we identified the potential pollution sources (of industrial, agricultural and urban origins) existing in the studied area that can affect the karstic groundwater. It is the most important reserve and the main source of drinking water supply of this area. Then, we mapped all these hazards on a topographic map at scale 1:25,000. Finally, a classified hazard map was established. This investigation clearly shows that the groundwater of TUA is far from being safe from the risk of pollution. Adequate and urgent actions must be taken in order to eliminate or to reduce the risks of contamination of this water resource which is highly vulnerable because of the lack of protection perimeters.

Keywords: Drinking water resource; Karst aquifer; Contamination risk; Hazard mapping

1. Introduction

Groundwater from karst aquifers is among the most important resources of drinking water for the growing population of the world [1]. In Algeria, and particularly in Tlemcen, the karst groundwater plays an important role in the socioeconomical development of the country [2]. This resource has provided for a long time the drinking water supply to the population of Tlemcen. Physicochemical analyzes have revealed that the karst water of the region of Tlemcen is of a very good quality. It has a calcium–magnesium bicarbonate facies, and its dry residue varies between 480 and 720 mg/L [3]. However, this water is vulnerable and its high quality may be jeopardized by anthropogenic impacts [4]. This vulnerability is mainly due to the highly heterogeneous structure of the karst aquifers which are recharged both by diffuse infiltration through the soil and by concentrated point recharge through dolines and swallow holes. In addition, the hydraulic behavior is strongly influenced by the presence of solutionally enlarged fractures and conduits; the permeability is very low in some regions, but very high through fractures and conduits

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[5]. A vulnerability study of this groundwater that was carried out in 2007 according to the European approach revealed that among a total of 28 wells drilled with the purpose of supplying drinking water, 15 were located in very high vulnerability regions [4]. The risk of pollution of this groundwater was pointed out in many publications [6], but so far no risk mapping of this region was performed. Since 2005, several springs and wells were closed due to their nitrate levels exceeding standards or their bacterial contamination rendering the water unsafe for human consumption. This contamination might have been caused by many factors such as the ejection of non-treated wastewaters directly into the natural environment, the irrigations with sewage, the use of chemical and organic fertilizers, and the drilling of private wells conducted with neglect and no consideration whatsoever for the safety standards. All these factors are, in fact, due to the non-respect of the groundwater protection policy [6]. This article is a study and a review of the potential and actual polluters of the karst groundwater in the urban area of Tlemcen. The different sources of pollution existing in this area are mapped on topographic maps, based on an exhaustive inventory. Finally, a classified hazard map is elaborated for the first time in this region. This map is of a great help to the local authorities. It allows deciding on the first actions to be undertaken in order to prevent pollution of the karst water of the region.

2. Description of the studied area

Tlemcen urban area (TUA) includes the municipalities of Tlemcen, Chetouane, Mansourah, and Beni Mester. It is bordered to the north by Sidi Yahia mountain and the plain of Hennaya, to the south by Tlemcen mountains, to the east by Oum El Allou mountain, and to the west by Oued Zitoun river (Fig. 1). The TUA surface area is over 20,000 ha and its population is more than 270,000 inhabitants. It is the most densely occupied region of the Wilaya (Territorial Division) of Tlemcen: it contains 24% of the population within only 1.2% of the total surface area of the whole Wilaya [7].

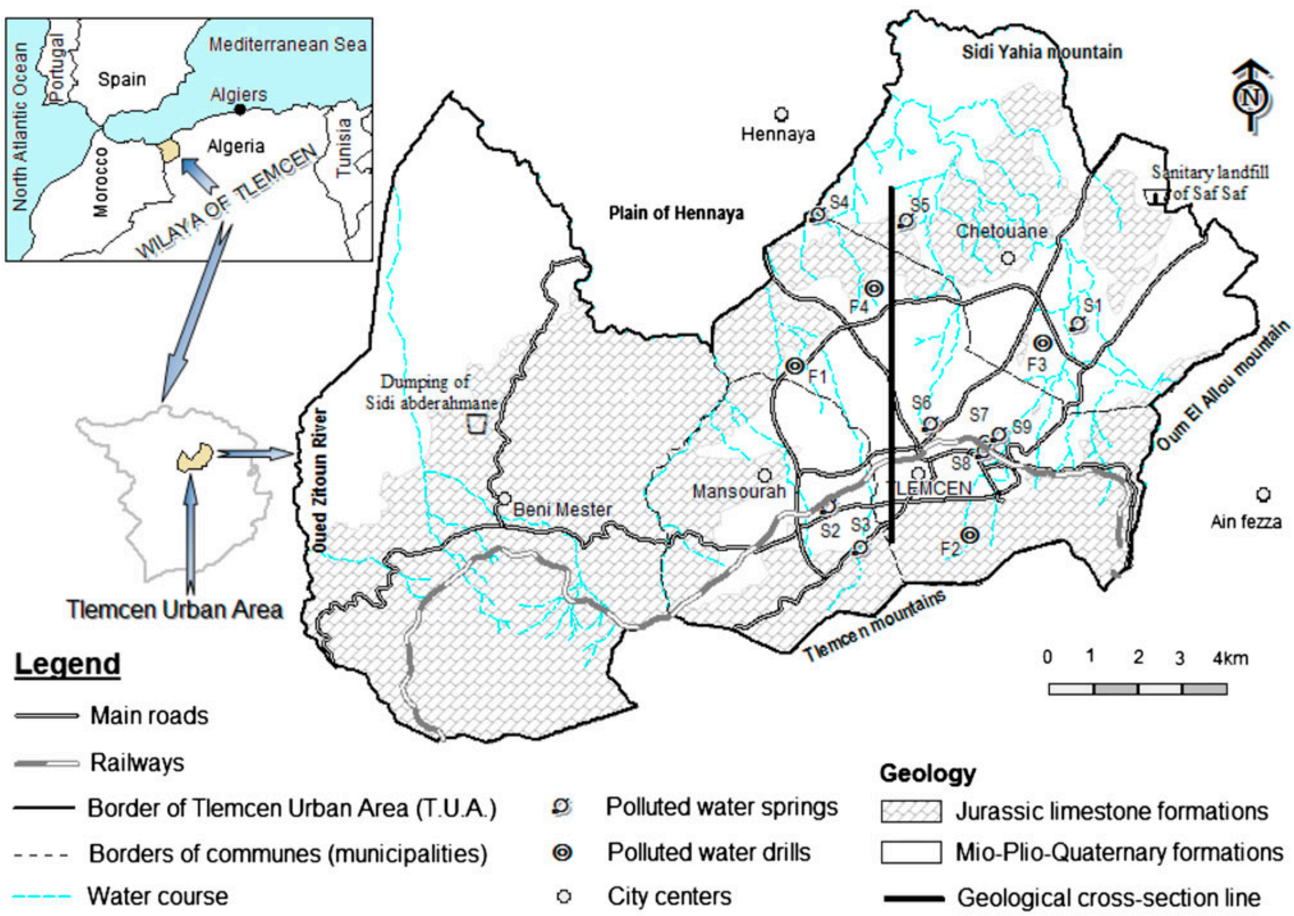

Fig. 1. Geological overview and location of the TUA.

The climate is sub-humid Mediterranean type with an average rainfall of 546 mm (1979–2010) and a mean annual temperature of 18˚C [8].

This studied area is located in the foothills of the Tlemcen mountains which are formed from a large horst whose surface consists of karstic limestones of the Upper Jurassic and Lower Cretaceous. In the TUA, these carbonate formations constitute an important karst which is covered by a thick neogene sedimentation. Fig. 2 shows a simplified cross-section of this area. The latter corresponds to a collapsed zone as a result of tectonic accidents. This structure was revealed by geophysical surveys and confirmed by drilling results.

The karst groundwater of this region is intensively pumped through boreholes and is an important supply of drinking water for the TUA. This water is of a good physicochemical quality, but is very vulnerable to pollution [4]. Karst aquifers are particularly vulnerable to contamination: the absence of thick vegetation, combined with thin soil, enables rapid infiltration of incoming water and its transfer over long distances through heterogeneous karstic underground [10]. Therefore, it is vital to protect this groundwater from any pollution which could reach the aquifer.

3. Materials and methods

In order to reach our aim, we have identified all potential pollution sources existing within the TUA that may expose karstic groundwater of the region to pollution risks. Hence, a detailed baseline was completed by surveying all the pollution sources due to anthropogenic actions in this region. We made an exhaustive inventory of all activities in the region, including agriculture and industry. Many on-site visits were made in order to verify and complete the already available information related to the various potential sources of pollution existing all over the TUA.

Field surveys and visits to different agencies were performed in order to collect all the required data about the various hazards identified on-site. The main local agencies visited are: the direction of the agricultural services (Direction des Services Agricoles), the direction of the environment (Direction de l'environnement), the direction of energy and mining (Direction de l'Energies et des Mines), the direction of the water resources of Tlemcen (Direction des Ressources en Eau de la wilaya de Tlemcen), the national agency for country planning (Agence Nationale de l'Aménagement du Territoire), and Tlemcen urban planning agency (Urbanisme de Tlemcen). Finally, the various sources of pollution within the TUA were identified according to the hazard inventory proposed by COST 620 [11] and mapped on a topographic map at scale 1:25,000. Specific symbols are adopted for the different categories of potential sources of pollution and the hazards are finally classified into five categories depending on their degrees of harmfulness as recommended by Ketelaere et al. [12].

4. Description of hazards

The main hazards that were identified in the study area are: waste water discharges into surface watercourses, garbage dumps, fuel loading stations, unsecured roads, wastewater release by industrial

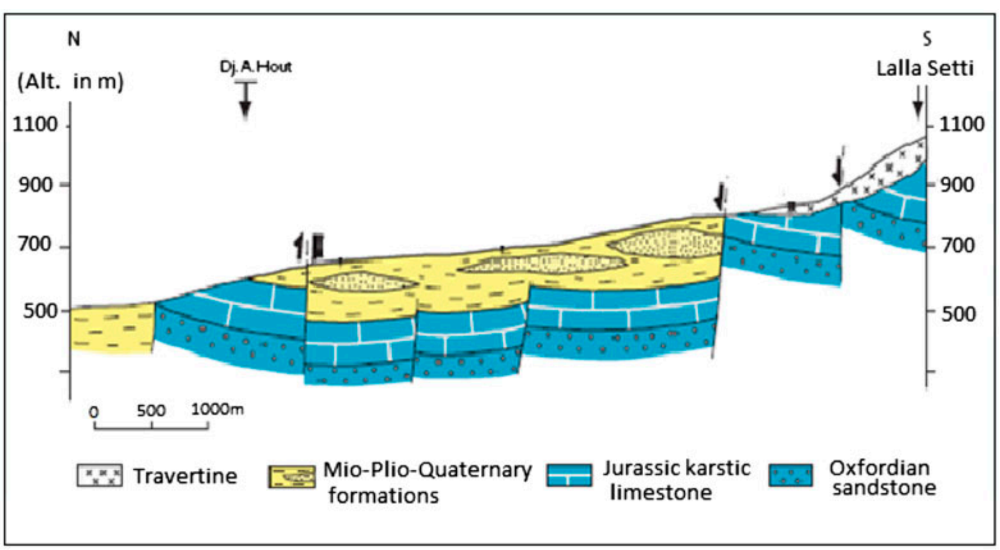

Fig. 2. Simplified geological cross-section of the TUA [9].

units, deserted quarries, irrigations by wastewater, and the excessive use of pesticides, chemical and organic fertilizers. All the hazards inventoried in the study area are described herein with more details and mapped on topographic maps at scale 1:25,000.

4.1. Water supply and sanitation within the TUA.

The localities of the TUA are supplied with drinking water for a long time by the dam of Maffrouch (located at about 4.5 km to the south of Tlemcen city center), as well as by many boreholes drilled in the karstic aquifer and by some high yield springs. In the recent years, because of the limited water resources in the region, the drinking water supply has been completed by two desalination plants (Honaine and Souk Tleta: located, respectively, at about 45 km to the northwest and 65 km to the extreme northwest of Tlemcen) and more recently, the dam of Sikkak (located at about 18 km to the north of Tlemcen city center). Some boreholes were left on standby, in order to be used only in case of special needs.

Until today, the rate of connection of the TUA to the drinking water network piping supply is about 95%, while the connection of the population to the sewage network is only about 92%. The latter is an old network of a unitary type and it is in bad condition [8].

4.2. Potential groundwater polluters over the TUA.

The poor urban planning associated with the rapid urban growth within the TUA has increased the risk of potential pollutants that could contaminate the groundwater of the region and consequently, may have a harmful effect on the health of the population.

Microbiological and chemical analyzes performed by competent local authorities in springs and boreholes, over the studied area, have shown a no negligible impact of human activities on the quality of the karst water. 13 supply points were found with concentrations exceeding the maximum permissible values for drinking water. These supplies were declared as unfit to the human consumption and were systematically closed. Fifty percent of these supply points were found with high nitrate concentrations, while the remaining points were found with important microbiological contaminations. Details on these pollutions are given in Table 1.

These contaminations might have been caused by many hazards such as the ejection of wastewaters directly into the natural environment without preliminary decontamination, the irrigations with sewage and the use of chemical and organic fertilizers.

Across the study area, we identified many hazards that can be classified into three main categories: infrastructures development, industrial activities, and agricultural activities.

4.2.1. Wastewater discharges

Among the potential sources of pollution, we can mention many wastewater discharges that should be treated but are still untreated up to the present day. The only sewage treatment plant of the TUA is located in A. El Hout. 66 discharge points of domestic and industrial wastewaters through the territory of the TUA were recorded in 2012 [8]. These discharge points are in very bad conditions as shown in Fig. 3

Table 1
Contaminated water supply points

Water supply point (see location on Fig. 1)	Type	Reasons for shutting down the water points	Year of shuttings
Koudia (F1)	Borehole	High level of nitrates (70 mg/L) and bacterial contamination	2005
Birouana (F2)	Borehole	Green colored water with bad smell and bacterial contamination	2005
A. Defla (F3)	Borehole	High level of nitrates (83 mg/L)	2007
Oudjlida (F4)	Borehole	Bacterial contamination (Coliformes & *Escherichia coli*)	
A. Bendou (S1)	Spring	High level of nitrates (110 mg/L)	2007
A. Mokdad (S2), A. Kobet El Djouz (S3), A. El Ançor (S4), A. El Houtz (S5)	Springs	High level of nitrates (64–104 mg/L)	2013
A. Sidi El Haloui (S7), A. Karadja (S6), A. Sidi Lahcen (S8), A. Dar Dbagh1 (S9)	Springs	Bacterial contamination (Coliformes & *Escherichia coli*)	2014

Fig. 3. Examples of wastewater discharges within the TUA (photograph by H.S. Fellah, 2012).

and their number is continuously increasing. In the context of environmental protection programs, a wastewater treatment plant, using activated sludge, of a capacity of 384,000 E/H is under construction in the city of Hennaya [13]. In spite of this effort towards better management of wastewater, there still remain some ejections from illegal and precarious neighborhood that cannot be connected to the sewage network.

4.2.2. Solid waste material

Solid waste material is one of the major problems caused by urbanization. It represents a risk to both human health and the environment. In the TUA, domestic household wastes are estimated at about 0.5 kg/inhab/d, equivalent to nearly 54,700 tons/year [13]. These unsorted wastes are directly transported to the sanitary landfill of Saf Saf and partly incinerated with no further consideration for their deleterious effects on the environment. Moreover, our investigation led to the identification of unauthorised garbage dumps in the studied area, such as the site of Koudia (Fig. 4) or the site of Sidi Abderrahmane located in the town of Beni Mester. The latter occupies today an area of two hectares and is in continuous expansion.

Fig. 4. Wild dumpsite of Koudia (photograph by H.S. Fellah, 2012).

4.2.3. Fuel loading stations

We have inventoried 12 fuel loading stations through the TUA (Including car wash and oil replacement services), which generate high quantities of used oils (13,000 L/month). These oils are stored in barrels that are in principle recovered by NAFTAL (National marketing company of petrochemical products) [8]. However, due to insufficient application of existing safety guidelines regulating their handling during storage and transportation, they remain a danger for the environment, and particularly, for the highly vulnerable karst groundwater.

4.2.4. Traffic

Within the TUA, the roads network is varied, dense, and characterized by a high rate of traffic accidents exposing the environment to a non-negligible pollution risk during transportation of hazardous products such as petrochemical substances. These accidents may be a real risk of pollution to the groundwater of the region, since only few roads in the TUA have regular roadside channels to collect and drain off meteoric waters (Fig. 5). Regarding the majority of roadways, dirt is directly washed off underground.

4.2.5. Wastewater release by industrial units

The existence of heavily polluting industries in wholly urbanized regions of the TUA is one of the most important sources of pollution that must be seriously taken into consideration. The wastewaters of these industries, which contain toxic chemical substances and heavy metals, are very often thrown directly into the natural environment without pretreatment. For instance, SOITEX (textile plant) discharges

Fig. 5. Traffic on a ring road of the TUA (photograph by F. Bensaoula, 2013).

255 m^3/d of wastewater directly in Sikkak River (Fig. 6) [13,14]. Indeed, not all the industrial plants in the region are equipped with individual pretreatment systems. The few units equipped with pretreatment systems record frequent failures and then, reject their wastewaters directly into natural watercourses.

4.2.6. Quarries

The territory of the TUA contains several quarries for the production of aggregates. They generate large amounts of waste oil from mechanical devices, operating at these quarries. More than 5,400 L of waste oil are manipulated each year by various engines of the quarries located within the TUA [14]. In addition, when quarries are deserted, they are often transformed to illegal dumping sites, to throw all kinds of products and become a dangerous source of pollution (like for instance the old quarry of Ain el Houtz, Fig. 7). Other abandoned quarries are being transformed into lakes of stagnant waters which can be a real risk of pollution to the groundwater. We cite, for instance, the quarry of Oudjlida (Fig. 7) which is situated on an outcrop of

Fig. 6. Wastewater of SOITEX (photographs by H.S. Fellah, 2012).

Fig. 7. Abandoned quarries of Ain El Hout (left) and Oujlida (right) (photographs by M. Adjim, 2013).

limestone karst area and hence can be favorable for the infiltration of stagnant waters which are often a mixture of storm waters and wastewaters.

4.2.7. Agricultural activities

Although the practice of irrigation with wastewater is prohibited by law, it is still fraudulently practiced in our study area. During the year 2012, more than 47 ha were irrigated with such non-conventional waters [15]. In addition to this dangerous source of pollution, it is worth mentioning the excessive and uncontrolled use of pesticides, chemical, and organic fertilizers. We also mention the practice of sheep, cattle, and poultry farming in the municipality of Beni Mester, which is of an agricultural vocation. However, the information in the exact locations of the breeding areas on this region was not available, and we took into consideration in our study, only the wastes resulting from this activity and which are evacuated to the dumping of Sidi Abderahmane. Thus, the production of large amounts of nitrogenous waste resulting from this activity should be managed with great care.

Finally, all researches, surveys, and site visits carried out during this work allowed us to obtain the map given in Fig. 8, which shows the hazards relevant to the TUA. This map shows all hazards in the studied area in red color, independent of their degrees of harmfulness. The symbols used in Fig. 8 are given in white and black in Fig. 9.

The unclassified hazards given in Fig. 8 are then classified according to suggestions given in the COST Action 620 report [12]. For this purpose, we have used the software "Data Collection Sheet for Inventory of Hazards" developed by Civita and Sappa [11]. The degree of harmfulness of each hazard is described by

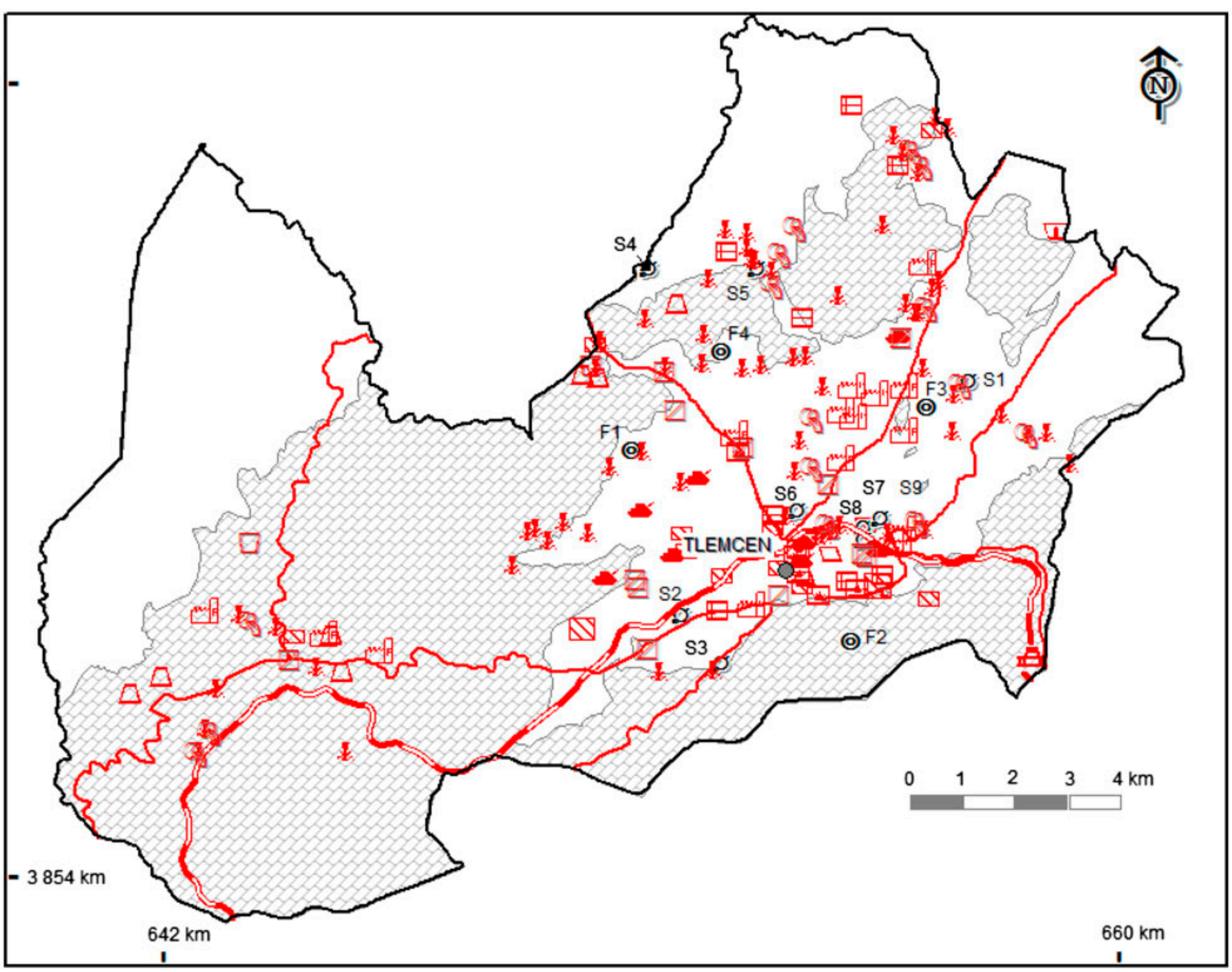

Fig. 8. Unclassified hazard map of the TUA.

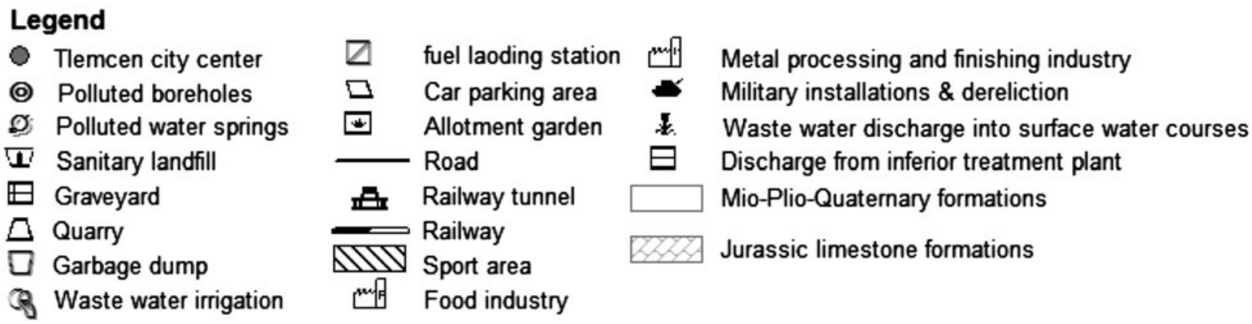

Fig. 9. Symbols representing the hazard within the TUA.

the hazard index (H_i), which is estimated by the following formula [12]:

$$H_i = H \times Q_n \times R_f$$

where H is the weighting value of each hazard which could vary from 10 to 100, depending on the toxicity as well as on the properties regarding solubility and mobility of the pollutant to be assessed. Q_n is the ranking factor which may vary between 0.8 and 1.2. This factor enables the comparison between hazards of the same type by the estimation of the relative quantity that can be released. The reduction factor (R_f) can be assigned a value between 0 and 1, depending on the likelihood of a contamination event to occur with respect to the specific hazard. This parameter takes into consideration factors like technical status or level of maintenance. Finally, the possible range of the hazard index H_i runs from 0 to 120 scores. This range is divided into five Hazard Index Classes which are assigned different colors as shown in Table 2.

The classified hazard map obtained by following the above-described procedure is given in Fig. 10. The symbols used in this map are the same as those given in Fig. 9. The hazards found in the studied area represent Hazard Index Classes ranging from very low to high hazard. There exist six industrial plants, all categorized as having a high hazard level. Areas irrigated by wastewater, fuel loading stations, and 92.4% of wastewater rejections are categorized as having a "Moderate" hazard level. The rest of the hazards are ranging from low to very low hazard level.

This map shows clearly that the pollution sources as well as the polluted boreholes and springs are spread nearly all over the study area. The bacterial contamination in the boreholes and springs may be eliminated by implementing protection perimeters. However, this is not always possible for the pollution by nitrates. Nitrate concentrations are very high in some water points and it is evident to believe that the origin of this pollution is due to both the ejection of waste waters directly into watercourses without treatment and to various agricultural activities.

Systems for treatment of wastewaters should be made mandatory in each industrial factory whether they are handling poultry and cattle slaughters or devoted to oil works. Consequently, it is necessary to manage efficiently the release of wastewaters in the natural environment by the realization of new treatment plants equipped with adequate channels to ensure the safe transport of these waters and their reuse in other appropriate fields such as in agriculture.

In regions of high hydraulic conductivity, the roads network of the studied area may present a potential risk of pollution in the event of accidental discharges of petrochemical products transported by tankers.

We have also inventoried the existence of a hydrocarbon depot in an urban area in the vicinity of agricultural fields where the groundwater is very close to the soil surface. Hydrocarbon leaks in such places would present a serious risk of pollution of the groundwater. In general, petrol stations may have a significant impact of pollution for the groundwater resources. Therefore, inspecting regularly all the hydrocarbons tanks would help prevent leakage threats or any other accident within these stations.

Table 2
Hazard index and hazard index classes [12]

Hazard index	Hazard index class	Hazard level	Color
0–24	1	No or very low	Blue
>24–48	2	Low	Green
>48–72	3	Moderate	Yellow
>72–96	4	High	Orange
>96–120	5	Very high	Red

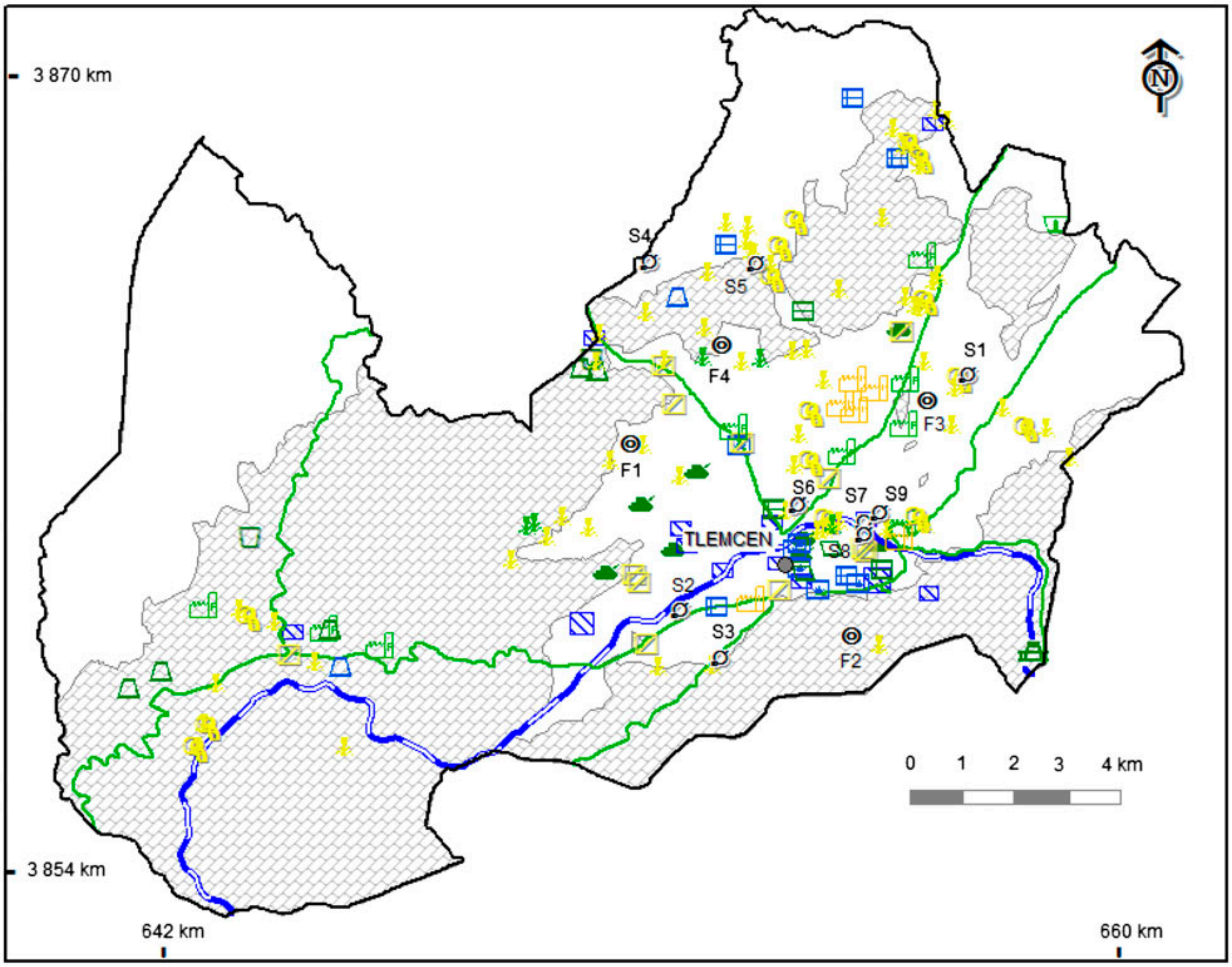

Fig. 10. Classified hazard map of the TUA.

The quarry and the dumpsite of Koudia are implanted in a karstic zone where the groundwater table is close to the soil surface. So, it is necessary to take adequate measures to eradicate all wastes in the actual site of this dump and move it to a place which presents less risks of groundwater pollution. Also, quarrying must be carried out according to standards in order to minimize the risks of polluting the groundwater of this region. Moreover, we recommend the protection of the unused (since 2007) quarry of Oudjlida, which is located in a karstic zone near a dense agglomeration in order to eliminate the risk of it being transformed into a wild dumping site.

5. Conclusion

Unclassified and classified hazards within the urban area of Tlemcen were mapped for the first time on topographic maps at scale 1:25,000. This work has allowed us to clearly notice that TUA counts many infrastructures development, industrial and agricultural activities. Each of these activities can constitute risks of pollution of the groundwater with different impacts and implications. Prevailing pollution sources of the karst groundwater come from the wastewater discharges without treatment, the irrigations with wastewater, and the use of chemical and organic fertilizers. Other sources of pollution are found in the vicinity of some settlements with illegal dumps. They may influence the quality of groundwater by bacterial and chemical contaminations. Traffic that is crossing the recharge area is a serious potential source of accidental contamination. Industrial effluents, particularly in the cases, where wastewater collection and drainage systems are not efficient may affect seriously the quality of the groundwater.

The conditions for groundwater protection are not very favorable over the urban area of Tlemcen which is densely inhabited and threatened by diverse types of hazards. Also, the actually existing groundwater pollution monitoring points are very scarce and may not reflect the real impact of the various polluters inventoried all over the studied region. The classified hazard map realized in this work may fairly help for the protection of the karst groundwater. Hence, the establishment of a risk map could be more helpful to the local authorities: it would render more efficient the protection of the vital groundwater of the region and the related operations. The establishment of such a map is the aim of further work.

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