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# Assessment of Groundwater Quality for Irrigation in the Sidi Allal Region Using Irrigation Water Quality Index

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## ABSTRACT

Water pollution has become a global concern, particularly due to the escalating demand for water. This study focuses on evaluating groundwater quality for irrigation purposes in the Sidi Allal Tazi region, Morocco, utilizing the irrigation water quality index. Indices like total disolved solids, sodium percentage, Kelly's ratio, and sodium adsorption ratio suggested that 22–66% of the samples were unsuitable for irrigation, whereas primality index, magnesium ratio, and residual sodium carbonate indices classified 91–100% of the wells as appropriate for irrigation in the Sidi Allal region. The values of irrigation water quality index, about, 29% of the wells were categorized as having severe restrictions, 7% as high restrictions, 22.2% as moderate restrictions, and 42.2% as low restrictions for irrigation in study area, it indicating that more than half of the area has wells suitable for irrigation. These results suggest that the majority of wells in the Sidi Allal region is appropriate for irrigation purposes. This research further suggests implementing suitable di-chlorination, sodium reduction, and denitrification methods to enhance the quality of ground-water for irrigation use.

**Keywords:** sodium adsorption ratio, magnesium ratio, primality index, irrigation water quality index.

## INTRODUCTION

The water problem is one of the most difficult problems facing the world today. The expansion of human populations, and the growing need for water resources across diverse sectors such as agriculture, industry, and tourism have collectively led to the depletion and contamination of our precious water sources (Yang et al., 2019). Maintaining water quality is paramount because water is essential for all life forms. In recent years, the quality of water has significantly declined due to pollution, climate change, and increased demand. This deterioration threatens public health and ecosystems. Access to clean water is vital for current and future generations, and preserving it is key to sustainability. The economic and social consequences of poor water quality are substantial, impacting healthcare costs, agriculture, and infrastructure. Addressing this issue requires improved wastewater treatment, pollution control, sustainable agricultural practices, and public awareness. It's a shared responsibility of governments, industries, communities, and individuals to safeguard our most precious resource (Boyd 2019; Meals et al., 2010). Morocco's agricultural sector is a linchpin of the country's development, actively contributing to both economic and social progress. Economically, it's a powerhouse, making a substantial contribution to the nation's Gross Domestic Product (GDP), accounting for about 14% of the total GDP. This underscores its significant impact on the economy, driving financial stability and growth (El Mountassir et al., 2022). Furthermore, the sector is a major engine for employment. It provides livelihoods for approximately 38% of the country's workforce, thereby playing a vital role in reducing unemployment and poverty. In rural areas, where agriculture is the primary means of subsistence, it becomes even more critical, contributing an impressive 74% of jobs within these regions. Water is the lifeblood of agricultural sector, essential for crop irrigation and maintenance. Given Morocco's arid climate, effective water management is of paramount importance to support agricultural productivity and food security. In essence, Morocco's agricultural sector is not only a significant economic contributor but also a primary source of employment, especially in rural areas. The judicious management of water resources is fundamental to sustaining this sector, which, in turn, plays a pivotal role in the broader economic and social development of the nation (Benabdelkader et al., 2021; Boulakhbar et al., 2020). Over the past decade, the agricultural sector in Morocco has experienced remarkable economic and commercial achievements, primarily driven by the implementation of the Green Morocco Plan strategy (Bounif et al., 2021; Montanari and Bergh 2019). However, Morocco faces the ongoing degradation of its natural resources and biodiversity, including water, soil, and forests. This deterioration is primarily attributed to arbitrary and unsustainable practices employed by agricultural producers and investors(El Mountassir et al., 2022). In addition to the climate change witnessed by our planet and its effects in general on water, soil and forests. Hence the importance of research and evaluation of the quality of water in the study area, as it is an important agricultural area in Morocco as a result of farmers' excessive use of fertilizers and the discharge of sewage as well as waste from various industries, which flow into the Esbou River and the Nador Canal surrounding the study area.

Misaghi et al., 2017) proposed an irrigation water quality index for the Ghezel Ozan River in Iran (Misaghi et al., 2017). This index, called the WQI-NSF, was developed by analyzing fifty years of monitoring data and incorporating guidance from the FAO's irrigation guidelines outlined by Ayers and Westcot in 1999 (Ayers and Westcot, 1999). The parameters included in the assessment were sodium, chloride, pH, bicarbonate, electrical conductivity, sodium adsorption ratio, and total dissolved solids. The water quality was categorized into 5 classes: "very bad," "bad," "average," "good," and "very good." The analysis of the river under investigation showed a transition in water quality from "very bad" to "good" over four seasons, indicating a noticeable influence of seasonal variations on water quality. Therefore, the irrigation water quality index (IWQI) serves as a valuable instrument for assessing water quality and has found extensive application in numerous academic and research projects. It has been employed in various studies conducted in different countries (Bedoui et al., 2022; Ibrahim et al., 2023; Misaghi et al., 2017; M'nassri et al., 2022, 2022; Zafar et al., 2022). This study aims to evaluate the quality of well water for irrigation purposes using the IWQI in the Sidi Allal Tazi region, Morocco.

## MATERIALS AND METHODS

### Study area

The study region is sited in the city of Sidi Allal Al-Tazi, Morocco, and is located in the Gharb-Cherada-Bani Hssen region, between the coastal region and the Sebou River in the northwest of the country. It is located between longitude -6.32 degrees west and latitude 34.51 degrees north (Al-Aizari et al., 2023). The climate of Sidi Allal Al-Tazi is characterized by a semi-arid to arid. Precipitation is higher in winter than in summer. The climate of the region is of Csa type. The middling annual temperature in Sidi Allal Tazi is 21 °C. The average annual precipitation is 5,600 mm. On the other hand, December records the heaviest rainfall of the year, with an average of 120 mm. In terms of temperature, August stands as the pinnacle of heat during the year, characterized by an average temperature of 30 °C. Conversely, January represents the coldest, with an average of 10 °C. Thus the climate of Sidi Allal Tazi is characterized by rainy winters and drier summers, with moderate temperatures throughout the year (Beniken et al., 2020; Mohammed et al., 2018).

### Field and laboratory methods

In January 2020, a field survey was conducted in the Sidi Allal region, during which 45 groundwater samples were collected. All samples were transported to the laboratory in Kenitra and preserved to facilitate measurements using standard chemical methods. The local measurement of electrical conductivity (EC) was performed using a conductometer (Thermo ORION 3 STAR), and pH values were measured using a pH meter (WTW) in the laboratory. Bicarbonate and chloride levels were determined using titration methods, while sodium levels were measured using photometers and a flame. All samples collected from the study area were analyzed in the laboratory following the procedures outlined by (Adams 2017). To assess the groundwater pollution index and its suitability for irrigation, various factors related to irrigation were calculated.

### Irrigation evaluation factors

The chemical parameters of groundwater play an important role in determining the characteristics of crops, plants, and soil. The most important of these factors are total dissolved solids, sodium percentage, sodium absorption ratio, Kelly ratio, magnesium ratio, residual sodium carbonate, and permeability index, to evaluate the quality of irrigation water. Mathematical equations to calculate the groundwater quality parameters.

Sodium percentage (Na%) was calculated by the following Equation 1:

$$Na\,\% = \frac{Na + k}{Na + Ca^{2+} + Mg^{2+}} \times 100 \quad (1)$$

The sodium adsorption ratio (SAR) was calculated by the following equation given by Equation 2:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (2)$$

The residuals of carbonates and bicarbonates can be calculated by the following equations. The residual sodium carbonate (RSC) is expressed as Equation 3:

$$RSC = (HCO_3^{-} + C0_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

Magnesium adsorption ratio (MR), also known as magnesium hazard, was calculated by Equation 4:

$$MR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (4)$$

where: the concentrations of $Ca^{2+}$, $Mg^{2+}$ and $Na^{+}$ are represented in meq/L.

The Kelly's ratio (KR) is calculated using the following Equation 5:

$$KR = \frac{Na^{+}}{Ca^{++} + Mg^{++}} \quad (5)$$

The permeability index parameter was calculated by the following Equation 6:

$$PI = \frac{Na^{+} + \sqrt{HCO3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \quad (6)$$

### Irrigation water quality index

IWQI has been widely employed to select the appropriateness of groundwater for irrigation purposes by (Misaghi et al., 2017). Meireles et al. (2010) derived the weights assigned to each parameter used in IWQI calculations (Meireles et al., 2010). It is estimated using Equation 7 (Table 1). Irrigation estimation using the IWQI have five different classes (Table 3).

$$IWQI = \sum W_i Q_i = \sum \left[ \left( \frac{w_i}{\sum_n^{i=1} w_i} \right) \cdot \left( q_{iamx} - \left( \frac{(\chi_{ij} - \chi_{inf}) \cdot (q_{iamp})}{\chi amp} \right) \right) \right] \quad (7)$$

where: $q_{imax}$ is the highest value of ($qt$), the observed value for the parameter is denoted as $X_{ij}$, while $X_{inf}$ corresponds to the value associated with the observed lower limit of the class to which the parameter belongs $q_{iamp}$ refers to the range of the class, and *Xamp* represents the class range to which the parameter belongs. To evaluate *Xamp* for the last class of each parameter, the upper limit is determined based on the highest value obtained from the physicochemical analysis of the water samples (Table 1).

Irrigation estimation using IWQ they are five different classes (Table 2).

## RESULTS AND DISCUSSIONS

To determine the suitability of groundwater for irrigation, the irrigation factors and IWQI were employed for each sample (Table 3).

### Irrigation evaluation factors

The assessment of irrigation water quality incorporates multiple factors such as potential

**Table 1.** Weights for the parameters of IWQI (Meireles et al., 2010)

| Parameters | Weight ($W_i$) |
|---|---|
| EC | 0.211 |
| SAR | 0.189 |
| $Na^+$ | 0.204 |
| $Cl^-$ | 0.194 |
| $HCO_3^-$ | 0.202 |

salinity, sodium adsorption ratio, sodium percentage, residual sodium carbonate, Kelley's ratio, magnesium ratio, and permeability index. These parameters collectively contribute to evaluating the suitability of irrigation water for agricultural purposes. Ameen emphasizes the significant impact of chemical parameters in groundwater on crop, plant, and soil characteristics. Evaluating the quality of irrigation water involves considering various factors. Table 4 displays the outcomes for all the irrigation factors.

Based on the total dissolved solids (TDS) for irrigation as described (Arshad and Shakoor 2017). The concentration of TDS ranged from 568.10 to 4966 with a mean of 1746.81 mg/l (Table 4, Figure 1a). About, 64.4% of the wells from the study area were classified as permissible, 9% of the wells were as doubtful, while 26% of wells were categorized as unsuitable for irrigation. It is possible that ion exchange and evaporation activities have increased salinity in most wells, resulting in reduced crop yields and plant fertility characteristics (Satish Kumar et al., 2016). The percentage of sodium in irrigation water quality can be assessed by calculating the concentrations of all dissolved cations in meq/l. The values of Na varied between 39.65 and 85.73%, with an average of 60.4% (Table 3). About 2.22% of the wells were classified as good, 54.55 as permissible, and 42.3% as doubtful for irrigation (Table 4, Figure 1b). The Wilcox diagram is a chart that ranks water samples based on their suitability for irrigation (Al-Aizari et al., 2024). According to the Wilcox diagram classification, approximately 66.7% of the wells were classified as good, 9% as permissible, and 24% as doubtful for irrigation in Sidi Allal Tazi region (Figure 2a) (Lanza et al., 2019; Todd and Mays, 2004). The values of the sodium adsorption ratio ranged from 1.39 to 17.91, with a mean of 5.45 (Table 4, Figure 2b). According to Al-Aizari et al. (2024), about 58% of the wells were suitable, 20% were moderate, and 22% were unsuitable in study area. Elevated sodium concentration in the soil leads to increased alkalinity, degradation of soil structure and texture, and adversely affects vegetation (Lanza et al., 2019; Todd and Mays 2004).

The values of the residual sodium carbonate (RSC) varied from -3.99 to 5.17, with a mean of 0.74 (Table 3). According to Al-Aizari et al. (2024), about 76% of the wells were classified as excellent, 16% as suitable, and 9% as unsuitable in Sidi Allal Tazi area (Table 4, Figure 3a). The

**Table 2.** Classification of water quality ranges and types of water based on IWQI

| Range IWQI | 0–40 | 40–55 | 55–70 | 70–85 | 85–100 |
|---|---|---|---|---|---|
| Quality of water | Severe restriction (SR) | High restriction (HR) | Moderate restriction (MR) | Low restriction (LR) | No restriction (NR) |

**Table 3.** Descriptive statistics of irrigation evaluation factors

| Variable | Maximum | Minimum | Mean |
|---|---|---|---|
| TDS | 4966.00 | 568.10 | 1746.81 |
| Na% | 85.73 | 39.65 | 60.40 |
| RSC | 5.17 | -3.99 | 0.74 |
| SAR | 17.91 | 1.39 | 5.45 |
| MR | 72.50 | 9.76 | 27.67 |
| KR | 5.98 | 0.62 | 2.07 |
| PI | 90.90 | 63.21 | 78.93 |
| IWQI | 83.73 | 6.61 | 55.70 |

**Note:** TDS – dissolved salt; SAR – sodium absorption rate; RSC – residual sodium carbonate; MR – magnesium ratio; PS – potential salinity; PI – permeability index; IWQI – irrigation water quality index.

**Table 4.** Evaluation of irrigation water quality parameters

| Irrigation water quality | Grade | Category | No | % |
|---|---|---|---|---|
| TDS | Excellent | < 175 | 0 | |
| | Good | 175–525 | 0 | |
| | Permissible | 525–1400 | 29 | 64.4 |
| | Doubtful | 1400- 2100 | 4 | 9 |
| NA% | Good | 20–40 | 1 | 2.22 |
| | Permissible | 40–60 | 25 | 55.55 |
| | Doubtful | 60–80 | 19 | 42.23 |
| KR | Suitable | < 1 | 15 | 34 |
| | Unsuitable | > 1 | 30 | 66 |
| RSC | Excellent | > 1.25 | 34 | 75 |
| | Suitable | 1.25–2.5 | 7 | 16 |
| | Unsuitable | > 2.5 | 4 | 9 |
| MR | Suitable | < 50 | 33 | 98 |
| | Unsuitable | > 50 | 1 | 2 |
| PI | Suitable | > 75 | 30 | 66 |
| | Good | 25–75 | 15 | 34 |
| | Unsuitable | < 25 | 0 | |
| SAR | Suitable | < 3 | 26 | 58 |
| | Moderate | 3–9 | 9 | 20 |
| | Unsuitable | > 9 | 10 | 22 |

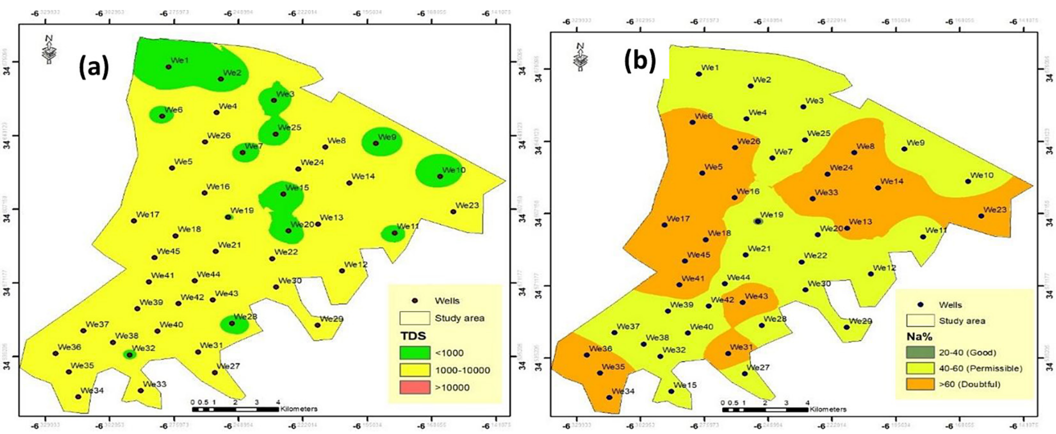


**Figure 1.** Spatial distribution of TDS (a) and Na%(b) in Sidi Allal Tazi region

occurrence of alkaline earth elements surpassing the concentration of carbonates in wells, along with elevated levels of carbonate and bicarbonate, can result in increased precipitation of alkaline earth minerals. This can have adverse effects on soil structure and potentially contribute to the activation of soil sodium, making it more susceptible to vulnerability (Janardhana Raju et al., 2011; Rawat et al., 2018).The values of KR ranged from 0.62 to 5.98, with an average of 2.07 (Table 3). According to the categories defined by Kelley (Al-Aizari et al., 2024), about, 34% of the wells were suitable, while 66% were unsuitable for irrigation due to high levels of sodium (Table 4, Figure 4b). The magnesium ratio (MR) for groundwater is divided into two categories: a ratio greater than 50 is considered unsuitable for irrigation, while a ratio less than 50 is considered suitable (Haritash et al., 2016). The values of the magnesium ratio ranged between 45.5 and 87.96, with a mean of 37.6 (Table 4). About 98% of the wells were suitable for irrigation, while

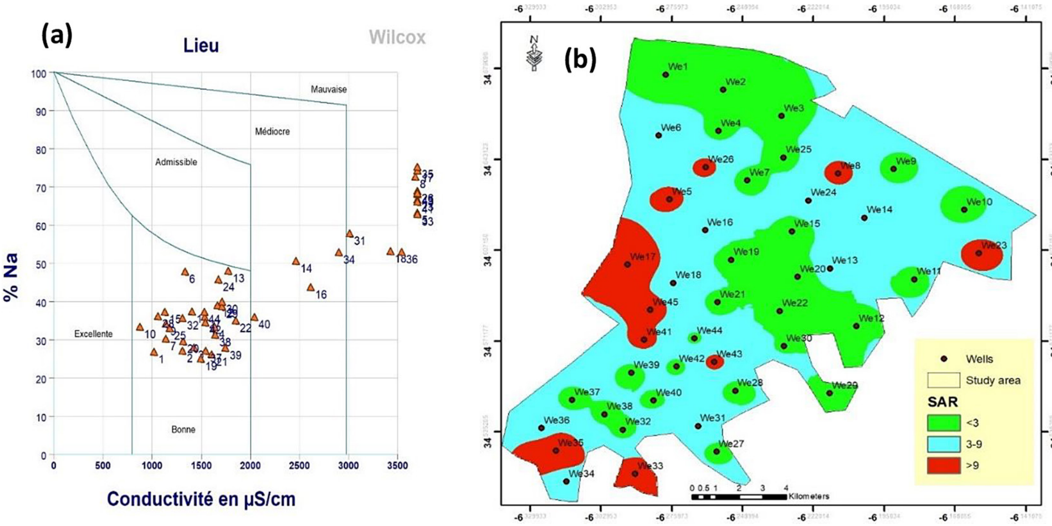


**Figure 2.** Wilcox diagram (interaction between Na% and EC), (a) and Spatial distribution of SAR (b) in Sidi Allal Tazi region

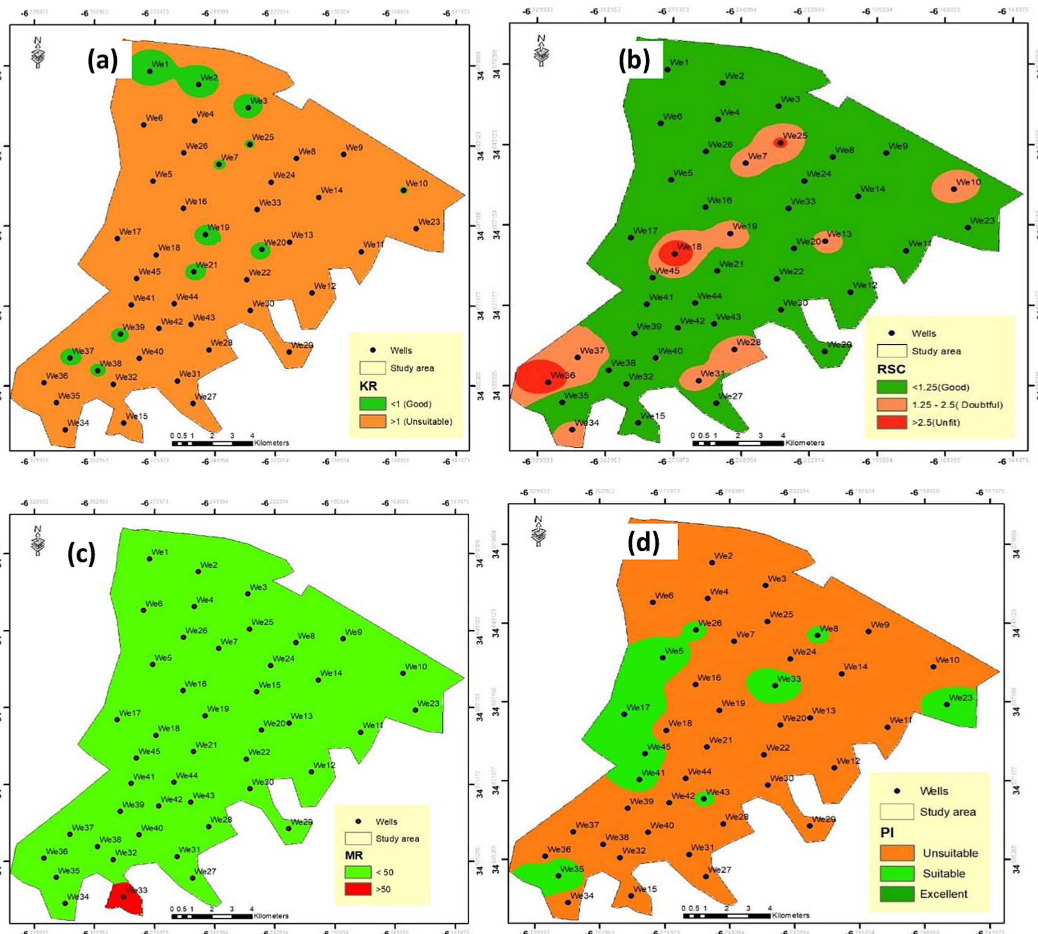


**Figure 3.** Spatial distribution of RSC (a) KR (b) MR (c) and PI (d) in Sidi Allal Tazi region

2% were unsuitable to irrigation in Sidi Allal Tazi area (Table 4 and Figure 4c). Calcium and magnesium play an important role in improving the degraded structure of plants and their basic functions. However, irrigation with groundwater affects the MR level, which, in turn, impacts the alkaline properties of the soil and agricultural yield (Gautam et al., 2015). According to

**Table 5.** Groundwater classification based on IWQI

| Stations | IWQI | Quality of water | Stations | IWQI | Quality of water |
|---|---|---|---|---|---|
| We1 | 77.83 | (LR) | We24 | 63.07 | (MR) |
| We2 | 72.17 | (LR) | We25 | 70.66 | (LR) |
| We3 | 70.82 | (LR) | We26 | 29.26 | (SR) |
| We4 | 80.22 | (LR) | We27 | 70.96 | (LR) |
| We5 | 19.60 | (SR) | We28 | 73.38 | (LR) |
| We6 | 63.07 | (MR) | We29 | 76.97 | (LR) |
| We7 | 75.39 | (LR) | We30 | 75.33 | (LR) |
| We8 | 25.53 | (SR) | We31 | 38.54 | (HR) |
| We9 | 73.10 | (LR) | We32 | 71.35 | (LR) |
| We10 | 83.73 | (LR) | We33 | 6.61 | (SR) |
| We11 | 67.06 | (MR) | We34 | 30.43 | (SR) |
| We12 | 79.34 | (LR) | We35 | 10.90 | (SR) |
| We13 | 68.49 | (MR) | We36 | 27.72 | (SR) |
| We14 | 45.09 | (HR) | We37 | 68.25 | (MR) |
| We15 | 74.10 | (LR) | We38 | 68.97 | (MR) |
| We16 | 44.14 | (HR) | We39 | 65.79 | (MR) |
| We17 | 15.08 | (SR) | We40 | 71.07 | (LR) |
| We18 | 29.55 | (SR) | We41 | 19.59 | (SR) |
| We19 | 69.58 | (MR) | We42 | 70.58 | (LR) |
| We20 | 72.02 | (LR) | We43 | 27.67 | (SR) |
| We21 | 69.62 | (MR) | We44 | 67.63 | (MR) |
| We22 | 75.59 | (LR) | We45 | 20.63 | (SR) |
| We23 | 21.01 | (SR) | | | |

**Note:** MR – moderate restriction; LR – low restriction; SR – severe restriction; HR – high restriction.

Selvam et al., 2013, the permeability index (PI) for groundwater samples can be classified into three categories for irrigation (Table 4) (Selvam et al., 2013). The values of the permeability index ranged from 63.21 to 90.90, with a mean of 78.93 (Table 3). Approximately 66% of the samples fell into the suitable category, while 34% were considered good (Table 4, Figure 4d). In the Sidi Allal area, certain samples exhibit favorable characteristics for soil permeability, making them suitable for various types of irrigation activities.

## Irrigation water quality index

The value of IWQI ranged from 24.95 to 69.48 with an average of 50.98 (Table 4). About 29% of the water samples were severe restriction (SR), 6.6% of samples were high restriction (HR), 22.2% of samples were moderate restriction (MR), and 42.2% of samples were low restriction for irrigation categories, suggesting that groundwater from the Sidi Allal region is suitable for irrigation purposes (Table 5, Figure 4). The results indicate that Lower values of IWQI for some of the wells may be attributed to the high levels of EC, $Na^+$, SAR, $Cl^-$, due to the city wastewater and irrigation return flows from agricultural land. it observed in this study that most of the wells contain low to medium IWQI values, It was found that more than a third of the study area is unsuitable for irrigation. the contamination of groundwater in the specific study area is primarily caused by two main sources: sewage waste and waste generated from agricultural activities. In other words, the presence of pollutants or harmful substances in the groundwater is a result of the discharge of untreated sewage or wastewater, as well as the release of agricultural chemicals and byproducts into the ground. These contaminants can have adverse effects on the quality and safety of the groundwater, which may pose environmental and health concerns in the area being studied. Through the use of IWQI, researchers and practitioners can make informed decisions about the suitability of

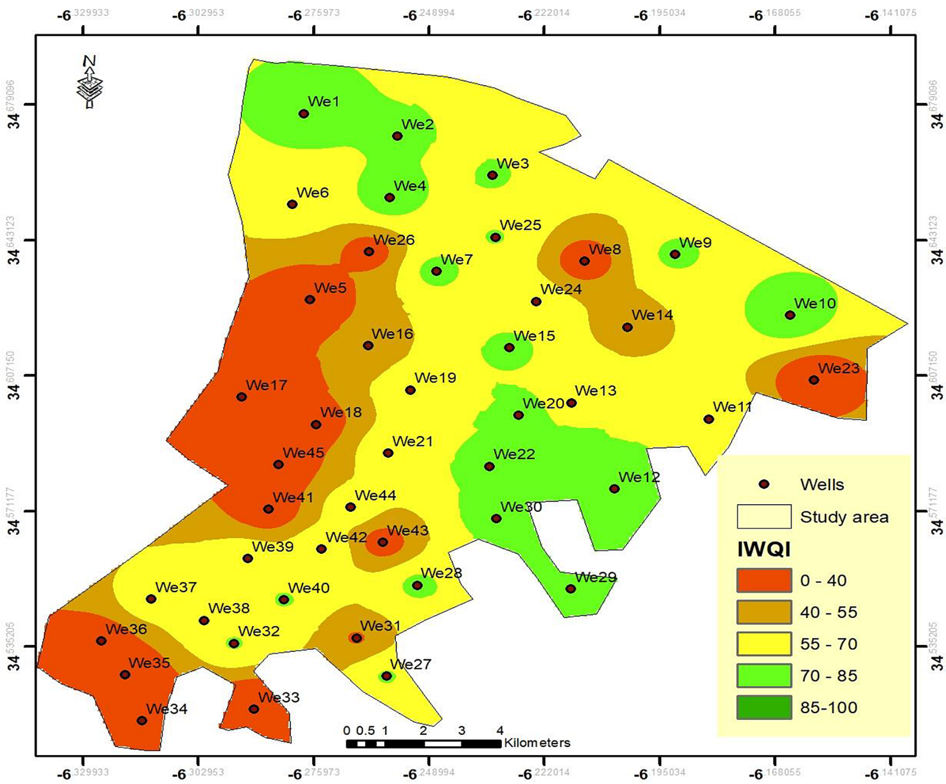


**Figure 4.** Spatial distribution of IWQI in Sidi Allal Tazi region

water for irrigation, helping to ensure that the water used meets standards and standards necessary to support healthy and productive crop growth. This indicator is a valuable tool in agricultural management, providing insights into the overall quality of irrigation water and helping to improve irrigation practices for sustainable and efficient crop growing.

## CONCLUSION

The consequences of TDS, %Na, KR, and SAR indices indicated that 22–66% of the wells are unsuitable for irrigation, while PI, MR, and RSC indices categorized 91–100% of the wells as suitable for irrigation in the Sidi Allal region. According to the IWQI map obtained, 42.2% of the study area was found to be unsuitable for irrigation. It is clear that more than half of the study area has underground well water suitable for irrigation, while approximately more than a third of the area is suitable for irrigation only. To grow salt-resistant plants. These results indicate that some groundwater in the Sidi Allal region is generally unsuitable for irrigation, especially wells near the Nador Canal and the Esbou Rive.

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