Study of Seasonal variation and Index Based Assessment of Water Quality and Pollution in Semi-Arid Region of Morocco

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Abstract: Water resources quality assessment a basic requirement for ensuring its sustainability. Groundwater resources being restricted under the earth crust are at high risk of being polluted as compared to rivers which flow continuously. This study evaluated groundwater quality in Mohammedia prefecture, Morocco in terms of physicochemical parameters and seasonal variation. The physicochemical parameters analysed were Temperature, pH, EC, TDS, Na^+, Ca^{2+}, K^+, NH^{4+}, NO^{2-}, NO^{3-}, PO_4^{3-}, SO_4^2. Seasonal variation was evaluated for winter and spring seasons. The water quality was assessed in terms of overall water and Pollution index. Cation/anion ratio to TDS revealed evaporation and rock weathering dominance. Based on Pollution index, water quality of 88% samples was in excellent to good category in winter season. The pollution index during winter season was <1 for all sample locations. In Spring PI was >1 only at Location P1 which was attributed to NO^{2-}. In Spring season 78% water samples were in Good to excellent category. The decrease in concentration during spring season was attributed to lack of soil-water interaction with reduced infiltration rate. The increase in concentration of parameters was attributed to anthropogenic activities. Further studies are needed to establish relationship between infiltration rate and pollutants concentration with respect to precipitation during monsoon season. Even though water quality in majority areas was fit for consumption and domestic use still further analysis should be carried out in terms of heavy metals and other emerging pollutants.

Keywords: groundwater quality, physicochemical parameter, dissolved solids, cation/anion ratio, electrical conductivity, pollution index.

1. Introduction

Water sources have been foundation for economic growth and development of society (Ghaffari et al., 2021; Ziarati et al., 2021). This has been realised globally and every country region and area which has led to water quality assessment of water resources worldwide (Gao et al., 2021; Tokatlı & Varol, 2021). Groundwater quality is of major concern as it is restricted within the earth’s crust contrary to continuous flow of rivers, and streams. This makes it renders it as more precious water source. Groundwater can be contaminated naturally by soil water interaction. However, industrialization, urbanization and economic growth are primarily responsible for groundwater pollution in modern times (Hossen et al., 2021; Sharma et al., 2021; Sihag et al., 2021; Khan et al., 2021). Natural contamination is restricted to only minerals present in soil. Nonetheless, anthropogenic activities render a complex matrix of pollutants in groundwater (Khan et al., 2019). Groundwater quality assessment is a necessary tool for decision and policy makers. Based on water quality the policies are adopted to ensure sustainable management of water resources. Hence, groundwater quality is being assessed globally. The research (Verma et al., 2021) has analysed groundwater quality in flood plains of Ganga-Gomti River in India. The study (Maleki & Jari, 2021) has evaluated groundwater quality in rural areas of Iran. Authors of the article (Tong et al., 2021) have evaluated quality of groundwater and surface water sources in China. The research (Abdelhalim et al., 2021; Mostafa et al., 2021) investigated groundwater quality in Egypt and research (Edokpayi et al., 2018) has investigated groundwater quality in South Africa. Authors of the article (Şener et al., 2017) have analysed groundwater quality using GIS in Turkey and the study (Addo et al., 2011) has assessed groundwater quality of open wells in Ghana. Morocco the North West country of African continent is no exception.

Groundwater quality assessment. Authors of the work (Moyé et al. 2017) has examined groundwater in the mines of Kettara, Morocco. Article researchers (Ait Benichou et al., 2018) has evaluated groundwater in Al Hoceima, Morocco, while author of the aticle (Del Vecchio, 2018) has analysed the groundwater policies in Morocco. Research (Smahi et al., 2013; Fekri et al., 2011; Vambol et al., 2019) has estimated groundwater pollution from landfills in Casablanca Morocco and Ukraine. In article (Malki et al., 2017) has analysed impact of agricultural activity on groundwater of Morocco and in work (Baki et al., 2017) has studies pre Saharan areas groundwater vulnerability to pollution. Authors of study (Benkaddour et al., 2020) determined occurrence of nitrates in groundwater of Eastern Morocco and in work (Lyazidi et al., 2020) estimated groundwater level in coastal aquifers of Morocco. In investigation (Hssaisoune et al., 2019) used noble gases to study groundwater dynamics in souss-massa basin in middle western Morocco. Authors of study (Mountadar et al., 2018) determined salinization of groundwater in El Jadida province Morocco. It is clearly evident from the literature that groundwater quality has been assessed in Morocco in different aspect and dimension with various techniques. Also, many regions of Morocco have been explored. However, literature on Mohammedia prefecture in Morocco is lacking.

Also, seasonal variation in groundwater quality is a major overlooked aspect in investigation of groundwater in Morocco. This is again validated with lacking literature from seasonal variation point of view. (Najib et al., 2016; Barakat et al., 2018; Gamar et al., 2018; Mountadar et al., 2018; Omrania et al., 2019; Kamal et al., 2021) have employed physicochemical parameters for evaluation of groundwater of Morocco. Hence, the objectives of this study are:

1. To investigate physicochemical parameter prevalence in groundwater of Mohammedia prefecture;
2. To compare seasonal variation of physicochemical parameters in groundwater;
3. To assess groundwater quality and its pollution status.

2. Method and Data Used

Study Area

The study area in this study was Mohammedia prefecture situated in Casablanca-Setat region on the shores of Atlantic Ocean. This proximity ensures that study area experiences arid to semi-arid climatic condition. Average daily temperatures during winter reaches in range of 8°C - 10°C, while in spring season the temperature ranges 11°C to 29°C. Precipitation during winter season is on an average around 30 mm while in spring it decreases to on average to 16 mm. Mohammedia prefecture is also host to three rivers *viz.* El Maleh, Hassar and Nfifikh. Besides being host to Oil refinery, Port city of Mohammedia, the prefecture is host to intensive agricultural activities.

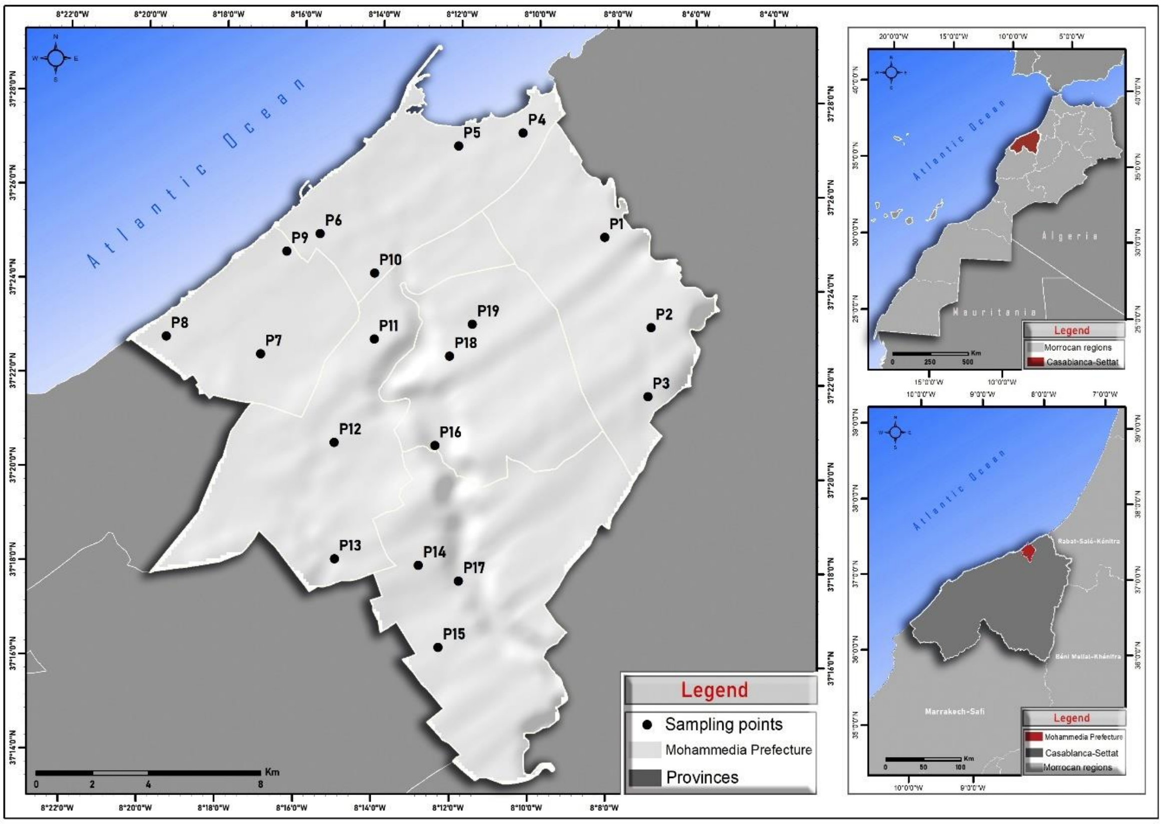


Figure 1. Study Area and sample point's location

Water sampling, collection and analysis

Sample collection was carried out during the month of January 2021 for winter season and Month of March for spring season. The selection of sample point was done on the basis of ensuring to present overall groundwater quality of Mohammedia Prefecture. Points P1-P3 was selected on the North eastern border of prefecture adjacent to river El Maleh River. Point P8 was selected in vicinity of coast and Daure El Marje Lagoon. Point P4 and P5 represent the groundwater condition in the North of prefecture. Point P6 and P9 were selected to represent Mohammedia city which is also a port city and also host oil refinery in its vicinity. Rest water samples in South and west of prefecture were selected keeping in mind Nfifikh River which is Tributary River to Hassar River which runs in across the heart of prefecture from P15 running to P6.

River water samples were collected from depth of 20 cm depth, since in (Custodio et al., 2020; Li et al., 2020) have also reported sampling at similar depth. The water samples were collected in amber glass bottles similar to study (Li et al., 2020). The collected water samples were stored in ice coolers at temperature 4°C to 10°C. The samples were brought to laboratory for further analysis. In case samples cannot be tested they were stored in lab refrigerators at 4°C similar to study (Hoang et al., 2021). The lab samples were brought to ambient room temperature prior to instrumental testing. Stored samples were tested during 48 hours after their arrival in Laboratory (Razak et al., 2021).

Instrumental Analysis

The water samples were tested for the detection of physicochemical parameters. The physical parameters analysed were Temperature, Electrical conductivity (EC), Total dissolved solids (TDS) which were tested onsite with water sampling kits. Cations (Na^+, Ca^{2+}, K^+, NH^{4+}) and anions (NO^{2-}, NO^{3-}, PO_4^{3-}, SO_4^{2-}) were tested in lab. The analysis of samples was carried out at National Centre for Studies and Research on water and energy. pH, TDS (total dissolved solids mgL^{-1}) and EC (electrical conductivity μs/cm) was measured on site using Hanna H198129 pH/EC tester. Nitrates (NO_3), nitrites (NO_2), ammonium ions (NH^+), and phosphates ($PO^{3-}{}_4$) was measured using spectrophotometer. Flame spectrophotometer was used for the measurement of potassium (K^+), calcium (Ca^{2+}), and sodium (Na^+).

Groundwater Quality Assessment

Indexing approach has been adopted for groundwater quality assessment in many studies. (Islam et al., 2020; Li et al., 2020) Indexing approach has been employed for assessing water quality in terms of physicochemical parameter (Heiß et al., 2020) and heavy metals (Shil & Singh, 2019; Jafarzadeh et al., 2020; Li et al., 2021). In Morocco, Heiß et al. (2020), Lotfi et al. (2020), Udeshani et al. (2020) has also utilized indexing approach to assess groundwater quality. Indexing approach cat be categorized as water quality index and heavy metal pollution index. Prior uses weightage factor of pollutant to assess groundwater quality while later approach assessing designated weight to pollutants but then utilities proportionate weightage factor based on total weightage factor to assess contribution of pollutant in influencing water quality (Edokpayi et al., 2018; Bodrul-Doza et al., 2019; Aithani et al., 2020; Egbueri, 2020; Sutradhar & Mondal, 2021). This study has adopted combination of both as predesignated weight will not ensure the real influence of pollutant on water quality as parameters influence concentration varies from mgL^{-1} to μgL^{-1} which means variation can be at least 1000 times. However, predesignated scale varies within 1-5 that will not enable correct representation of varying water quality parameters. Therefore, weightage factor based on respective permissible limits as adopted in WQI approach is more scientific. Nevertheless, it doesn't take into account contribution of weightage factor to overall weightage factor. Hence this study obtained unit weight factor Wp for each parameter with respect to its permissible limits as per Equation 1. Then relative weight Rw was obtained by diving Wp by summation of all Wp, as per Eq. 2. Degree of contamination or status (Cd) of contamination (Sc) was obtained by dividing measured concentration with their respective permissible limits as per Eq. 3. Pollution index (PI) was obtained by multiplying Sc with Wp.

$$Rw = \frac{1}{\text{Permissible}_{\text{limits}}} \quad (1)$$

$$Wp = \frac{R_w}{\sum R_w} \quad (2)$$

$$Sc = \frac{\text{Measured}_{\text{conc.}}}{\text{Permissible}_{\text{limits}}} \quad (3)$$

$$PI = Wp \times Sc \quad (4)$$

$$PI_{total} = HPI(_{Ca2+}) + HPI_{(Na+)} + HPI_{(NH^+)} + HPI_{(K^+)} + HPI_{(SO43-)} + HPI_{(NO3-)} + HPI_{(NO2-)} + HPI_{(PO43-)} \quad (5)$$

Table 1. Parameters used in this study for water quality analysis

Parameter	Unit	Rw	Wp	Permissible Limit
T	°C	0.04	0.0064	25
pH	--	0.125	0.0199	6.5-9.5
EC	µs/cm	0.0004	0.0001	1000
TDS	mgL^{-1}	0.0017	0.0003	600
NH^{4+}	mgL^{-1}	2	0.3180	0.5
SO_4^{3-}	mgL^{-1}	0.0025	0.0004	400
NO_2^-	mgL^{-1}	2	0.3180	0.5
NO_3^-	mgL^{-1}	0.02	0.0032	50
PO_4^{3-}	mgL^{-1}	2	0.3180	0.5
Na^+	mgL^{-1}	0.005	0.0008	200
K^+	mgL^{-1}	0.0833	0.0132	12
Ca^{2+}	mgL^{-1}	0.01	0.0016	100

3. Result and Discussion

Physicochemical parameter analysis

Morocco experiences significant precipitation annually which can be assessed seasonally. This will eventually affect groundwater quality as precipitation will directly affect the rate of infiltration (Bahir et al., 2021). The results of physicochemical parameter analysis of groundwater in Mohammedia prefecture for winter and spring season is presented in Figure 2 and Figure 3. The groundwater temperature range was found to be 16.9°C to 23.4°C during winter season. During spring season, temperature range was in between 19.3°C to 24.4°C. (Sarti et al., 2021) has reported groundwater temperature range in Northwest of rural Morocco to be 17.2°C to 20.5°C, but did not specify the season for groundwater sampling. Kamal et al. (2021) has reported groundwater temperature range as 19°C to 29°C in central Morocco.

The pH range was observed to be 6.98 - 7.8 to 6.74 - 7.79 during winter and spring season respectively. Most of the samples were alkaline in nature. However, P2 & P6 during winter, P2, P11, P12 & P13 were found to be slightly acidic during spring season. P2 was acidic in nature in both seasons which can be attributed to natural sources. However, P6, P11, P12 and P13 with acidic nature only in one season indicate anthropogenic activities influence. Kamal et al. (2021) has reported similar results for groundwater of Morocco. Authors (Sarti et al., 2021; Bahir et al., 2020) have reported groundwater pH to be alkaline.

Electrical conductivity (pH) is directly proportional to dissolved ions in water. Groundwater flow direction, velocity and aquifer formation matrix also significantly affect EC. The EC range in winter season was 687 µs/cm to 5098 µs/cm, while in spring season it increased to range of 1570 µs/cm to 5706 µs/cm. During winter season P10 and P 15 water samples only had EC < 1000 µs/cm. during spring season none of the water sample reported EC values to be < 1000 µs/cm. the standard limit for EC is 1000 µs/cm (Sarti et al., 2021). Sea spray and leachate of aerosols through runoff infiltration have been identified as possible EC in groundwater (Bahir et al., 2020). However, only five sample points are close to Atlantic Ocean to have influence of sea spray. For the rest of 12 samples EC concentration can be attributed to infiltration of aerosols. Also, P15 is located in south of the Prefecture which has low EC value during winter and it increases to 1683 µs/cm during spring. This further validates infiltration as cause of high EC values.

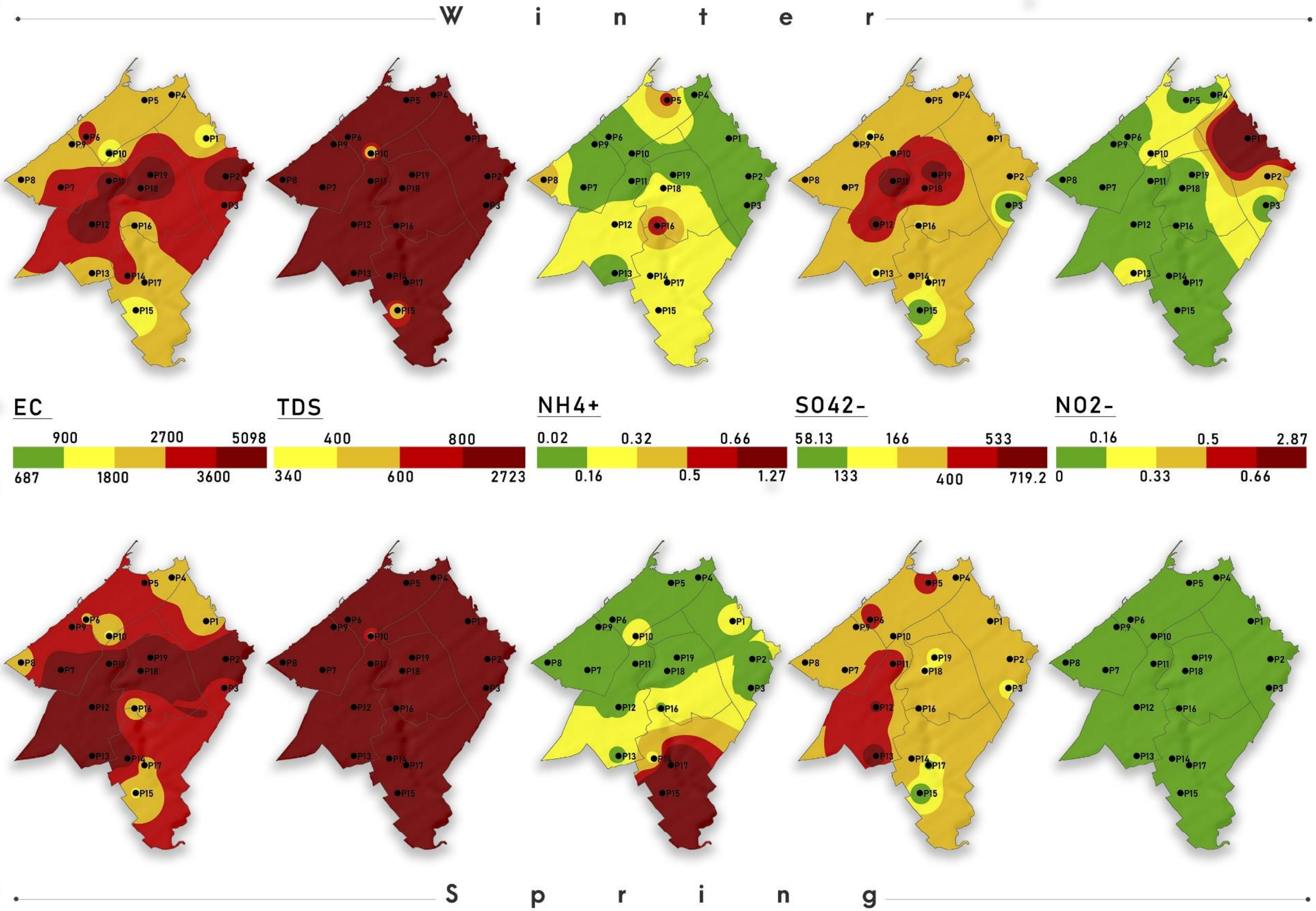
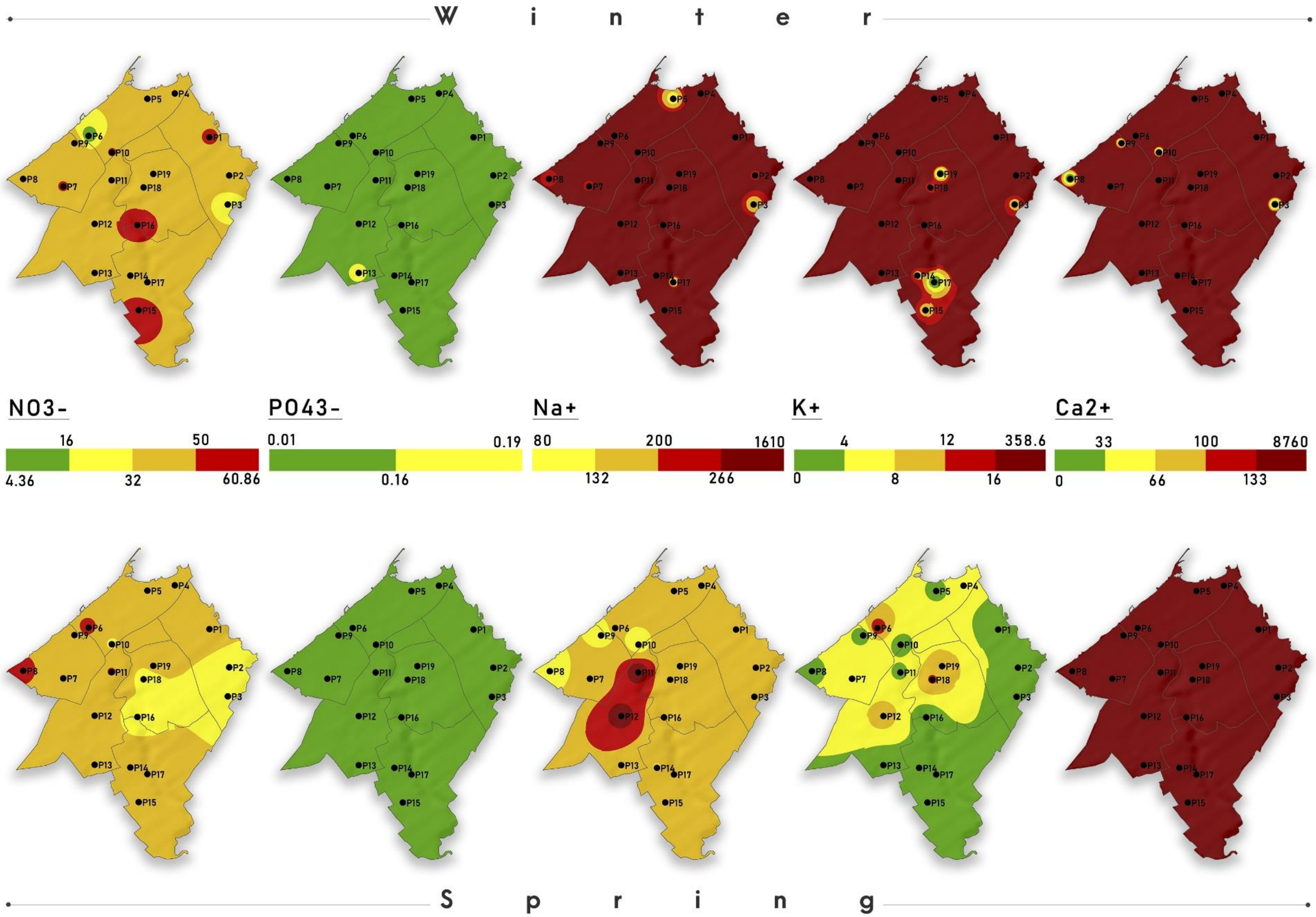

W i n t e r
EC
900 2700 5098
687 1800 3600
TDS
400 800
340 600 2723
NH4+
0.02 0.32 0.66
0.16 0.5 1.27
SO42-
58.13 166 533
133 400 719.2
NO2-
0.16 0.5 2.87
0 0.33 0.66
S p r i n g

Figure 2. Spatial distribution of EC, TDS, NH^{+}, SO_4^{2-}, and NO^{2-} in Mohammedia prefecture during winter (top) and Spring (bottom) season (red colour denotes that concentration is above permissible limit, green colour denotes that concentration is 33% of permissible limit, yellow colour signifies concentration between 33-66% of permissible limit, and golden colour depicts concentration range of 66-100%)



Winter
NO3-
16 50
4.36 32 60.86
PO43-
0.01 0.19
0.16
Na+
80 200 1610
132 266
K+
4 12 358.6
0 8 16
Ca2+
33 100 8760
0 66 133
Spring

Figure 3. Spatial distribution of NO^{3-}, PO_4^{3-}, Na^+, K^+, and Ca^{2+} in Mohammedia prefecture during winter (top) and Spring (bottom) season

Total dissolved solids (TDS) during spring season were in range 535 mgL^{-1} to 2723 mgL^{-1} and in winter season the range 340 mgL^{-1} to 2603 mgL^{-1}. The TDS concentration below 600 mgL^{-1} was found to be at P10 (340 mgL^{-1}) and P15 (436 mgL^{-1}) during winter season. However, during spring season only P10 (535 mgL^{-1}) has concentration below 600 mgL^{-1}. Udeshani et al. (2020) has employed Gibbs plot to assess relationship between groundwater lithological characteristics and chemical composition of water. Gibbs plot is obtained by plotting cation/anion ratio against TDS (Najib et al., 2016). This study used it to evaluate groundwater mechanism in the study area. From Figure 4 it can be inferred that majority of samples lie between evaporation and rock weathering dominance. This further confirms that water quality is altered upon infiltration through soil-water interaction.

Cation concentration in water sample dominated over anion concentration. Among cations the order of dominance in decreasing order was Ca^{2+} (0-8760 mgL^{-1}) > Na^{+} (80-1610 mgL^{-1}) > K^{+} (0-360) > NH^{+} (0.016-0.061 mgL^{-1}). Ca^{2+} concentration was below detection level at P3, P8, P9, P10 and P17 during winter season. Nonetheless, during spring season the Ca^{2+} concentration for same location was observed to be 3876 mgL^{-1}, 2896 mgL^{-1}, 3123 mgL^{-1}, 5157 mgL^{-1} and 840 mgL^{-1}. This high concentration difference indicates major influence of anthropogenic activities i.e., pollution through infiltration. Bahir et al. (2021) has reported Ca^{2+} concentration between 13-1942 mgL^{-1}. High Ca^{2+} can also be attributed to carbonate deposits in earth's crust (Kamal et al., 2021). However, calcium concentration was observed to decrease in spring season.

Na^{+} was second dominating cation in study area. During winter season the range was 80-1610 mgL^{-1}, while during spring season the range was 90-331 mgL^{-1}. P3, P5 and P17 water samples were observed to have Na^{+} below its permissible limit during winter season. Nonetheless, during spring season except for P11 and P12 location all water samples were found to have concentration less than 200 mgL^{-1}. Kamal et al. (2021) has found Na^{+} concentration in groundwater of Morocco in range of 29-260 mgL^{-1}. K^{+} also followed the similar trend of Na^{+}. The range of K^{+} concentration in winter 0-360 was reduced to 0.8-15 during spring season. 0.9-3938 mgL^{-1} concentration has been reported by Kamal et al. (2021) for K^{+}. NH^{+} concentration during winter season in whole Mohammedia prefecture was below the permissible limit of 0.5 mgL^{-1} except for location P16. During winter season the range was 0.016- 0.61 mgL^{-1}. Contrary to other cations NH^{+} concentration increased during spring season. The concentration range increased to 0.11-1.26 mgL^{-1} during spring season.

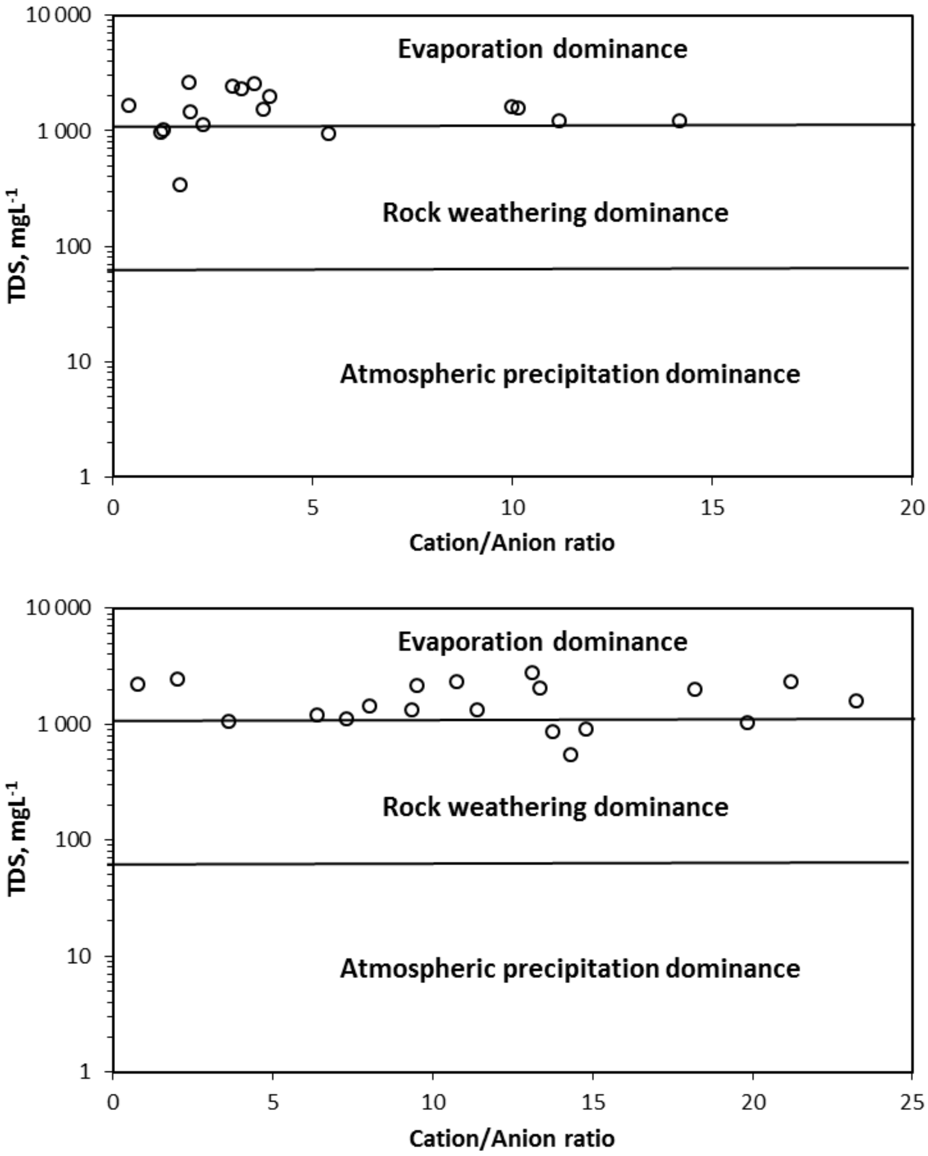


Figure 4. Plot of total dissolved solids vs cation/anion ratio in Mohammedia prefecture, Morocco during winter (top) and spring (bottom) season

In anion concentration the dominance order was SO_4^{2-} > NO^{3-} > NO^{2-} > PO_4^{3-} in both winter and spring season. SO_4^{2-} concentration during winter was between 58-719 mgL^{-1} and in spring season the concentration range was 103-617 mgL^{-1}. At point P11, P12, P18 and P19, SO_4^{2-} concentration was above permissible limit during winter while in spring P11, P12 P13, P5 and P6 were above the standard limit. Point P11, P12 and P13 are adjacent to River Hassar in same water table hence the concentration was similar in both the season. P18 and P19 during winter season with high concentration indicated anthropogenic activity interference. Kamal et al. (2021) has found 35-5347 mgL^{-1} of SO_4^{2-} concentration. NO^{3-} and NO^{2-} both showed decrease in concentration during spring season as compared to spring season. NO^{2-} concentration was below the permissible limit for all water sample and in both seasons. NO^{3-} on the other hand was above the permissible in winter (P7, P9, P10, P15 and P16) and in spring (P6, P8, P9 & P11). Authors (Sarti et al., 2021) has reported only two water sample for concentrations below permissible limit in Northwest Morocco. PO_4^{3-} results were also similar to NO^{2-} and were below permissible limit in both the seasons.

Statistical analysis was performed to analyse relationship between the analysed parameters. The correlation of parameters is presented in Table 3 and 4. EC has significant relationship with TDS, and SO_3^{3-} during winter season. While during spring season EC has significant correlation with TDS and Na^+. Also, pH has significant relation with EC, TDS and SO_4^{3-}. The relationship between parameters in terms of origin was determined through p value (Li et al., 2020). P value < 0.01 indicates strong relationship between pH and EC, EC & SO^{3-}, TDS & SO_4^{3-}, and NH^+ & Ca^+. A very strong relationship between was observed between EC and TDS with P values < 0.01. These relationships indicate that these parameters have same source of origin (Gamar et al., 2018).

Reduction in concentration of several parameters during spring season is attributed to reduced infiltration rate which is again attributed to reduced precipitation in the prefecture. The reduced precipitation reduces soil-liquid interaction so natural occurrence of ions in water sample is also reduced. The concentrations above permissible limits indicate influence of anthropogenic activities. Among anthropogenic activities agricultural activities are primary suspect as local factor as use of fertilizer, since nitrogen, potassium and phosphate form basic of chemical fertilizer (Benkaddour et al., 2020). Intensive agriculture prevailing in the Mohammedia prefecture their widespread use is not a hidden factor. It can be clearly observed that many parameters at several locations are above the permissible limit in both the seasons. This calls for evaluation of water quality assessment for its suitability for drinking and domestic purpose (Gamar et al., 2018; Idrees et al., 2018).

Table 3. Correlation of the physicochemical parameters analysed during winter season

	T	pH	EC	TDS	NH	SO_4	NO_2	NO3	PO4	Na	K	Ca
T	1											
pH	-0.027	1										
EC	0.245	-0.453	1									
TDS	0.214	-0.431	.972**	1								
NH	0.088	0.297	-0.258	-0.298	1							
SO4	0.023	-0.186	.548*	.573*	-0.142	1						

NO2	-0.337	-0.255	-0.252	-0.186	-0.258	-0.030	1					
NO3	-0.071	0.222	-0.257	-0.247	0.324	0.247	0.179	1				
PO4	-0.406	0.381	-0.090	-0.081	-0.205	-0.236	-0.042	-0.124	1			
Na	0.043	-0.192	0.233	0.175	0.049	0.280	0.114	0.258	0.194	1		
K	-0.149	0.231	-0.346	-0.386	-0.088	0.157	-0.078	0.194	0.108	-0.191	1	
Ca	-0.250	0.136	-0.296	-0.332	.494*	-0.288	-0.102	0.374	0.013	0.293	-0.274	1

Table 4. Correlation of the physicochemical parameters analysed during spring season

	T	pH	EC	TDS	NH	SO_4	NO_2	NO_3	PO_4	Na	K	Ca
T	1.000											
pH	-0.042	1.000										
EC	0.134	-0.636	1.000									
TDS	0.181	-0.588	0.974	1.000								
NH	0.188	0.334	-0.357	-0.346	1.000							
SO_4	-0.041	-0.722	0.354	0.273	-0.471	1.000						
NO_2	0.383	-0.166	0.257	0.261	-0.098	0.220	1.000					
NO_3	0.320	-0.255	-0.131	-0.171	0.077	0.386	-0.022	1.000				
PO_4	0.015	0.044	-0.042	-0.120	-0.194	0.243	-0.107	0.165	1.000			
Na	0.028	-0.502	0.606	0.469	-0.027	0.485	0.197	0.156	0.314	1.000		
K	0.231	-0.135	0.316	0.292	-0.247	0.148	0.030	0.167	0.197	0.174	1.000	
Ca	0.100	0.080	-0.067	-0.109	-0.366	0.087	-0.031	-0.148	0.057	-0.238	0.212	1.000

Groundwater quality assessment and pollution index

Indexing approach is an easy tool for assessing water quality (Smahi et al., 2013; Moyé et al., 2017; Bodrul-Doza et al., 2019; Maity et al., 2020). WQI and Pollution index are two commonly used terms to represent water quality assessment (Bodrul-Doza et al., 2019; Maity et al., 2020). This study analysed water quality in terms of Status of contamination (Sc), Overall water quality (Ow) and Pollution Index. Status of contamination aids in identifying state of each parameter with respect to its permissible limit. Any value >1 means water is polluted and higher the value greater the pollution for the respective parameter. Overall water quality also presents the quality of water in terms of individual parameter by employing weightage factor and status of contamination. The overall quality of water during spring and winter season is presented in Table 5. PI can be categorized as 0-0.25 (excellent water), 0.25-0.5 (Good Water), 0.5-0.75 (Poor water), 0.75-1 (very poor water) and >1 means water is unfit for consumption (Egbueri, 2020; Atangana & Oberholster, 2021; Sutradhar & Mondal, 2021). During winter season 52% of samples were in excellent water quality category, 36% were in good water category, and only P15 and P17 were found to be in very poor category. In spring season 36% of water samples were in Excellent category, 42% of water samples were in good category. 10% of samples were in Poor water category. P1 was the only sample location whose PI value was >1 and thereby not fit for consumption. The PI value at sample point P1 is attributed solely to nitrite with contribution of 1.81 in total 1.91 PI value Table 5. Spatial distribution of PI for winter and spring season is presented in Figure 4.

Table 5. Overall quality of Groundwater with respect to parameter analysed for each location

	Point	T	pH	CE	TDS	NH_4^+	SO_4^{2-}	NO_2^-	NO_3^-	PO_4^{3-}	Na^+	K^+	Ca^{2+}
Spring	P1	0.006	0.018	4E-05	0.0004	0.11	0.00024	0.0064	0.0029	0.032	0.0006	0.001	0.066
	P2	0.006	0.017	0.0001	0.0012	0.10	0.00024	0.0191	0.0014	0.006	0.0006	0.002	0.052
	P3	0.005	0.019	7E-05	0.0007	0.08	0.00015	0.0254	0.0013	0.013	0.0006	0.001	0.062
	P4	0.005	0.019	5E-05	0.0005	0.09	0.00029	0.0318	0.0026	0.07	0.0007	0.006	0.017
	P5	0.005	0.018	6E-05	0.0006	0.09	0.00043	0.0382	0.0025	0.013	0.0006	0.004	0.084
	P6	0.006	0.018	6E-05	0.0006	0.09	0.00044	0.0382	0.0033	0.013	0.0005	0.017	0.071
	P7	0.006	0.018	9E-05	0.0009	0.08	0.00039	0.0318	0.0027	0.019	0.0006	0.005	0.063
	P8	0.006	0.018	5E-05	0.0005	0.09	0.00035	0.0382	0.0034	0.021	0.0004	0.004	0.046
	P9	0.006	0.019	6E-05	0.0006	0.10	0.00035	0.0382	0.0032	0.022	0.0004	0.002	0.050
	P10	0.005	0.018	3E-05	0.0002	0.12	0.00033	0.0445	0.0019	0.02	0.0004	0.002	0.082
	P11	0.005	0.017	0.0001	0.0010	0.07	0.00052	0.0572	0.0033	0.013	0.0013	0.003	0.002
	P12	0.006	0.017	0.0001	0.0010	0.08	0.00055	0.0509	0.0027	0.057	0.0012	0.012	0.097
	P13	0.006	0.017	0.0001	0.0011	0.07	0.00061	0.0827	0.0022	0.019	0.0008	0.002	0.018
	P14	0.006	0.018	9E-05	0.0009	0.15	0.0002	0.089	0.0029	0.013	0.0005	0.002	0.069
	P15	0.006	0.019	4E-05	0.0004	0.79	0.0001	0.0445	0.003	0.013	0.0006	0.002	0.030
	P16	0.006	0.019	4E-05	0.0004	0.10	0.00022	0.0763	0.0013	0.019	0.0006	0.001	0.073
	P17	0.006	0.019	5E-05	0.0005	0.81	0.00012	0.0318	0.0022	0.013	0.0007	0.002	0.013
	P18	0.006	0.019	0.0001	0.0010	0.08	0.00015	0.0572	0.0018	0.019	0.0006	0.014	0.058
	P19	0.006	0.018	9E-05	0.0009	0.08	0.00013	0.0445	0.0021	0.013	0.0006	0.011	0.032
Winter	P1	0.005	0.018	3E-05	0.0004	0.02	0.00027	1.8237	0.0033	0.005	0.0040	0.022	0.012
	P2	0.005	0.017	0.0001	0.0011	0.02	0.00024	0.2086	0.0029	0.018	0.0010	0.044	0.009
	P3	0.005	0.018	6E-05	0.0006	0.03	5.8E-05	0.0292	0.0015	0.007	0.0006	0.011	0.000

P4	0.005	0.019	5E-05	0.0005	0.01	0.00022	0.0417	0.002	0.03	0.0017	0.088	0.049
P5	0.005	0.018	5E-05	0.0005	0.35	0.00037	0.0521	0.0026	0.008	0.0004	0.088	0.012
P6	0.005	0.017	7E-05	0.0007	0.05	0.00012	0.0139	0.0003	0.013	0.0019	0.055	0.012
P7	0.006	0.019	6E-05	0.0007	0.04	0.0003	0.0299	0.0032	0.005	0.0009	0.066	0.017
P8	0.006	0.019	4E-05	0.0004	0.29	0.00023	0.0348	0.0032	0.005	0.0009	0.144	0.000
P9	0.006	0.018	4E-05	0.0004	0.03	0.0003	0.0362	0.0032	0.015	0.0010	0.199	0.000
P10	0.005	0.019	1E-05	0.0002	0.08	0.00039	0.1634	0.0033	0.009	0.0016	0.397	0.000
P11	0.005	0.018	9E-05	0.0011	0.01	0.00071	0.089	0.0031	0.006	0.0026	0.044	0.012
P12	0.006	0.018	0.0001	0.0011	0.13	0.00057	0.0064	0.003	0.006	0.0064	0.155	0.007
P13	0.004	0.019	5E-05	0.0005	0.04	0.00016	0.1526	0.0025	0.121	0.0048	0.144	0.014
P14	0.006	0.018	7E-05	0.0007	0.18	0.00017	0.0445	0.0024	0.006	0.0044	0.011	0.015
P15	0.005	0.018	2E-05	0.0002	0.20	9.8E-05	0.0191	0.0039	0.013	0.0061	0.011	0.085
P16	0.005	0.019	4E-05	0.0004	0.39	0.00015	0.0064	0.0038	0.013	0.0034	0.022	0.139
P17	0.006	0.019	5E-05	0.0007	0.13	0.00016	0	0.0022	0.019	0.0003	0.000	0.000
P18	0.005	0.019	9E-05	0.0009	0.17	0.00049	0.0254	0.0027	0.013	0.0049	0.011	0.014
P19	0.006	0.018	1E-04	0.0010	0.05	0.00062	0.0127	0.0025	0.013	0.0056	0.000	0.012

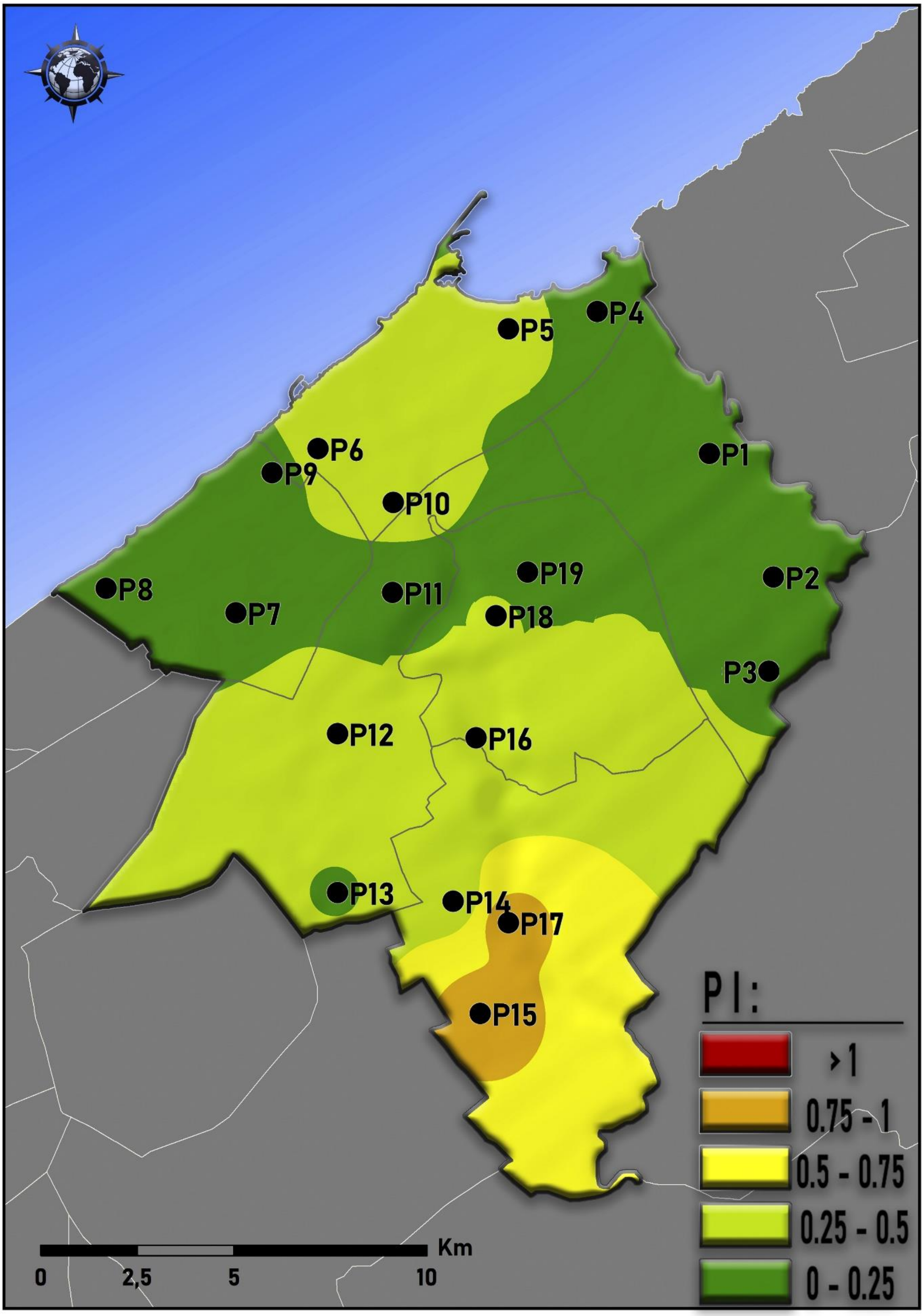


Figure 5. Spatial distribution of pollution index in groundwater of Mohammedia prefecture based on physicochemical parameter during winter season

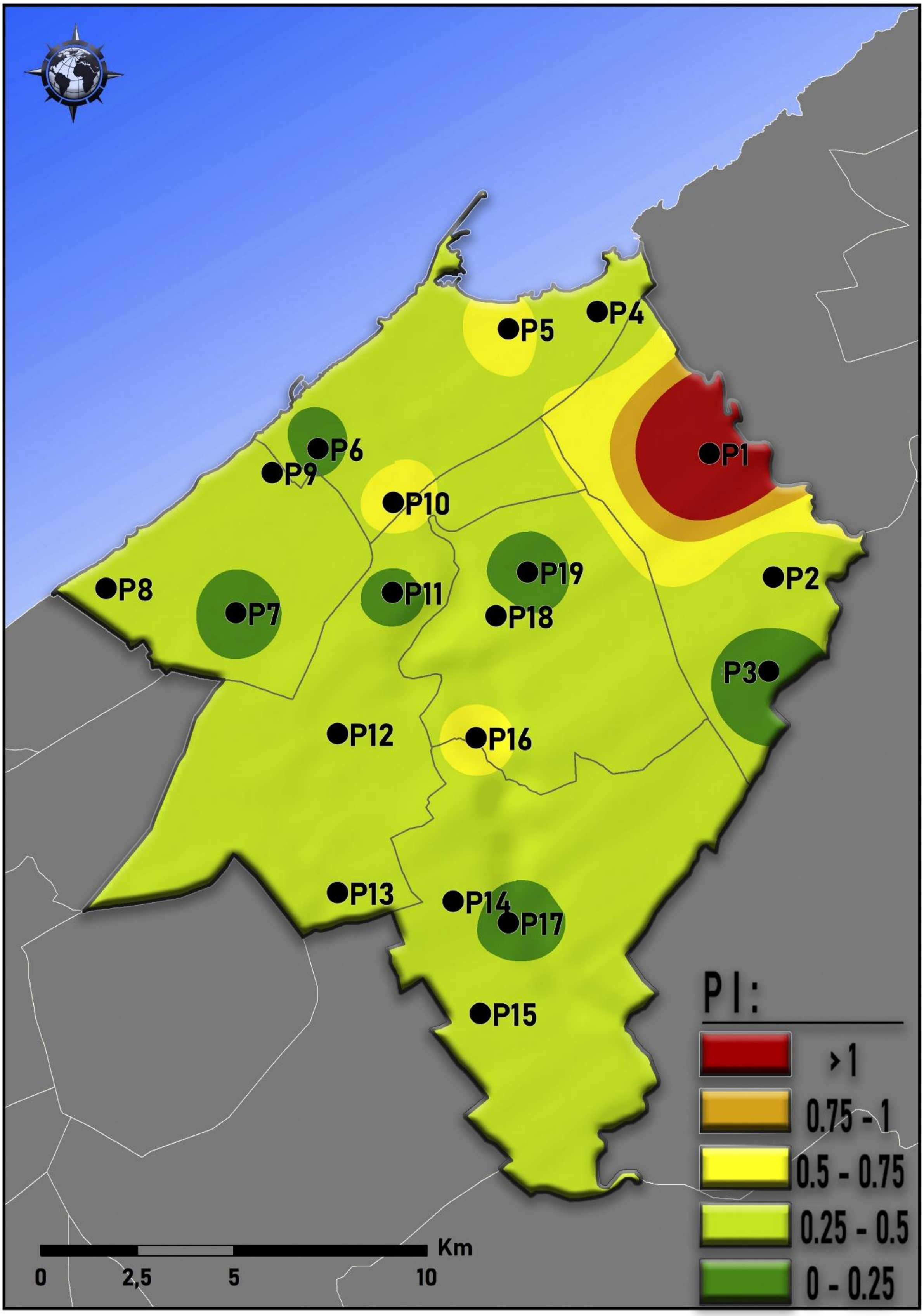


Figure 6. Spatial distribution of pollution index in groundwater of Mohammedia prefecture based on physicochemical parameter during spring season

Conclusion

This study was carried out to conduct water quality assessment in Mohammedia prefecture during spring and winter season. Groundwater quality was assessed in terms of physicochemical parameters. Upon analysis it was noted that electrical conductivity and TDS were in high concentration range. The water was in general alkaline in nature *i.e.* < pH greater than 7. But was within range of 6.5-8.5 as per Moroccan standards. The seasonal variation was analysed. In spring season, the reduced concentration was attributed to lack of precipitation which resulted in reduced infiltration and thereby minimizing water-soil interaction and hence parameter concentration was reduced during spring season. Occurrence of ions and TDS was attributed to evaporation and rock weathering dominance. During winter season 88% of groundwater samples were under excellent to good-category. While during spring season 78% of water samples were in excellent to good category. Hence, this study concludes that in general water quality of Mohammedia prefecture is fit for drinking purpose, especially during winter season as compared to spring season. Also, this study found that with increase in precipitation the water quality improved which is contrary to literature which reported with high infiltration causing increased pollution. However, this fact depends upon the quality of soil from where water is percolating which can explain the water quality better. Further studies are required to assess water quality with respect to precipitation increase during monsoon season. Also, other pollutants like heavy metals, pesticides etc. are required to be analysed for seasonal variation and their impact on water quality.

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Supplementary Material

Table S1. Descriptive analysis in Spring

Parameter	Minimum	Maximum	Mean	Std. Deviation
T	19.30	24.40	22.2632	1.35860
pH	6.74	7.78	7.3342	0.29988
EC	1570.00	5706.00	3357.8947	1407.59017
TDS	535.00	2723.00	1601.8421	641.02741
NH	0.11	1.27	0.2619	0.35109
SO4	103.41	617.78	307.7066	154.96933
NO2	0.01	0.14	0.0700	0.03300
NO3	21.04	52.93	38.7642	10.66928
PO4	0.01	0.11	0.0332	0.02518
Na	90.70	331.20	161.5316	62.26544
K	0.80	15.20	4.4053	4.34760
Ca	125.40	6090.00	3257.2316	1678.98265

Table S2. Descriptive analysis in Winter

Parameter	Minimum	Maximum	Mean	Std. Deviation
T	16.90	23.40	20.6953	2.15298
pH	6.94	7.80	7.3747	0.26300
EC	687.00	5098.00	2727.4211	1282.83360
TDS	340.00	2603.00	1459.5263	668.10357
NH	0.02	0.61	0.1826	0.18690
SO4	58.13	719.20	298.2579	186.65764
NO2	0.00	2.87	0.2316	0.64560
NO3	4.36	60.86	42.6232	12.98509
PO4	0.01	0.19	0.0268	0.04083
Na	80.00	1610.00	695.2632	526.04783
K	0.00	360.00	72.1053	88.16518
Ca	0.00	8760.00	1354.2105	2196.88748