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Pollution and health risk assessment of water quality: a case study in Mohammedia prefecture in Morocco

R. El morabet [a], L. Berhazi [a], R.A. Khan [b], S. Bouhafa [a], N.A. Khan [c,*], T. Hakh [d], A. Romaniv [e]

[a] Department of Geography, LADES, FLSH-M, Hassan II University of Casablanca, Mohammedia, Morocco

[b] Department of Civil Engineering, King Khalid University, Abha, Saudi Arabia

[c] Civil Engineering Department, Jamia Millia Islamia, New Delhi-110025, India

[d] Department of Applied Ecology and Environmental Sciences, National University «Yuri Kondratyuk Poltava Polytechnic», Poltava, Ukraine

[e] Department of Civil Safety, Lviv Polytechnic National University, Lviv, Ukraine

* Corresponding e-mail address: hramcov044@gmail.com; er.nadimcivil@gmail.com

ORCID identifier: https://orcid.org/0000-0003-4366-9639 (N.A.K.); https://orcid.org/0000-0002-0173-7069 (T.H.); https://orcid.org/0000-0002-3878-1741 (A.R.)

ABSTRACT

Purpose: Water is vital for the sustenance of every life form. Urbanization, growing population and industrial development has led to exploitation of water resources globally. This study assesses quality of water resources of Mohammedia prefecture.

Design/methodology/approach: The water quality analysis was carried out based on physio-chemical and heavy metal concentrations. The physio-chemical analysis comprised of status of concentration, overall quality and water pollution index evaluation. The heavy metal evaluation consisted of Ecological Risk Index, non-carcinogenic risk and carcinogenic risk assessment.

Findings: The landfill near Ben Nfifikh River reported insignificant (WPI<1) – low level of pollution (>1≤1.5) for surface and groundwater points. However, the groundwater for Zenata region was found to pose both carcinogenic (CRt > 0.0001, range 0.4-35.31) and non-carcinogenic risks (HQ>1, range 6 -34) of higher degree rendering it unfit for human consumption. Hence, this study concludes that groundwater resources should not as water supply; instead, Oud El Maleh River can serve as surface water source for meeting requirements of Zenata region.

Research limitations/implications: The data obtained can be categorized as landfill area near river Nfifikh and landfill area near river El Maleh. Both areas have been investigated for groundwater and surface water quality assessment.

Practical implications: This study demonstrates the need to study the characteristics of groundwater (depth, flow rate, water renewal, etc.) before arranging a waste dump. This problem is especially relevant for arid countries, since residents experience a shortage of water, as well as a lack of rainfall provides a weak renewal of groundwater, which can contribute to the accumulation of a higher concentration of carcinogens in groundwater and provide a high risk to public health. If policymakers in arid countries and decision-makers have effective water quality maps, then the country can be more efficiently managed water resources without risking the population.

Originality/value: The current study is planned as a multi-stage, each of which is supposed to conduct field studies of groundwater and surface water quality with appropriate parameters, analysis of institutional reports and related scientific studies in order to create an effective water quality map for rational water use.

Keywords: Water quality assessment, Water pollution index, Ecological risk, Non-carcinogenic risk, Carcinogenic risk

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INDUSTRIAL MANAGEMENT AND ORGANISATION

1. Introduction

Water is vital for any life form. Access to safe drinking water is a basic human right [1,2]. Also, in modern times it is crucial for social and economic development [3,4]. Number of research works has reported deteriorating effect on human health and environment owing to water contamination [5-8]. Water quality is affected by various factors originating from natural and anthropogenic activities [9-11].

Hence, it is necessary to collect water quality information from time to time; in order to develop policy and measures to meet future demands. This has led to numerous researches on water quality assessment for various regions and countries across the globe [12-16]. In the prefecture of Mohammedia, Morocco, several studies have been carried to assess water quality and their possible contamination sources for developing plans for sustainable management of water resources [17-20].

Numerous studies prove the negative impact of landfills on surface water quality [21-23]. Study authors [19] conducted hydro-geological and hydro-geochemical study of groundwater near the controlled landfill in Mohammedia prefecture, and in [18] analysed wastewater discharge into surface water bodies and its quality deterioration in terms of physio-chemical parameters. In 2015 Taleb et al. [24] studied Hydrogen sulphide concentration in sewer network of Mohammedia and also reported variation in wastewater characteristics leading to nuisance for residents, users, and respective flora and fauna. Laaouan et al. in [25] reported groundwater contamination from leachate resulting from a closed landfill and reported organic matter presence originating from agro-food industries. In addition, the company responsible for landfill management of Beni Yakhlef landfill also conducts regular checks with sampling points as 1. Raw leachate at the landfill basin; 2. Leachate treated at landfill 3. Three boreholes near to landfill 4. Upstream of Nfifikh River 5 downstream of Nfifikh River. However, these studies and field data do not present an overall scenario of groundwater and surface water qualities of Mohammedia prefecture but are limited to subdivisions within. Additionally, even though there are various studies but the evaluation parameters are of varying degree with some studies reporting only physio-chemical parameters, other extending to bacteriological contamination even lesser studies reported for heavy metal contamination [26-29].

Because of their biodiversity, estuaries have grown in significance and drawn interest to biologists, administers and environmentalists [30-32]. As an area of intensive activity between land and sea, estuaries sensibly adapt to natural processes and anthropogenic activities [33,34]. Metals may experience various physicochemical reactions, such as adsorption, desorption, dissolution and precipitation in aquatic systems that are affected by prevailing sediment redox conditions [35-37]. Metals are transported into water or as an essential part of suspended substances by dissolved organisms [38-41]. They may be in the environment volatilized or deposited in fluvial sediments [42,43]. They may be in solution or suspension, precipitate, create or absorb species. Contamination by heavy metals in soil can impair the water quality of aquatic ecosystems and thus biologic assimilation and bioaccumulation of metals, with long-term consequences for human and ecological health [44-46]. For the estimation of heavy metal emissions in aquatic ecosystems, a detailed knowledge of the depositional features of surface soil and contaminants is crucial [47]. The Sebou River is the biggest Moroccan river on the Atlantic coast. Some of the experiments also shown that heavy metals are distributed in river sediments. Metals are not well known to be associated with Surface River Sediments in Sebou Estuary as the experiments are limited [48-51]. If the effect of surface soil properties on the level of metals has been recognised, any possible metal exposure caused by anthropic activity can be traced quickly and can assist in forensic environmental research [52]. To understand the release and use of heavy metals, the awareness of the impact of sediment grain dimensions on metal concentration is required. The habitats play an important role in transportation from rivers to seas of both dissolved and suspended particles [53]. Heavy metals are one in the main ingredients of anthropogenic practices such as industrial wastewater treatment facilities, the processing industry and farming activities of the diverse products carried into estuaries [54]. The number of metals that may have harmful effects on the aquatic environment will raise significant inputs [55]. Owing to their toxicity, various origins, non-biodegradable type, longevity, bioaccumulation and bio amplification properties, heavy metals are of great environmental concern. Estuarine sediments are a pivotal field for science and also one of the last ponds for heavy metals. The structure of sediment significantly affects the collection and release of metals, which relies in part on the type and quantity of content released from a waterfront.

Along with the above gap another fact that Mohammedia prefecture is going to develop a new city named as Zenata will only add to the water demand. This will lead to additional wastewater and solid waste disposal burden. Hence, it is necessary to assess the water quality for whole of Mohammedia Prefecture. Therefore, the objectives of this study are:

1. Overall quality assessment of surface and groundwater resources;
2. Physio-chemical based water pollution assessment;
3. Ecological risk, carcinogenic risk and non-carcinogenic risk assessment for heavy metals contamination.

2. Data and methods used

2.1. Study area

The prefecture of Mohammedia is situated on west coast of Morocco at latitude 33.6751ºN and longitude 7.4057ºW.

Mohammedia prefecture is of significance importance as it is host to Port which led to development of Mohammedia city overtime. Also, a new proposed city of Zenata near to Mohammedia city further increases its importance in the Region. Actively developing industrial activity in cities contributes to significant climatological and meteorological problems [56], providing a threat to environmental safety, including water quality. In the industrial zones of Mohammedia, there is a significant emission of pollutants into the atmosphere, which contributes to global warming [57,58], and, consequently, climate change, which in the future will provide serious changes in water resources. Mohammedia industrial zone has the highest intensity of surface urban heat island [59], especially in refineries. Thus, the study of the problems of this region can be useful for solving similar problems in other regions of the world.

Currently it experiences hot-summer Mediterranean climate. The November-April experiences mild and rainy climate with average temperature range 17ºC-8ºC. While the period May-October experiences hot-dry climate with average temperature 15ºC-26ºC. Study area experiences High rainfall during months of November to January in range of 64-77 mm. Least rainfall is experienced during the months of June to September in range of 1-6 mm on average.

2.2. Data collection

The data for this was obtained from institutional reports, and field surveys. The data was also verified against the published research works. [18,20,23,60]. The sample points covered in this study are in Figure 1. The points covered are divided into four categories viz. groundwater, surface water, and wastewater and landfill leachate/wastewater locations. A total of forty-nine points are covered in this study comprising of all four categories. In this study term “point” and “sample” are interchangeable as deemed to fit the use of language for better understanding. The data obtained can be categorized as landfill area near river Nfifikh and landfill area near river El Maleh. Both areas have been investigated for groundwater and surface water quality assessment.

2.3. Water resources

The water resources in Mohammedia can be categorized primarily into groundwater sources and surface water sources. The surface water sources primarily consist of two rivers viz. Oud El Maleh running across the middle of the prefecture. While Oued Nfifikh running along the western border of the prefecture. Oued El Maleh receives annual inflow of around 68.8 million m^3 [17]. Nfifikh River drains watershed of an area of 830 km^2, with a flow of 550L/s. The geological constitution of impermeable and very thick primary formations renders the prefecture hydrologically poor in water resources. The main groundwater table “lower Chaouia” is located between Casablanca and Mohammedia. Additionally, there is hydrological basin on the west formed by El Maleh River and on east by Nfifikh River preventing any lateral feeding. In north and south impermeable deposits of natural basins prevents marine influence. The uneven distribution of groundwater can again be validated with difference between piezometric levels of groundwater table.

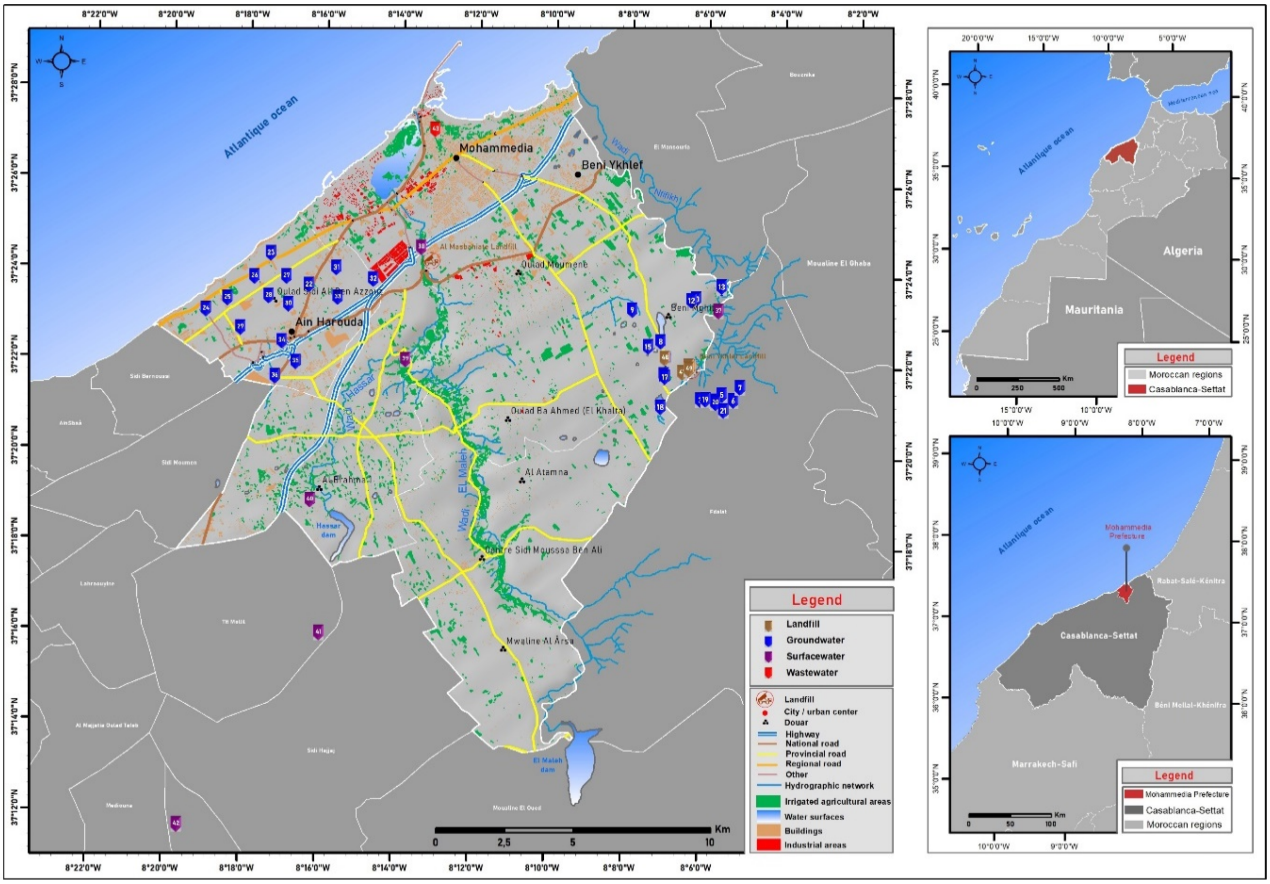


Fig. 1. Map of study area showing the location details of each sample location

2.4. Instrumental analysis

The parameters analysed were pH, TDS (total dissolved solids), EC (electrical conductivity), NO_3 (nitrate), NO_2 (nitrite), PO^{3-}_4 (Phosphate), TKN (Total Kjeldahl nitrogen), K^+ (Potassium), Na^+ (sodium) and Ca^{2+}(calcium). Hanna H198129 pH/EC tester. Was used to test water sample on site for pH, TDS and EC. Spectrophotometer was used to measure NO_3, NO_2, NH^+, TP, PO^{3-}_4 and TKN. K^+, Ca^{2+}, and Na^+ were analysed in water samples using flame spectrophotometer. Heavy metals Fe, CU, Cd, Pb and Fe were analysed by employing UNICAM 929 AA solar atomic absorption spectrophotometer.

2.5. Water quality assessment

Water quality in this study was assessed with respect to drinking water quality standards. Pollution index of groundwater (PIG) has been used in various literatures for water quality assessment [1]. However, since this study covers both groundwater and surface water, it is termed as water pollution index (WPI). Water pollution index was calculated in five steps. Relative weight (Rw) is defined for each water quality parameter in concern on a scale of 1-5. The Rw was defined based on their impact on human health, significance in water quality assessment and literature as given in Table 1 [1, 61-63].

In second step weight parameter (Wp) was estimated for each parameter (Eq. 1). Wp aids in assessing relevant contribution of each water quality parameter in overall water quality of groundwater and surface water. Third step involves estimation of status of contamination (Sc) by dividing the concentration (C) of each water quality parameter by their existing water quality standards (S) Eq. 2. The standards used in this study are International Organization for Standardization (ISO) and World Health Organization (WHO). The fourth step comprises of calculating Overall quality of water (Ow); obtained by multiplying Wp by Sc (Eq. 3). Relative weight was obtained by dividing a unit weight by the standard permissible limit

Table 1.
Parameters used in Water Pollution Index (WPI) assessment

Parameter	Unit	Relative weight (Rw)	Standard Limits
pH	--	3	7
Ca^{2+}	mg/L	2	75
Mg^{2+}	mg/L	2	50
Na^{+}	mg/L	4	200
K^{+}	mg/L	1	12
HCO^{3-}	mg/L	3	250
Cl^{-}	mg/L	4	250
SO_4^{2-}	mg/L	5	250
NO^{3-}	mg/L	5	50
NO^{2-}	mg/L	5	5
PO^{3-}	mg/L	5	50
NH^{4+}	mg/L	4	50

of the constituent in drinking water. Once relative weight Rw was obtained weighted parameter was obtained by dividing individual relative weight by summation of all relative weights of parameter under consideration for evaluating drinking water quality. The final step involves deriving WPI which is obtained by summation of all Ow values for each parameter. WPI presents influence of all analysed variables for each water sample; and can depict various scenarios of contamination of water samples [1,61].

$$\text{Wp} = \frac{R_W}{\Sigma R_W} \quad (1)$$

$$\text{Sc} = \frac{C}{S} \quad (2)$$

$$\text{Ow} = \text{Sc x Wp} \quad (3)$$

$$\text{WPI} = \Sigma\text{Ow} \quad (4)$$

2.6. Ecological Risk Index (ERI)

ERI quantifies the risk of toxic effect on biological species from trace elements. ERI is the total risk of trace element on biological species. It is calculated as summation of risk index (RI) [1] or ecological risk (Er) [57]. PI or Er is calculated is calculated by multiplying Contamination Factor (CF) [1] or Status of contamination (Sc) [61] by toxic response factor (Tr). ERI for each sample investigated for trace elements was obtained using Eq. 5. The toxic response factor values of 1,5,5,1,30,5,1,40 and 1 were adopted for Al, Cu, Pb, Cr, Cd, Ni, Zn, Hg, and Fe respectively.

$$\text{ERI} = \Sigma\text{RI} = \Sigma(\text{Tr x PI}) \quad (5)$$

2.7. Non-carcinogenic risk

Contaminants enter human body through exposure pathways. Hence exposure pathways are vital for health risk assessment. Exposure pathways are of two kinds; first active intake (ingestion or inhalation); second passive intake i.e. dermal contact. The human body receives contaminants either through consumption of water (active intake) or/both bathing and swimming activities (passive intake). Reference dose (RfD) is required for calculating non-carcinogenic risk assessment for local population. RfD values are established jointly by World Health Organization, Food and Agriculture Organization, Environmental Protection Agency United States and Expert Food committee [1,61,64]. ADD (Annual Daily Dose) and HQ (Hazard Quotient) defined as ratio of ADD and RfD was calculated for oral pathway. Hazard Index (HI) was obtained as summation of all HQ for each contaminant. HI assess total potential non-carcinogenic risk due to exposure to any pathway. USEPA (2002) has provided guidelines and theoretical equations also followed by other studies [61-63, 65] for calculating non-carcinogenic risk following equations (Eq. 6-8).

$$\text{ADD} = \frac{C\ x\ IR\ x\ EF\ X\ ED}{BW\ x\ AT} \quad (6)$$

$$\text{HQ} = \frac{ADD}{RfD} \quad (7)$$

$$\text{HI} = \sum_{i=1}^{i=n} HQI \quad (8)$$

where, ADD is average daily dose through ingestion, C is concentration in water (µg/l); EF is frequency (day/year); IR is ingestion rate of water; ED is duration (year); BW is body weight and AT is average time (day).

2.8. Carcinogenic risk

Exposure to pollutants renders an individual susceptible to develop cancer over lifetime. This incremental probability of developing cancer is termed as carcinogenic risk. Each metal has varying values of CSF and it also varies for each exposure pathway [63]. CR was calculated by multiplying ADD with cancer slope factor (CSF) Eq. 9.

$$\text{CR} = \text{ADD x CSF} \quad (9)$$

When several carcinogenic elements are considered, the CR is the summation of all cancer risks. As per International Agency for Research on Cancer (IAR); Al, Cr, Cd, Ni, Fe and Zn were treated as potential carcinogenic contaminants, while Pb and Hg were regarded as non-carcinogenic elements. The RFD, and CSF values were obtained as in accordance with US EPA and IAR [64,66].

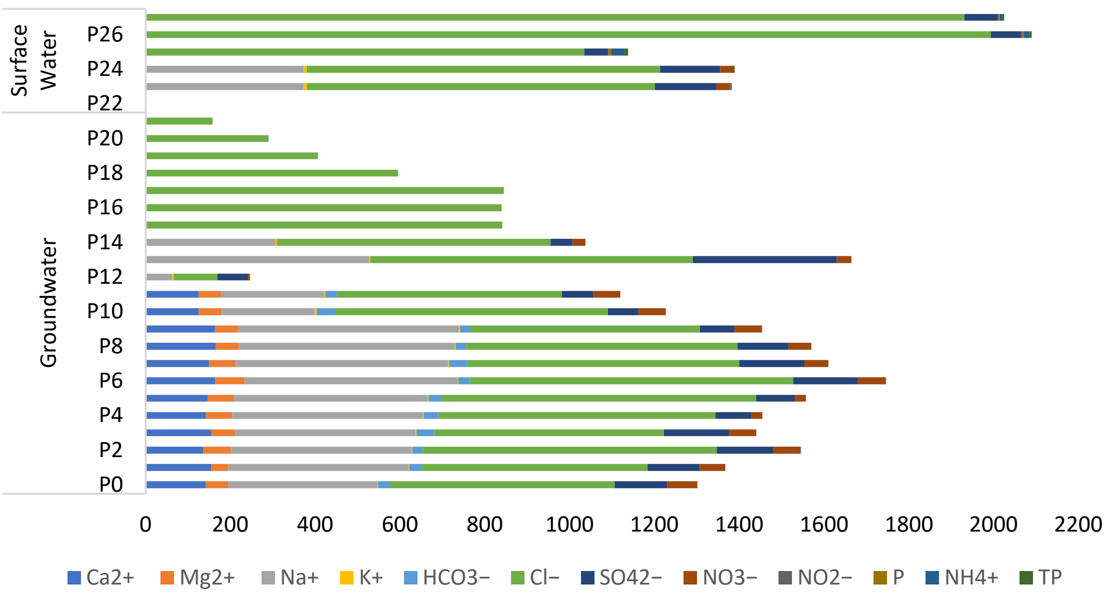


Fig. 2. Distribution of ion concentration in groundwater and surface water

3. Results and discussion

3.1. Hydrogeochemistry

Groundwater chemical composition if primarily affected by hydro-geological settings, rate of weathering (rock and mineral), redox reactions, climatic conditions and anthropogenic activities. The groundwater and surface water quality (physio-chemical parameters) are presented in this study from various institutional reports, studies and field reports. Physio-chemical parameters were available for groundwater samples (P0-P22) for surface water point (P35-P40). The pH in groundwater for all samples is above 7 making it alkaline in nature and within the standard range of 6.5-8.5 as per Moroccan drinking water Standards. For surface water pH at P25 (point 38) was 6.47 slightly lower than acceptable standard. In central Morocco pH in range of 6.8-9.2 was reported for groundwater [67], pH in range of 6.59-7.87 was reported for groundwater of northern Morocco [68]. Hence the Ph range in this study is in lieu with previous study with ranging from slightly acidic to basic pH values.

Major ion distribution in groundwater sample is presented in Figure 2. In groundwater anion concentration was in order of Na^+>Ca^{2+}>Mg^{2+} and anion order was Cl^->SO_4^{2-}>NO_3^->HCO_3^->NO_2^-. In anionic concentration Na^+, Ca^{2+}, and Mg^{2+} all exceeded the permissible limits for safe drinking water. K^+ was under safe drinking water concentrations for all groundwater water samples. The Cl^- concentration in groundwater sample exceeded safe drinking limits by at least two times on average. NO_3^- concentration was also higher than standards in majority of samples. NO_2^-, HCO_3^- and SO_4^{2-} were well within the permissible limits with SO_4^{2-} only exceeding the limits at P13.

Ion concentration for each sampling point is presented in Table 2.

Continental and aquatic conditions affect the estuarine and coastal climate. Estuarine sediments generally consist of salts, metals and organic waste that can differ across a longitudinal or vertical profile. Changes in scale of the individual sediment forms are directly linked to trends of water movement (tidal and wave energy regimes).

Over the course of the survey, sand was between 1.94 and 40.75%; sludge and clay were between 19.71% and 63.58%, and between 8.34% and 43% to 2.87%, with a silt and clay difference. The mouth and middle estuarine were found with the sand accumulation, while the domination at the other sites was fine-grained fractions (silty-clay). Intensive hydro-dynamic actions from waves and the dominant mare currents influence the structure and distribution of the grain in the estuary. The diffusion of grain size and organic carbon content were identified in related studies as two critical factors affecting metal distribution in sediments, and the distribution of grain size may lead to metal enrichment. The condensed humic compounds make up coats and complexes, while the organic material constructs algae flocks and tiny parts of decaying plant material in the greater fractions. The action of sorption can vary by origin and organic material composition.

Table 2.
Chemical ion concentration (mg/L) in groundwater and surface water (OP= Orthophosphate, TP = Total Phosphate, NR = Not Reported)

	Points	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	NO_2^{-}	OP	NH4+	TP	pH
Groundwater	P0	142.0	52.0	352.0	2.5	26.0	532.0	124.0	71.0	0.01	NR	NR	NR	7.3
	P1	154.0	41.0	425.0	2.1	30.0	532.0	123.0	60.0	0.01	NR	NR	NR	7.1
	P2	136.0	65.5	426.0	1.8	24.0	694.0	134.0	64.0	0.07	NR	NR	NR	7.5
	P3	154.0	58.0	425.0	2.4	41.0	542.0	154.0	64.0	0.01	NR	NR	NR	7.3
	P4	142.0	62.4	450.0	2.0	34.0	654.0	84.0	26.0	0.02	NR	NR	NR	7.6
	P5	146.0	62.4	457.0	2.5	30.0	742.0	92.2	25.1	0.02	NR	NR	NR	7.2
	P6	164.0	70.0	502.0	2.1	26.0	764.0	152.0	66.0	0.08	NR	NR	NR	7.6
	P7	150.0	61.0	503.0	2.1	42.0	642.0	154.0	56.0	0.01	NR	NR	NR	7.6
	P8	165.0	54.0	510.0	2.2	25.0	640.0	120.0	54.0	0.01	NR	NR	NR	7.3
	P9	164.0	54.0	520.0	3.5	24.0	542.0	82.0	64.0	0.01	NR	NR	NR	7.5
	P10	125.0	54.0	220.0	4.4	45.0	642.0	72.0	64.2	0.01	NR	NR	NR	7.4
	P11	125.0	53.0	243.0	3.0	28.0	530.0	74.0	63.1	0.01	NR	NR	NR	7.4
	P12	NR	NR	62.6	3.5	NR	103.0	73.0	3.9	0.01	NR	NR	NR	7.6
	P13	NR	NR	527.0	3.7	NR	760.0	340.0	34.1	0.04	NR	NR	NR	7.8
	P14	NR	NR	307.1	2.6	NR	646.0	51.0	30.0	0.02	NR	NR	NR	7.7
	P15	NR	NR	NR	NR	NR	841.4	NR	NR	NR	NR	NR	NR	8.1
	P16	NR	NR	NR	NR	NR	840.0	NR	NR	NR	NR	NR	NR	7.3
	P17	NR	NR	NR	NR	NR	845.6	NR	NR	NR	NR	NR	NR	7.3
	P18	NR	NR	NR	NR	NR	595.0	NR	NR	NR	NR	NR	NR	7.2
	P19	NR	NR	NR	NR	NR	406.7	NR	NR	NR	NR	NR	NR	8.3
	P20	NR	NR	NR	NR	NR	290.5	NR	NR	NR	NR	NR	NR	8.0
	P21	NR	NR	NR	NR	NR	158.2	NR	NR	NR	NR	NR	NR	8.0
Surface Water	P22	NR	NR	NR	NR	NR	BDL	NR	NR	NR	NR	NR	NR	7.2
	P23	NR	NR	372.4	7.9	NR	821.0	145.0	31.5	3.3	NR	NR	1.5	7.7
	P24	NR	NR	372.2	7.6	NR	834.0	142.0	32.1	0.06	NR	NR	1.5	7.7
	P25	NR	NR	NR	NR	NR	1034.7	56.5	1.8	0.0	5.1	31.8	8.5	6.4
	P26	NR	NR	NR	NR	NR	1994.0	71.1	4.0	0.0	2.8	14.1	4.5	7.4
	P27	NR	NR	NR	NR	NR	1932.0	77.2	3.3	0.0	1.9	7.7	2.8	7.6

The ionic concentration of surface water orthophosphate, total phosphate and ammonia concentration were obtained in place of Ca^{2+}, Mg^{2+} and HCO_3^{-}. The dominance order of anions in surface water was Na^{2+}>NH_4^{+}. K^{+}>TP>PO_4^{3-}. While cation dominance was of order Cl^{-}>SO_4^{2-}>NO_3^{-}>NO_2^{-}. The exceeding of Cl^{-} concentration in surface water bodies was 3-4 times more than acceptable drinking water standards. Total Phosphate concentration exceeded 1 mg/L concentration for all samples. All other ionic concentrations were below permissible limits except of P35 for NO_2^{-} concentration.

The ion concentration in wastewater and landfill sources was not investigated similarly to groundwater and surface water. However, primarily SO_4^{2-} was investigated for wastewater and while other ions were non-existent. For landfill on the other hand Cl^{-}, NO_3^{-}, NH_4^{+}, K^{+}, total Kjeldahl nitrogen, and total phosphate were investigated. Chloride concentration in landfill leachate dominated over other ionic concentration. Also, ion distribution in wastewater and landfill leachate is not of significant importance as compared to its significance in terms or organic loading. Hence, little investigation of ion distribution is reported in literature and institutional reports.

3.2. Physical and organic parameter distribution

Physical and organic matter concentration in surface and groundwater is presented in Figure 2. Temperature for all groundwater and surface water were below acceptable limit of 30ºC. Water in its pure form is not a good conductor of electricity. Electrical conductivity (EC) of water increases owing to increase in ions concentration. As per WHO standards conductivity should not exceed 400 µs/cm. In general, number of dissolved solids in water determines EC. Except for P15-P21 all other samples of groundwater and surface exceeded the limit by 4 -10 times (1500-4000 µs/cm). However, TDS being a parameter to determine EC did not hold for Mohammedia prefecture as the three surface samples tested for TDS reported 1.73, 2.38 and 2.36 mg/L of concentration as opposite to 3223 µs/cm, 4427 µs/cm and 4369 µs/cm of EC for points P25, P26 and P27.

The presence of organic matter in groundwater is indicator groundwater pollution as it will lead to consumption of oxygen present in groundwater. Thereby deteriorating the groundwater quality. Few institutional reports and literature studies have covered SS, BOD_5, and COD for groundwater. However, groundwater (P12-P21) and surface water (P35-40) were reported for the presence of organic matter. BOD_5 was well under permissible limits in both underground and surface water. However, COD concentration not expected but exceeded permissible limits of 25 mg/L in groundwater and surface water at majority of points. Even though BOD_5 and COD did not exceed permissible limits at many points but their presence itself is an indication of pollution of groundwater (Fig. 3). As per Moroccan standard DO should be 7 mg/L for potable water. All groundwater and surface water samples were reported for DO concentration in range of 6.1-8.3 mg/L. Suspended solids concentration was reported for only three each point for groundwater sample between 2-11 mg/L and 7.2-8.3 mg/L. Organic matter and solids distribution in Groundwater and surface water is presented in Figure 4 and physical and organic matter concentration for all sample point is presented in Table 3.

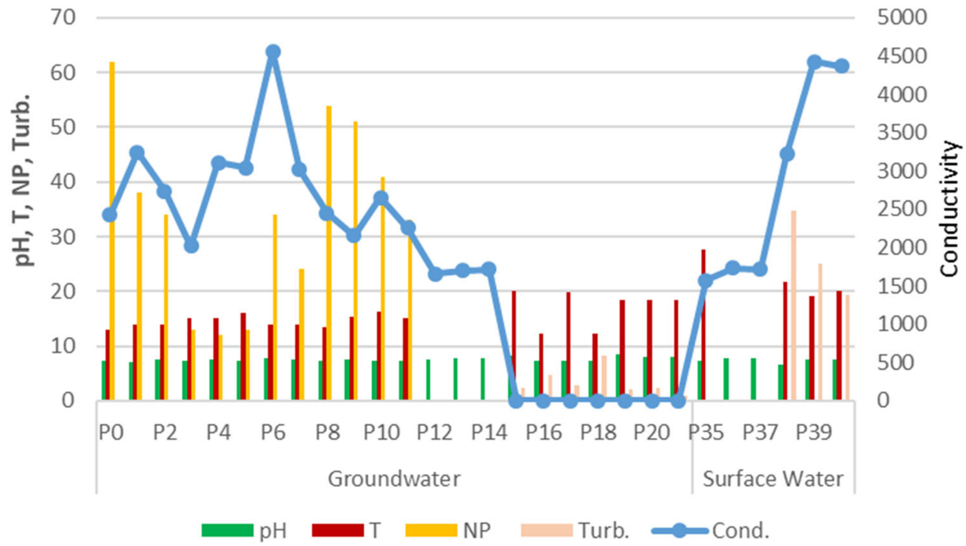


Fig. 3. Physical parameters distribution in groundwater and surface water (T = temperature, NP = peizometric level, Turb. = Turbidity)

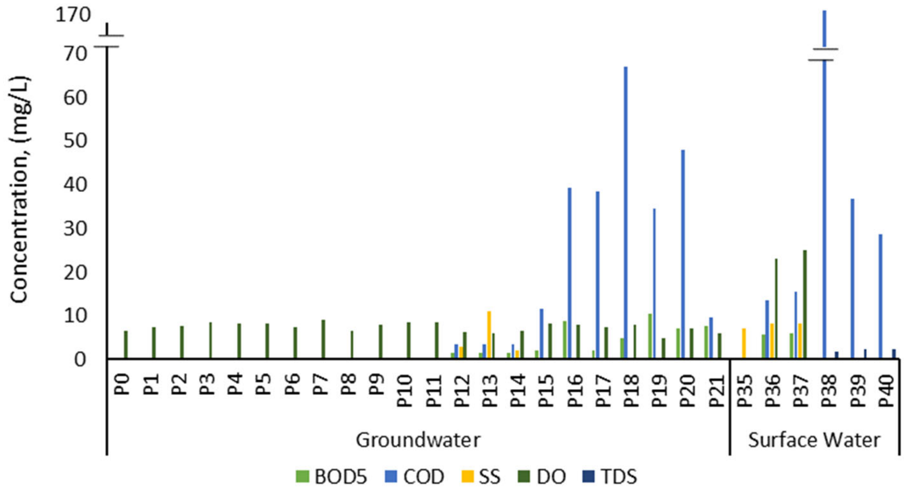


Fig. 4. Organic matter and solids distribution in groundwater and surface water

Table 3.
Physical and Organic matter concentration in groundwater and Surface water (EC = Electric Conductivity, T= Temperature, PN = Piezometric Level, Turb = Turbidity, BOD_5 = Biological Oxygen Demand, COD = Chemical Oxygen Demand, SS = Suspended Solids, DO = Dissolved Oxygen, TDS = Total Dissolved Solids)

	Sample	EC	TºC	NP	Turb	BOD5	COD	SS	DO	TDS
Groundwater	P0	2430	13.0	62.0	NR	NR	NR	NR	6.6	NR
	P1	3245	14.0	38.0	NR	NR	NR	NR	7.4	NR
	P2	2741	14.0	34.0	NR	NR	NR	NR	7.8	NR
	P3	2024	15.0	13.0	NR	NR	NR	NR	8.4	NR
	P4	3112	15.0	12.0	NR	NR	NR	NR	8.1	NR
	P5	3045	16.0	13.0	NR	NR	NR	NR	8.3	NR
	P6	4562	14.0	34.0	NR	NR	NR	NR	7.4	NR
	P7	3014	14.0	24.0	NR	NR	NR	NR	9.0	NR
	P8	2450	13.4	54.0	NR	NR	NR	NR	6.5	NR
	P9	2157	15.4	51.0	NR	NR	NR	NR	8.0	NR
	P10	2653	16.2	41.0	NR	NR	NR	NR	8.5	NR
	P11	2254	15.0	33.0	NR	NR	NR	NR	8.5	NR
	P12	1658	NR	NR	NR	1.4	3.6	3.0	6.3	NR
	P13	1700	NR	NR	NR	1.4	3.6	11.0	6.1	NR
	P14	1716	NR	NR	NR	1.6	3.6	2.0	6.5	NR
	P15	2.5	20.0	NR	2.4	2.1	11.5	NR	8.2	NR
	P16	1.9	12.3	NR	4.7	8.7	39.4	NR	7.8	NR
	P17	2.6	19.8	NR	2.8	2.1	38.4	NR	7.4	NR
	P18	1.9	12.3	NR	8.2	4.9	67.2	NR	7.9	NR
	P19	1.8	18.5	NR	2.1	10.4	34.5	NR	4.8	NR
	P20	1.2	18.3	NR	2.2	7.1	48.0	NR	6.9	NR
	P21	0.8	18.3	NR	0.8	7.6	9.60	NR	6.1	NR
Surface Water	P22	1575.0	27.6	NR	NR	NR	NR	7.2	7.2	NR
	P23	1732.0	NR	NR	NR	5.7	13.6	8.1	8.1	NR
	P24	1715.0	NR	NR	NR	6.0	15.6	8.3	8.3	NR
	P25	3223.3	21.7	NR	34.6	NR	168.0	NR	NR	1.7
	P26	4427.7	19.1	NR	24.9	NR	36.8	NR	NR	2.3
	P27	4369.1	20.1	NR	19.3	NR	28.8	NR	NR	2.3
Wastewater	P28	3.9	NR	NR	705.0	NR	5.5	2600.0	NR	NR
	P29	15.5	NR	NR	1150.0	125.0	4.6	1600.0	NR	NR
	P30	19.8	NR	NR	3100.0	100.0	5.5	1600.0	NR	NR
	P31	13.5	NR	NR	3750.0	100.0	27.6	9400.0	NR	NR
	P32	17.5	NR	NR	3800.0	850.0	11.9	1500.0	NR	NR
	P33	9.4	NR	NR	2450.0	750.0	11.9	500.0	NR	NR
	P34	6.0	NR	NR	1150.0	200.0	5.5	200.0	NR	NR
Leachate	P35	43700.0	27.0	NR	NR	742510.0	111840.0	342.0	NR	NR
	P36	27600.0	26.2	NR	NR	189510.0	31968.0	13.1	NR	NR
	P37	1575.0	27.6	NR	NR	7.6	40	29.9	7.2	NR
	P38	2170.0	50.5	NR	NR	NR	NR	NR	7.4	NR
	P39	2240.0	22.0	NR	NR	NR	NR	NR	8.8	NR
	P40	57300.0	NR	NR	NR	8130.0	22000.0	600	0.8	NR

3.3. Water Pollution Index (WPI)

In water pollution index assessment, contribution of each chemical variable was examined. The Ow value (Tab. 4) of 0.1 indicates 10% contribution to the value of 1 for WPI [1]. This enables to identify the influence of the parameter contamination the water sources. The overall chemical quality of water is presented in Table 1. The values of 0 in the table present the parameters of negligible influence since the values were more than two decimal places. In terms of chemical quality of water, HCO_3, K, Mg, NO_2 and SO_4 were well below 0.1 and hence were not parameters of any influence. Chloride was determined as most influencing parameters in both groundwater and surface water. The other influencing parameters were Na, NO_3 and pH in groundwater and Na and No_3 in surface water. Indicating they have high impact in pollution of groundwater and surface water.

Table 4.
The Overall quality (Ow) of water samples (groundwater and surface water)

Overall quality	Ground water	Surface water
Ow (Ca)	0.000-0.18	0.00
Ow (Cl)	0.08-0.44	0.00-0.43
Ow (HCO_3)	0.00-0.01	0.00
Ow (K)	0.00-0.01	0.00-0.01
Ow (Mg)	0.00-0.07	0.00
Ow (Na)	0.02-0.25	0.00-0.14
Ow (NO_2)	0.00	0.00-0.06
Ow (NO_3)	0.00-0.16	0.00-4.46
Ow (pH)	0.06-0.12	0.04-0.06
Ow (SO_4)	0.00-0.13	0.00-0.06

The WPI values ranged from 0.02-25.5 for both groundwater and surface water. The drinking water degree pollution is classified into five categories: WPI<1.0 (insignificant pollution); 1.0-1.5 (low pollution); 1.5-2.0 (moderate pollution); 2.0-2.5 (high pollution) and WPI> 2.5 (very high Pollution) [1,61,62]. In groundwater 38% of sample has insignificant pollution, while 62% of samples are low polluted. In surface water, except for one-point P39 all other samples were insignificantly polluted. The point P39 is also the point where wastewater from landfill meets the surface water however; this pollution is reduced to insignificant level at point P40 i.e. the pollution is reduced owing to self-cleansing capacity of wadi hassar. It again can be verified at point P38 which is before the point of wastewater meeting the surface water body and also has insignificant pollution.

Among the metals estimated, the relationship between Mn and organic carbon has been significantly positive slight importance for metal adsorption. The metal content decreased as the fraction of clay in sediments was reduced. Metals are adsorbed mostly by tiny, mostly clay particles than by grosser fractions. A rise in the metal content of the fine silt and clay fraction may be responsible for the aggregated fine inorganic waste. Comparisons with those in other estuaries with the metal concentrations in Sebou estuarine sediments.

The metal correlation coefficients. For Zn versus Mn, Mn versus Fe and Pb versus Mn, the most important similarities were found.

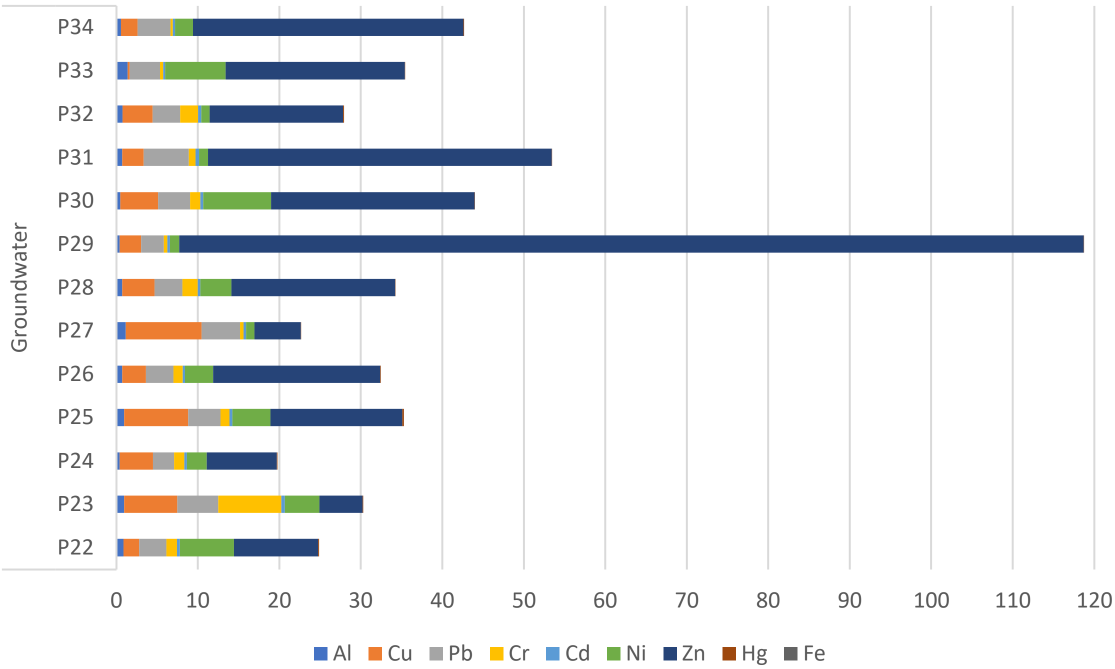
The OC and Mn, OC and sand and OC/silt and OC- and clay-strong correlation (strong associations were observed. To determine the sources of the metals, the degree of similarity between metals and other main components is also used. Previous experiments have shown that grain is an important component in the regulation of concentrations of sedimentary metals. Moderate to high positive links of the metals with silt and clay mean that the fine grain sediments are linked with organic metal and organic carbon as these elements are easier to adsorb to clay minerals. For these sediments, the joint value as a geochemical matrix is important for metal concentration. The near ties between metals show that the action of all the metals is governed by similar processes. The strong association between Fe and Mn suggests co-precipitation or sediment adsorption processes as their mechanisms of deposition and dissemination.

A moderate to high positive association between organic carbon and metals often shows its widespread aggregation in the sediment fraction. Due to its vast area, large cation exchange capability and widespread supply, the adsorption characteristics of fine grain sediments.

In the literature for various urbanised and polluted areas, even the high level of interaction between the metals were recorded (iron, manganese, plum and zinc). However, it is apparent that metal abundance is much more influenced by the source areas than the scale of organic matter or the sediment particle by the analysis of the spatial distribution of metals. The bar diagram clearly shows the changes in sand, silt, mud and metals at different sites in the estuary. The accumulation of metals in the surrounding coastal region can be attributed to lithogenic sources and existing trends. Due to mechanism of adsorption and coagulation, metals associated with silt and clay particles are usually accumulated at the boundary between freshwater and marine water regions.

3.4. Heavy metal distribution

In terms of heavy metal distribution in groundwater, data was available only for Zenata area for 13 samples (22-34) (Fig. 5). However, heavy metal concentration was reported in surface water for point 38-40. Hence ecological risk assessment, non-carcinogenic risk assessment and carcinogenic risk assessment were carried out only for these samples. The reported heavy metals are Cd, Cr, Cu, Fe and Zn. Cr, Cu, Fe and Zn in surface water were under permissible limits. Nevertheless, Cd was reported to be of concentration of 0.02 mg/L above permissible limit of 0.003 mg/L limits. Since Cr, Cu, Fe and Zn concentrations are below permissible limits at present they do not present risk health challenges. However, Cd contamination exposes consumers to adverse health risks. The Cd, sources can be linked to leachate end effluents of industrial waste. As river El Maleh is also surface water body receives wastewater discharges at various points, which also carries industrial waste.



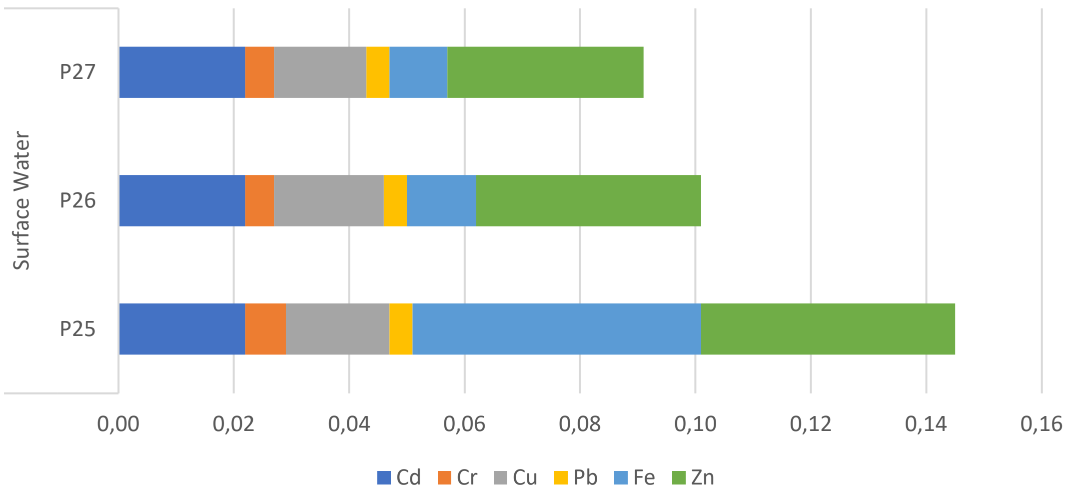


Fig. 5. Heavy metal concentration in groundwater and surface water

3.5. Ecological risk assessment

Potential ecological risk was calculated for each of the metals and water samples viz. groundwater (Point 22-34) and surface water (Point 38-40) as presented in table 5. RI classification is as follows; low potential ecological risk (RI<40), moderate potential ecological risk (40 ≤ RI < 80), considerable potential ecological risk (80 ≤ RI < 160), high potential ecological risk (160 ≤ RI < 320) and high potential risk (≥) [1]. In this study all the samples of groundwater and surface water pose low ecological risks.

Ecological Risk Index (ERI) is classified as; low ecological risk (ERI<150), moderate ecological risk (150 <ERI < 300), considerable ecological risk (300 < ERI < 600) and very high ecological risk (> 600). The ERI values for surface water ranged from 0.76-0.77 and groundwater samples ranged from 42.74 to 99.59. Hence all the samples were categorized under low ecological risk index. However, as compared to groundwater samples surface water samples are of much better quality.

In this research, the city's groundwater is polluted with many metals, and toxic waste dumping and waste disposal from the sample region are possible causes of contamination. For Pb, Cd, Ni and Cr, the estimated probability of cancer has exceeded the appropriate maximum values. Calculated for Pb and Cr, noncarcinogenic risk values suggest the high levels to health danger of human communities in the polluted groundwater area. The spatial distribution plots demonstrate the high concentrations of Pb, Ni, Cr and Cd in the groundwater samples obtained from the stations near a cement factory. Increased amounts of Cu and Mn in groundwater from stations near dumpsites. The data collected from this research can be used as a basis for future studies on the impacts on soil water quality of industrial operations and dumpsites in the study region. However, the high levels of metals in the city's groundwater are of grave concern to the health of the people in the district. Removing pollution from waste facilities and agricultural effluents requiring immediate intervention. In order to verify the extent of contamination and management of drinking water sources, continuous monitoring of groundwater quality in a research field is important in preventing health risks in this field.

3.6. Non-carcinogenic risk assessment

If value of hazard quotient; HQ < 1 then it is inferred that that there will be no adverse health effect experienced by the consumer. However, non-carcinogenic health effect will occur if HQ ≥. In surface water samples, HQ value was less than 1 for all points 38-40 (Fig. 6). Cu, Cd, Fe and Hg values of HQ for all points of groundwater and surface water were less than 1. Hence, they do not pose any non-carcinogenic risk. Pb except for one point (31) HQ was found to be 1.05 and for rest of the samples it was less than 1. For Zn, 100% (13 samples, 22-24), Ni, 69% (9 samples, 22-26, 28,30, 33, 34), Cr 69% (9 samples, 22-26, 28, 30-32) and Al, 69% (9 samples, 22, 23, 25-28, 31-33) all were found to have HQ value more than 1, hence pose non-carcinogenic risk.

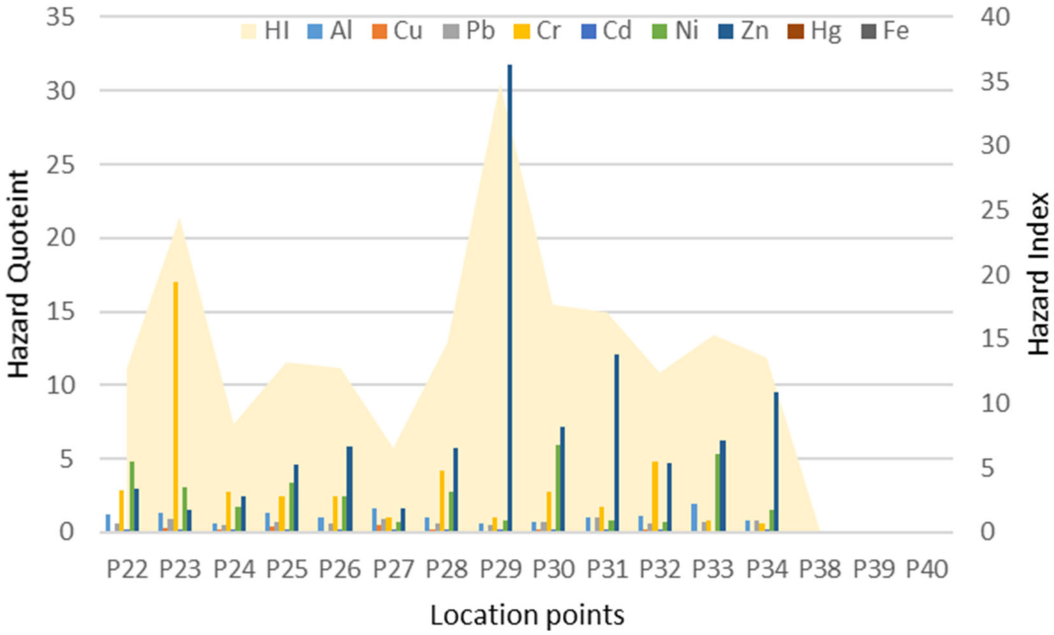


Fig. 6. Non-carcinogenic risk assessment of groundwater samples in Zenata region

The study of the interaction between metals and sediment grain size indicates a close connection between metals and fine fractions. There are comparatively low amounts of metal inside the sample region. Moreover, Igeo and CF were used to test the effects by anthropogenic heavy metal emissions. In the region under examination fine sediments ranged from unpolluted to mildly contaminated ratios compared to the studied metals, geo-accumulation indices were distinctly varied. The analysis thus shows that the Sebou estuary is not contaminated by anthropogenic activities and any variation in the metal content represents and can be detected in future on the part of human pollution as shown in Tables 4, 5. However, the CFs for Zn at the mid-estuarine reaches were relatively large suggesting a mild contamination of Surface Sediments, possibly due to anthropogenic activity and need further analysis.

In general, HI value less than 1 indicates no potential non-carcinogenic risk. HI value more than 1 indicates potential non-carcinogenic risk to exposed population. All surface water samples were having HI<1 and hence there was no non-carcinogenic risk for consumers. However, for all groundwater samples the results were contrary, and HI was found to be far greater than value of 1. The least HI value obtained was 6 for sample 27 and maximum HI value being 34 for sample 29.

3.7. Carcinogenic risk assessment

In carcinogenic risk assessment (Fig. 7) a Cr value of 10^{-4} indicates that 1 in 10,000 people have the probability of developing cancer. But when there are more than one carcinogenic constituent the CR from all carcinogen are summed to consider additive effects. A range of 1 x 10^{-4} – 1 x 10^{-6} (0.0001-0.000001) is considered an acceptable CR risk. All surface water samples (38-40) were within the acceptable range. Hence, surface water consumption poses inconsequential risk. However, when groundwater samples are observed every sample (22-34) pose great consequential risk. The CR_t range from 35- 0.41 which is 4156 times to 353163 times higher than the acceptable range of 0.0001. The order of contribution was Zn> Cu > Ni > Cr> Al > Cd. The Fe concentration was not analysed for groundwater samples. Carcinogenic risk was primarily attributed to Zn with 90% contribution followed by Cu with 8.3% contribution. Nevertheless, the CR_t values are above the acceptable limits. This calls for mitigation measures for groundwater quality as the consumers are highly exposed to carcinogenic risk. A Groundwater Quality Assessment enables for major thresholds to be established and thus provides clearer insight on the causes of pollution. The findings of this analysis show that metal ions already have an optimal concentration and do not exceed thresholds which may be detrimental to human health. The research, however, clearly shows toxic metal concentration levels like Fe, Cr, etc. which are slightly excessive in each season in one or two stations. While current requirements comply with existing regulations, potential issues will arise if conditions are not changed to avoid the contamination and improper use of groundwater. Suitable preventive steps for the protection of this valuable resource should be put in place.

Table 5.
The potential ecological risks (RI) for water samples

Sample	RI(Al)	RI(Cu)	RI(Pb)	RI(Cr)	RI(Cd)	RI(Ni)	RI(Zn)	RI(Hg)	RI(Fe)	∑ERI
P22	0.004	9.65	16.75	1.29	10.50	33.30	0.003	0.73	0.00	72.23
P23	0.005	32.55	25.30	7.74	12.30	21.30	0.001	0.40	0.00	99.59
P24	0.002	20.40	13.05	1.24	9.60	12.30	0.002	0.46	0.00	57.06
P25	0.005	39.45	19.75	1.12	9.90	23.4	0.005	1.13	0.00	94.76
P26	0.004	14.45	17.00	1.12	9.30	17.25	0.006	0.40	0.00	59.53
P27	0.006	46.5	23.50	0.45	9.90	4.95	0.001	0.40	0.00	85.70
P28	0.004	19.75	17.20	1.89	8.70	19.15	0.006	0.33	0.00	67.03
P29	0.002	13.10	14.00	0.44	9.30	5.60	0.037	0.26	0.00	42.74
P30	0.002	23.35	19.60	1.25	10.20	41.60	0.008	0.33	0.00	96.34
P31	0.004	13.00	27.75	0.81	12.90	5.50	0.014	0.33	0.00	60.31
P32	0.004	18.40	17.00	2.19	11.10	5.15	0.005	0.66	0.00	54.51
P33	0.007	1.20	18.60	0.39	7.20	37.05	0.007	0.20	0.00	64.65
P34	0.003	10.15	20.30	0.27	8.10	11.00	0.011	0.33	0.00	50.16
P38	0.00	0.09	0.02	0.007	0.66	0.00	1.47E-05	0.00	1.0E-05	0.77
P39	0.00	0.09	0.02	0.005	0.66	0.00	1.33E-06	0.00	2.4E-06	0.78
P40	0.00	0.08	0.02	0.005	0.66	0.00	1.33E-06	0.00	8.0E-07	0.76

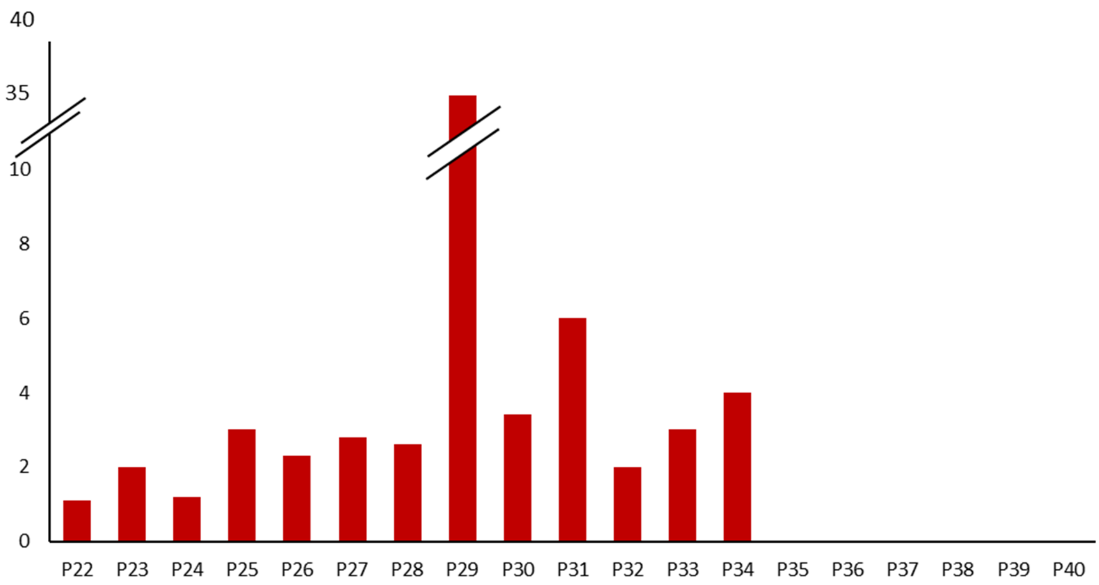


Fig. 7. Carcinogenic risk assessment for groundwater in Zenata region

The groundwater HPI was determined to be less than the vital value of 100. In the field of research this demonstrates the groundwater in heavy metals is not contaminated. Precautionary steps must nevertheless be taken, such as the introduction of a surveillance programme on groundwater quality, prohibiting wastewaters from being used in farming, controlling overuse of organic fertilisers, monitoring wastewater pre-treatment (from mills) prior to discharge into the receiving area and restricting polluting industries.

4. Conclusions

This study was carried out to assess water quality and its pollution in Mohammedia prefecture. This study provides a general overview of the water resources in the study area as well as the water quality and its likely impact on public health. The data collected in the study area show that the groundwater in the Mohammedia prefecture is degraded due to the high mineralization and the high nitrate content generated by agricultural activity; without forgetting the infiltration of the leachate produced by the two landfills (the disinfected landfill and the current controlled landfill) of the prefecture, among others. Regarding the rivers (El Maleh and Nfifikh) of the prefecture, the water quality is generally average (medium) to good, due to the absence of sources of pollution, especially upstream of the river, on the other hand in downstream the values of the pollution parameters largely exceeding the surface water quality standards traced by the Moroccan Ministry of Health and WHO because of the concentration of the population and industrial activity (anthropogenic factors).

The groundwater quality assessment based on physiochemical analysis reveals low-insignificant pollution level for landfill area near river El Nfifikh. Even based on different piezometric levels in this landfill area the water quality depicts insignificant variation. Whereas groundwater in Zenata region is highly polluted and poses non-carcinogenic and carcinogenic risks to consumers health. Hence groundwater cannot be used as water supply source for Zenata residents. On contrary the surface water sources i.e. the two rivers; river El Nfifikh and river El Melah; water quality is fit to use for human consumption. Based on the results even when meeting wastewater source, the surface water source self-cleansing capacity is enough to deal with it and render the water again fit for consumption.

However, the current Zenata region was chosen in vicinity of Mohammedia city which again is primarily derived from the fact that it can serve as a shuttle town for meeting the growing urban demands of Mohammedia city viz. industrial, residential, commercial activities. Hence, this study identified the factors currently being used by policy and decision makers for the development of urban area in Morocco. So did the environmental concern was overlooked in previous water quality reports. The answer to this lies in understanding the values of report and its analysis. As per the values obtained from water analysis the heavy metal concentration was found to be under the governing standards and hence, it was declared that water quality was safe for human consumption. However, these understanding does not hold in terms of heavy metal concentration. The reason lies in the terms heavy metal itself which in long term is subjected to bioaccumulation and hence trigger carcinogenic risks in the receiving organism. This shortcoming in terms of comprehension of the water quality data led carcinogenic risks to be overlooked.

However, this analysis is for lifespan time of 70 years. Which means as per current scenario water can be used for industrial and commercial need. However, for regular human consumption water needs to be treated to reduce the risks. This will provide the timeframe for the decision and policy makers to mitigate groundwater contamination and render it as a sustainable water resource for future generations to come. This study was limited due to non-uniform analysis of groundwater and surface water resources based on location and parameters. Hence further studies are required to assess water quality in Mohammedia prefecture with same parameters to aid in developing sustainable policies with respect to urban development and water resources utilization.

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