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Spatial and Temporal Water Quality Analysis of a Semi-Arid River for Drinking and Irrigation Purposes Using Water Quality Indices and GIS

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ABSTRACT

Aim This study aimed to assess the water quality of Ardak River and analyze its suitability for drinking and agricultural purposes.
Materials & Methods In this research, water samples were collected during dry and wet seasons in 2018 from previously selected 5 sampling stations. Then, the water quality index (WQI) and irrigation-related indices were calculated.
Findings The calculated WQI values are between 156.77 and 379.59 in the study area, which shows the water quality of Ardak River is in the "poor" to "unsuitable for drinking" range both periods. The effects of water quality parameters on the WQI were evaluated, and the obtained outcomes indicate that the highest mean effective weight value belongs to the fecal coliform and phosphate parameters compared to the other parameters. Furthermore, various indices such as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium hazard (MH), Kelly's index (KI), and Permeability index (PI) were used to assess river water quality for irrigation purposes. The results indicate that the river water quality is generally moderately suitable to safe with exceptions at a few sampling stations in the dry season, which are unsuitable for irrigation purposes.
Conclusion Due to the negative effects of anthropogenic pollutants such as animal husbandry, intensive agricultural activities, and rural wastewater discharging, the water quality of the Ardak River is deteriorating. Therefore, necessary protection steps should be taken in the Ardak Watershed.

Keywords WQI; Environmental Pollution; Water Quality; Irrigation Indices; Spatial Distribution

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Introduction

The development of the global economic system caused by modernization and industrialization has deteriorated water quality, reducing its total use. Hence, apart from researching the number of water resources, quality research is vital for sustainable development. Therefore, water quality assessment as a water quality component has become a popular topic among scientists and researchers to protect the water environment [1]. There are different methods and purposes in the subject of water quality assessment. Some researchers focus on groundwater quality assessment [2-4], and others focus on surface water resources [5, 6] in their studies based on their aims. According to the significant role of rivers as the main freshwater resource for different purposes, it is wise to have reliable water quality information for effective water resources management [7]. Generally, water quality encompasses the water's aesthetic, physical, chemical, and biological characteristics [8]. The assessment of these water characteristics is essential due to extreme demand and vulnerability to pollution, especially in developing countries [9].

On the one hand, the assessment of surface waters for drinking purposes is the most significant aspect as it is directly related to human health. Different organizations of various countries have recommended the standards for drinking water quality for ensuring good health. Nevertheless, the comparison with these standards does not indicate the suitability of water for drinking. Hence, the researchers formulated a water quality index (WQI) to evaluate the water quality for drinking purposes very efficiently and effectively. WQI aggregates the measured concentration of water quality parameters into a single-digit, which is easy to understand. While there is no standard protocol for calculating WQI, however, every country or region calculates WQI according to its convention. In 1965, Horton developed WQI as a mathematical technique to assess its status by incorporating the eight significant water quality parameters [10]. Afterward, in the 1970s, Brown, in collaboration with the National Sanitation Foundation of USA, proposed a modified index, known as National Sanitation Foundation Water Quality Index (NSFWQI) [11].

Nevertheless, these additive formulae lacked sensitivity, as a single toxic parameter can influence all the parameters' value, which cumulatively gives the result of the water quality index (WQI). Therefore, Brown again formulated a multiplicative index to transcend this limitation. Besides, many researchers and scientists have changed the concept as per the need of the hour and the region [12, 13]. Numerous water quality indices have been formulated by different organizations around the world such as the U.S. National Sanitation Foundation Water Quality Index (NSFWQI) [14], Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) [15], British Columbia Water Quality Index (BCWQI), and Oregon Water Quality Index (OWQI) [12]. Şener *et al.* [16] evaluated the river water quality for drinking purposes using the water quality index (WQI) method and GIS in Aksu River, Turkey. Their study indicated that the effects of pollutants dominate the river water quality, and COD and Mg were the most effective water quality parameters on the determination of WQI. Wu *et al.* [17] proposed the minimum water quality index (WQI_{min}), which was developed based on a stepwise linear regression analysis to assess river water quality in Lake Taihu Basin, China. According to the authors, this method can be beneficial for water quality management and could be applied for low-cost and rapid water quality assessment. In another study, Tian *et al.* [18] used a water quality index to evaluate the water quality of the upper and middle streams of the Luanhe River, northern China. Their study's outcomes showed that agricultural and urban-related activities were the most important factors affecting this region's water quality. Ajorlo & Abdullah [19], Ewaid & Abed [20], Pirali Zefrehei *et al.* [5], and Lkr *et al.* [6] also calculated WQI in order to assess the spatial and temporal variability of surface water quality for drinking purposes. In Iran, Ebrahimi *et al.* [21] assess the water quality of the Tajan River with the use of biological and quality indicators. According to the results of this study, the water quality of the Tajan River ranged from medium to very bad. Hosseini *et al.* [22] evaluated the application of water quality index (WQI) and hydro-geochemistry for surface water quality assessment in Chahnimeh reservoirs in the Sistan and Baluchestan Province. Their results showed that the use of WQI was helpful for fast data interpretation for drinking water purposes in the area, and the majority of the samples are falling under the good to poor water category.

In another study, Moravej *et al.* [23] using Water

Quality Index and GIS, evaluated Karun River's water quality status. According to their results, Karun river water quality has increased slightly compared to the past. After the Dez river junction, a relatively high decrease in WQI occurred that can indicate Dez River's lower quality because of entering pollutant loads in Dezful station downstream and calls for control measures on the river.

On the other hand, surface waters also are used heavily in agriculture setup. This is because agriculture is a vital sector contributing significantly to many countries' economic scenarios and provides life support to a major portion of the world [24]. The quality of irrigation water mainly affects soil quality and crop yield. Furthermore, the poor irrigation water quality causes numerous hazards such as salinity hazards, infiltration and permeability issues, specific ion toxicity, and various problems [25]. Therefore, irrigation water quality assessment is highly important for sustainable agriculture. Different researchers use some physicochemical and hydro-geochemical parameters, and irrigation indices are used by different researchers [25-27]. Quite recently, an irrigation water quality evaluation using sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and permeability index (P.I.) was undertaken by Kundu & Ara [28] in Bangladesh to assess the usability of Chitra river water for irrigation during pre-monsoon, monsoon and post-monsoon. Their study indicated that the water of Chitra River is chemically suitable for irrigation during pre-monsoon. Tomaz *et al*. [29] investigated the spatial and temporal dynamics of irrigation water quality under drought conditions in Portugal's large reservoir. The results exhibited significantly higher values of the physicochemical parameters in the most upstream sites, located near tributaries inflows, and a rising ion concentration trend throughout the year. In Iran, researchers assessed river water quality for irrigation purposes using statistical and graphical techniques such as principal component analysis (PCA) and Wilcox diagram [30, 31], and using irrigation quality indices was more common for groundwater quality assessment.

This study was conducted on the Ardak River in upstream of the Ardak dam, located in the north of Khorasan Razavi province, Iran. This dam reservoir has a pivotal role in providing the water supply of the downstream regions, especially for Mashhad's drinking sector, with a population of around 3 million, which is one of the largest cities in Iran. Additionally, Ardak Watershed is a major agricultural productive region of Khorasan Razavi province, and crop production here significantly depends on the Ardak River water for irrigation. However, there is not sufficient information about the water quality of the Ardak River. This research's novelty and contribution to the literature describe it using a new WQI method and irrigation water quality indices for river water quality assessment upstream of an important dam in Iran. Therefore, this study on the Ardak River has to be done to help water quality management and address downstream pollution concerns. The main objectives of this research were (1) to evaluate the physicochemical characteristics of the river water, (2) to determine the water quality of the Ardak River through water quality indices, and create spatial distribution maps using GIS, (3) to evaluate various irrigation indices such as sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), permeability index (P.I.), Kelley's ratio (K.R.) and magnesium hazard (M.H.) and (4) to discuss the suitability of the water for drinking and agricultural purposes.

Materials and Methods

Description of the study area

The Ardak Watershed is located in the north of Khorasan Razavi province, Iran, and extends for an area of about 479km^2, and lies within 36°43'07"N to 36°59'32"N latitudes and 59°08'07"E to 59°31'37"E longitudes. The minimum and maximum elevations in this region are 1235 and 2950m.a.s.l, respectively (Figure 1).

The mean annual temperature and precipitation are 9°C and 419mm, respectively. According to De Martonne Index climatic classification, Ardak Watershed is characterized by the Mediterranean climate. A total of 10 residential centers are evident, which are sporadically distributed across the study area. A 55.5km of roads -paved an unpaved- are extended across the region. Land covers were disintegrated in terms of type, the density of the vegetation cover, and usage-wise to attain more realistic and precise results. Based on the latter, poor pasture covers the largest area (74.5% of the entire region), followed by moderate-condition pastures (8.5%) and very-low-density forests (8.1%) while the remaining area is shared between orchards, rainfed farming, low-density forests, and woodlands. The lithology of Ardak Watershed is different, and it is surrounded by Chaman Bid (dark grey argillaceous limestone and marl), Mozduran (grey thick-bedded limestone and dolomite), Shurijeh (pale red argillaceous limestone, marl, gypsiferous marl, sandstone, and conglomerate), Tirgan (grey oolitic and bioclastic orbitolina limestone), and Sarcheshme (dark grey marl and bioclastic limestone) formations which cover around 5%, 49%, 30%, 15% and 1% of the study area, respectively. Evaluation of river water quality is vital within this area because the dam mentioned above, the reservoir in the southernmost part of the Ardak Watershed, supplies drinking water and irrigation requirements.

Sampling and analytical procedure

The water samples were collected in two field surveys along the Ardak River during dry and wet seasons in 2018 from previously selected five sampling stations. These stations were selected based on the geo-environmental conditions, ease of access, and points at the downstream end of relevant sub-watersheds. Based on Iran Water Quality Index for Surface Water Resources ($IRWQI_{SC}$) and suggestions in previous publications, fourteen representative parameters were chosen to measure to calculate WQI for water quality assessment for drinking purpose, including fecal coliform, biological oxygen demand (BOD), nitrate (NO_3^-), dissolved oxygen (D.O.), electrical conductivity (E.C.), chemical oxygen demand (COD), ammonium (NH_4^+), phosphate ($P.O._4^{3-}$), turbidity, total hardness (T.H.), pH, arsenic (As), lead (Pb), and cadmium (Cd), and six parameters including calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), potassium (K^+), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}) were selected for calculating various irrigation water quality indices (Table 1). The temperature and pH values were directly determined in situ using a laboratory mercury thermometer and pocket pH meter. The water samples were collected manually from a depth of 10 cm from the water's surface, preferentially where the flow of the water was high, to obtain good homogenized samples [32]. After collecting the samples, they were transported to the laboratory with a favorable temperature (<4°C). The pretreatment and determination for the other parameters in the laboratory followed the procedures described in APHA 2017 [33] and using various equipment such as conductivity meter, spectrophotometer (nitrate, ammonium, phosphate), D.O. meter, atomic absorption (arsenic, cadmium, lead), flame photometer (Sodium, potassium, calcium, Magnesium), incubator (fecal coliform, biological oxygen demand), COD meter, and turbidity meter.

Analytical methods

Water quality: WQI is defined as a rating that indicates the mixed influence of various water quality parameters [16, 34]. First of all, each of the chemical parameters was assigned various weights (w_i) on a scale of 1 (least influence on water quality) to 5 (highest influence on water quality) based on their perceived influences on primary health and according to its relative importance in the quality of drinking water (Table 2). The highest weight of 5 was assigned to parameters that have crucial health influences and whose presence above the World Health Organization (WHO) 's critical concentration limits (WHO), which could limit the usability of the water resources for drinking and domestic purposes [35, 36]. Fecal coliform, NO_3^-, D.O., As, Pb, and Cd were assigned the highest weight (5) because of their great importance in the assessment of water quality. The relative weight (W_i) is calculated from the following equation [16]:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

where W_i is relative weight, w_i is the weight of each parameter, and n is the number of parameters. Then, a quality rating (q_i) for each parameter is assigned by dividing its concentration in each water sample by its limits values given by the WHO [37] and the result multiplied by 100 [16]:

$$q_i = \frac{C_i}{S_i} \times 100 \tag{2}$$

where q_i is the quality rating, C_i is each parameter concentration in each water sample in mg/L, and S_i according to the WHO guidelines, each parameter in milligrams per liter is the standard of drinking water [37]. To compute WQI, firstly the value of $S.I._i$ should be determined with the following equations [16]:

$$SI_i = W_i \times q_i \tag{3}$$

$$WQI = \sum_{i=1}^{n} SI_i \tag{4}$$

where $S.I._i$ is the sub-index of the ith parameter; q_i is the quality rating based on the concentration of the ith parameter. The calculated WQI values are categorized into five classes: Excellent (<50), Good (50–100), Poor (100–200), Very poor (200–300), Unsuitable for drinking (>300) [34, 35].

Furthermore, to determine the parameter with the greatest effect on WQI results, the effective weight (E_{wi}) for each water quality parameter was defined by dividing its sub-index value by overall WQI value and the result multiplied by 100 as in the following equations [16]:

$$E_{wi} = \frac{SI_i}{WQI} \times 100 \quad (5)$$

where, E_{wi} is the effective weight of ith parameter; $S.I._i$ is the sub-index of the ith parameter, and WQI is the overall WQI calculated by Equation 4. The effective weights were compared with relative weights, which is reflects the significance of each parameter concerning the other parameters applied in WQI calculations.

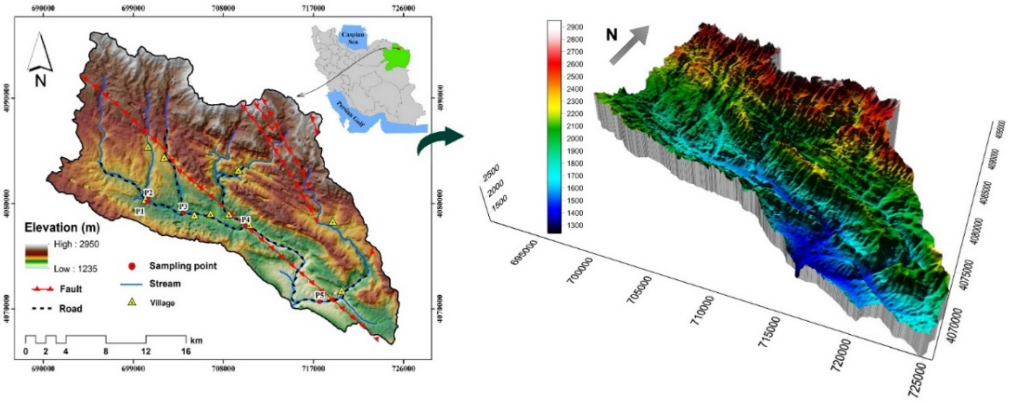

Figure 1) Geographical location of the study area in Khorasan Razavi province in Iran with an oblique view of the region

Table 1) Statistical summary of the physical and chemical parameters of the river water

Parameters	Dry period				Wet period			
	Maximum	Minimum	Mean	S.D.	Maximum	Minimum	Mean	S.D.
Fecal coliform (MPN/100ml)	1120.00	1080.00	1105.00	15.81	1350.00	103	779.60	553.48
BOD (mg/L)	9.00	4.50	6.46	1.96	4.80	3.69	4.15	0.46
NO_3^- (mg/L)	55.20	10.90	27.28	17.72	37.40	11.00	20.08	11.32
DO (mg/L)	10.40	7.70	9.02	0.96	8.25	7.15	7.55	0.42
EC (µS/cm)	1247.00	650.00	832.40	238.49	863.00	512.50	683.60	140.29
COD (mg/L)	24.00	10.00	18.00	6.00	15.61	5.80	9.75	3.80
NH_4^+ (mg/L)	3.38	0.09	0.82	1.43	1.10	0.21	0.48	0.35
PO_4^{3-} (mg/L)	1.13	0.40	0.61	0.30	0.48	0.17	0.32	0.14
Turbidity (NTU)	4.21	0.20	1.89	1.48	41.53	5.68	25.24	15.28
Total hardness (mg/L)	550.00	244.05	360.95	114.98	300.00	205.00	262.40	46.02
pH	7.79	7.48	7.68	0.12	7.97	7.81	7.88	0.07
As (mg/L)	0.0054	0.0040	0.0047	0.0006	0.0034	0.0031	0.0033	0.0001
Pb (mg/L)	0.0079	0.0063	0.0073	0.0006	0.0142	0.0113	0.0126	0.0012
Cd (mg/L)	0.0025	0.0001	0.0010	0.0010	0.0045	0.0019	0.0033	0.0012
Ca^{2+} (mg/L)	186.00	60.00	133.80	52.49	73.00	46.60	62.48	11.22
Mg^{2+} (mg/L)	96.00	20.20	39.45	31.96	29.40	19.80	25.61	4.70
Na^+ (mg/L)	44.00	15.00	30.64	11.31	51.13	14.58	31.94	13.85
K^+ (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCO_3^- (mg/L)	214.00	164.00	196.00	19.65	187.20	159.12	176.90	10.67
CO_3^{2-} (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2) the Relative weight of chemical parameters and statistical analysis of the effective weight

Parameters	WHO standards (2008)	Weight (wi)	Relative weight (Wi)	Effective weight (%)			
				Min	Max	Mean	S.D.
Fecal Coliform	50	5	0.0847	11.08	64.43	52.71	16.94
BOD	2	4	0.0678	3.93	10.13	6.51	2.06
NO_3^-	50	5	0.0847	0.58	4.04	1.53	1.17
DO	7.5-14	5	0.0847	1.22	2.92	1.86	0.52
EC	400us/cm	4	0.0678	2.29	6.29	4.69	1.27
COD	10	4	0.0678	1.57	5.26	3.24	1.08
NH_4^+	0.5	3	0.0508	0.30	9.31	2.12	2.70
PO_4^{3-}	0.1	3	0.0508	3.78	15.56	8.39	4.21
Turbidity	5NTU	4	0.0678	0.09	27.46	7.66	9.93
TH	300	3	0.0508	0.98	2.52	1.91	0.51
pH	6.5-8.5	4	0.0678	1.62	4.06	2.34	0.79
As	0.01	5	0.0847	0.72	1.85	1.25	0.36
Pb	0.01	5	0.0847	1.64	7.68	3.36	2.04
Cd	0.003	5	0.0847	0.08	5.66	2.43	1.99

∑Relative weight (Wi)= 1; ∑Weight (wi)= 59

Pearson's correlation

Pearson's correlation coefficient is an important statistical tool to present the degree of dependency of one variable to the others [38]. In other words, correlation analysis is applied to measure the interrelation and extent of associations among the parameters. The correlation coefficient value +1 exhibits a good relationship between the variables, and −1 exhibits a good relationship, but the variables vary inversely, and zero values mean there is no relationship between the variables [39]. Pearson's correlation coefficient values r>0.7 are considered a strong correlation, while r values between 0.5 and 0.7 are considered moderate. Pearson's correlation matrix portrays the dependency of parameters with each other.

Irrigation water qualities

The water suitability for irrigation purposes depends on the water's chemical and physical characteristics, especially on the dissolved salts. The irrigation water suitability is evaluated mainly in terms of undesirable dissolved salts or constituents, and in some limited cases, evaluated on plant nutrients [40, 41]. The main river water parameters that help assess irrigation purposes' suitability are E.C., pH, Sodium, calcium, Magnesium, potassium, TDS, hardness, chloride, and carbonate, bicarbonate, sulfate, and nitrate [41, 42]. Some computed indices that also help to evaluate the irrigation water suitability are discussed in the following parts accordingly.

Sodium adsorption ratio (SAR): SAR is also expressed as sodium content or alkali hazard, which is a significant index to determine the water suitability for irrigation purposes [43]. Excessive Sodium in water imparts undesirable influences on the soil characteristics and reduces soil permeability [42]. Higher salinity interferes with the osmotic activities that decrease the absorption of nutrients and water from the soil, prevents plant metabolism, and impedes water from reaching plants' leaves [28]. A high amount of Sodium in water results in the genesis of alkaline soil. The SAR measures the relative proportion of sodium ions to the magnesium and calcium ions in a water sample. In other words, SAR demonstrates the sodium hazard and is calculated using the following formula [28].

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Mg^{2+} + Ca^{2+}}{2}}} \quad (6)$$

Ionic concentrations are measured in meq/L.

Residual sodium carbonate (RSC): Concentrations of carbonate and bicarbonate play an essential role in determining water suitability for irrigation purposes. When the total carbonate concentration exceeds the total concentrations of Magnesium and calcium, and the excess residual carbonate concentration is too high, the carbonate ions combine with the magnesium and calcium ions to shape a scale. This solid material then settles out of the water. As the Magnesium and calcium settle out of the water as solid scales, the relative abundance of Sodium increases, creating deteriorating plants' results. The carbonate and bicarbonate quantity over alkaline earth metals (Magnesium and Calcium) is denoted by 'residual sodium carbonate' (RSC) [28, 42]. The term was recommended by Eaton [44] and is determined by the technique, as proposed by Allison & Richards [24]. Residual sodium carbonate is computed by the following formula [45].

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad (7)$$

All the concentrations are expressed in meq/L.

Magnesium hazard (M.H.): Magnesium and calcium ions maintain a state of equilibrium in most natural water [45]. Magnesium and calcium are not chemically equivalent, especially in the soil system. A higher concentration of Mg ion in water usually originates from the higher amount of exchangeable Na ion in irrigated soils. A high concentration of Mg ion in water adversely influences the soil quality, making the soil alkaline, contributing to low crop yield [42]. The harmful influence of Magnesium in irrigated water is measured as the magnesium ratio. Paliwal introduced an index' magnesium hazard' to determine the harmful influences of Magnesium in irrigation water and is computed as magnesium hazard (M.H.) using the following formula [42, 46]. The concentrations of magnesium and calcium ions are measured in meq/L.

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (8)$$

Kelly's index (K.I.): Water quality Suitability for irrigation purposes is also determined based on Kelly's index. In Kelly's index, Sodium is measured against Magnesium and calcium. K.I. is computed by the following formula [46] :

$$KI = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (9)$$

Where ion concentrations are expressed in meq/L.

Permeability index (P.I.): Permeability index (P.I.) is also applied for determining the irrigation water suitability [43]. The permeability of soil is influenced by long-term irrigation water exposure that contains a high quantity of Sodium, Magnesium, calcium, and bicarbonate ions [28]. Permeability index (P.I.) is introduced by Doneen to evaluate the irrigation water suitability and is computed by the following formula [43].

$$PI = \frac{(Na^{+} + \sqrt{HCO_3^{-}}) \times 100}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \quad (10)$$

The concentrations are expressed in meq/L.

Spatial distribution maps

The integration of geographical information systems (GIS) with water quality indices is one of the most popular and advanced techniques among hydrologists, as it helps in better visualization of water quality in the study area. Also, spatial distribution maps allow researchers to convey findings and information that are difficult to express verbally or to condense information that would be lengthier to describe in words. They are often more memorable because they have shape and color. They can be used to show relationships in a more striking way – by indicating the intensity of an issue in one place relative to the intensity in another place or by indicating the change in the distribution of a resource over time. Therefore, to indicate the spatial distribution of the river water quality, ArcMap 10.3 software was used for preparing the various thematic maps of water quality indices such as WQI for drinking purposes, and SAR, RSC, P.I., K.R., and M.H. for agricultural purposes. The values of the water quality indices for both seasons were assigned to each of the sampling stations considered, and "symbol size" and "color ramp" techniques were applied to the data imported, which resulted in the generation of maps that showed the variation of the WQI, SAR, RSC, P.I., K.R., and M.H. for both seasons.

Findings and Discussion

In this research, water quality indices of Ardak River were calculated for each sampling station and in both dry and rainy seasons of 2018. A statistical summary of surface water quality parameters of two different seasons (dry and wet) are presented in Table 1. The results exhibited that fecal coliform values in the sampling stations of Ardak River in the dry season varied from 1080 to 1120 and varied from 103 to 1350 in the wet season. All obtained values during both seasons exceed the WHO standard (zero in 100cm^3). These high values were due to discharges of untreated sewage in Ardak River and nonpoint sources such as runoff from livestock waste [47]. The results also showed that P2 and P4 sampling stations located downstream of major villages (Boghmech and Talghur) with a large population have the highest fecal coliform values during both dry and wet seasons. Our results confirmed the study of Culbertson *et al.* [48], who investigated the sources of fecal coliform in the Meduxnekeag River, the downstream of residential areas have the highest amount of fecal coliform values. This could be due to the river receiving many villages' wastewater discharge at these sites. BOD is the amount of oxygen used by the microorganisms to break down organic compounds for 5 days in the laboratory [18]. Hence, BOD is an indicator of organic pollution with higher values showing higher organic pollution [49]. In Ardak River, it extended from 4.50 to 9.00mg/L in the dry season, and from 3.69 to 4.80mg/L in the wet season. It was generally high, according to the quality standard of <2mg/L of the WHO [37]. The higher values of BOD highlighted the presence of prominent organic pollution sources near the sampling stations. Nitrate (NO_3^-) is an undesirable parameter in river water with detrimental health influences. The nitrate contents of water were 10.90–55.20mg/L in the dry season, and 11.00-37.40mg/L in the wet season (Table 1). Except for the P1 station in the dry season, other NO_3^- values of water samples fell far below 50mg/L, the threshold value of the WHO. The high values of nitrate in P1 station may be due to intense agricultural activities upstream. Dissolved oxygen (D.O.) is the parameter that affects biological changes by anaerobic or aerobic organisms. Therefore, the measurement of dissolved–oxygen is important to maintain aerobic treatment processes intended to purify domestic wastewaters. The standard value for good water quality is 7.5 to 14mg/L of D.O., ensuring healthy water quality for drinking [16]. The water samples' dissolved oxygen values varying from 7.70 to 10.40mg/L in the dry season, 7.15, and 8.25mg/L in the wet season and were higher during the dry season. This result is consistent with the Dongjiang River discoveries, where the D.O. values were higher in the dry season compared to the wet season [50]. The different temperature and rainfall between dry and wet seasons may affect the distributions of D.O. contents. Electrical conductivity (E.C.) of water is related to the dissolved solids concentration in the water. Furthermore, contaminants can cause high E.C. values in rivers. The E.C. values of Ardak River vary within a range of 650–1247μS/cm in the dry season and 512.50–863μS/cm in the wet season. It was always more than 250mS/cm, the standard value of WHO. COD tests anticipate oxygen requirements during the oxidation of inorganic chemicals and decomposition of organic matter. Theoretically, higher COD concentration contributes to polluted water [51]. The COD values were between 10mg/L and 24mg/L in the dry season, and between 5.80 and 15.61 in the wet season. Except for P1, P2, and P3 in the wet season, other values from all sampling stations over the permissible limit set by WHO [37] of 10mg/L. The ammonium (NH_4^+) contents of the Ardak River water contents were measured as ranging from 0.09–3.38mg/L in the dry season, and at a rate of 0.21–1.10mg/L in the wet season (Table 1).

Only the NH_4^+ concentrations measured at the P2 station that is located downstream of wastewater discharges of Boghmech exceeded the permissible limit of WHO Standards (0.5mg/L) in both seasons. This showed the negative effect of discharges from villages on the water quality of the Ardak River. The observation was in good agreement with the study of Barakat *et al.* [52]. The measured values for phosphates ($P.O_4^{3-}$) were 0.40mg/L to 1.13mg/L in the dry season and 0.17mg/L to 0.48mg/L in the wet season, which was higher than 0.1mg/L recommended by the WHO for drinking purposes. It was found that the turbidity values of the water samples were between 0.20 and 4.21NTU in the dry season, and between 5.68 and 41.53NTU in the wet season. The permissible limit of the turbidity is 5NTU, according to WHO 2008. The obtained results indicate that the turbidity values were over the limit values at all sampling stations during the wet season. Total hardness (T.H.) values were between 244.05mg/L and 550mg/L in the dry season, and between 205 and 300 in the wet season. The maximum T.H. values belong to the P2 station in both seasons. Furthermore, except for the P1 station, other stations obtained higher values than 300mg/L, the WHO's permissible drinking water levels, in the dry season. Water pH exhibits an acidic or basic nature, and it is a vital parameter in drinking and irrigation usages of water. It has profound influences on water quality, affecting the solubility of metals, hardness, and alkalinity of water [16]. Ardak River samples' pH values varied from 7.48 to 7.79 in wet and 8.81 to 9.97 during dry seasons. These results indicate that water samples of the river had alkaline characteristics. The As, Pb, and Cd contents of water samples were determined as ranging from 0.0040-0.0054mg/L, 0.0063-0.0079mg/L, and 0.0001-0.0025mg/L in the dry season, respectively. The As, Pb, and Cd contents were changed to 0.0031-0.0034mg/L, 0.0113-0.0142mg/L and 0.0019-0.0045mg/L in the wet season, respectively (Table 1). As concentrations were within the permissible limit (0.01) of WHO (2008). However, Pb concentrations at all sampling stations and Cd concentrations at P3, P4, and P5 stations exceeded the permissible limits of WHO (2008) in the wet season. Ca^{2+} and Mg^{2+} concentrations of river water samples changed from 60 to 186mg/L and 20.20 to 96mg/L in the dry season, 46 to 73 mg/L, and 19.80 to 29.40mg/L in the wet season, respectively. Na^+ concentrations varied from 15 to 44mg/L and from 14.58 to 51.13mg/L in the dry and wet seasons, respectively. HCO_3^- Water contents were determined as 164 to 214mg/L and 159.12 to 187.20mg/L in the dry and wet seasons, respectively (Table 1). Variation in bicarbonate concentration in river water may be due to bicarbonate weathering and wastewater discharge into the river [50].

To calculate the WQI, water quality variables, viz. fecal coliform, biological oxygen demand (BOD), nitrate (NO_3^-), dissolved oxygen (D.O.), electrical conductivity (E.C.), chemical oxygen demand (COD), ammonia (NH_4^+), phosphate ($P.O_4^{3-}$), turbidity, total hardness (T.H.), pH, arsenic (As), Lead (Pb), and Cadmium (Cd) were considered. The highest weight value of 5 was assigned to parameters such as fecal coliform,

NO_3^-, D.O., As, Pb, and Cd have prominent influences on water quality [16]. The WQI values varied from 289.35 to 369.28 in the dry season and from 156.77 to 379.59 in the wet season (Figure 2, a and b). Sampling stations P1 and P4 designated as very poor water; P2, P3, and P5 are unsuitable for drinking in the dry season. P1 and P3 regarded as poor water; P5 as very poor water; and P2 and P4 as unsuitable for drinking. The water quality of Ardak River is in the "poor" to "unsuitable for drinking" range for both periods, mainly due to input of rural wastes, animal husbandry, and intensive agricultural activities discharge at the bank of the river. Quantitatively, the wet season's water quality is slightly better due to a part of the pollutants is diluted and washed away with heavy rainwater.

The effective weight values of the water quality parameters were calculated by using Equation 5. The outputs were statistically summarized in Table 2, and the effective weights were compared with relative weights of the water quality parameters. Regarding calculations, the highest mean effective weights value belongs to fecal coliform, $P.O_4^{3-}$, turbidity, and BOD parameters with 52.71%, 8.39%, 7.66%, and 6.51%, respectively, and these parameters are the most effective in the calculations of WQI. However, the relative weight of $P.O_4^{3-}$ (5.08%) is lower than the turbidity (6.78%) and BOD (6.78%) parameters. Two parameters (NH_4^+ Moreover, T.H.) with low relative weights also show low effective weights. The fecal coliform, BOD, E.C., COD, and turbidity also shows high effective weights, exceeding the relative weight assigned by WQI. As and NO_3^- parameters have the lowest mean effective weights, with 1.25% and 1.53%, respectively. The most striking result is that NO_3^-, D.O., As Pb and Cd, have the highest relative weights, and at the same time have the lowest mean effective weights (Table 2). This is because these parameters were measured at very low concentrations in water samples.

Pearson correlation analysis was carried out by using SPSS 16.0 software to understand the influence among water quality parameters (fecal coliform, biological oxygen demand (BOD), nitrate (NO_3^-), dissolved oxygen (D.O.), electrical conductivity (E.C.), chemical oxygen demand (COD), ammonium (NH_4^+), phosphate ($P.O_4^{3-}$), turbidity, total hardness (T.H.), pH, arsenic (As), Lead (Pb), Cadmium (Cd), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), and bicarbonate (HCO_3^-)) (Table 1) in both dry and wet seasons. Pearson correlation matrix analysis represents significant positive correlations between E.C.–NH_4^+, E.C.–$P.O_4^{3-}$, E.C.–T.H., E.C.-Mg^{2+}, $NH_4^+ - P.O_4^{3-}$, NH_4^+-T.H., $NH_4^+ - Mg^{2+}$, $P.O_4^{3-}$-T.H., $P.O_4^{3-} - Mg^{2+}$, and T.H.-Mg^{2+} in the dry season (Table 3). In the wet season, $NO_3^- - P.O_4^{3-}$, E.C.–T.H., E.C.–Ca^{2+}, E.C.–Mg^{2+}, T.H.–Ca^{2+}, T.H.–Mg^{2+}, and $Ca^{2+} - Mg^{2+}$ were found to exist positively correlated (Table 4). While this signifies that these parameters change with direct proportionality, some parameters were an insignificant negative correlation, signifying that they change with inverse proportionality. Table 3 indicates that during dry season pH with E.C., NH_4^+, $P.O_4^{3-}$, T.H., and Mg^{2+}, fecal coliform with NO_3^-, COD with Ca^{2+} and HCO_3^-, and Cd with Na^+ have a significant negative correlation. Furthermore, during the wet season, Pb with fecal coliform and BOD, Cd with $NO_3^-$and $P.O_4^{3-}$, D.O. with HCO_3^-, and pH with Ca^{2+} are negatively correlated (Table 4). Generally, correlation coefficients between pairs of water quality parameter concentrations demonstrate that saltwater influenced indicator parameters (E.C., T.H., Ca^{2+}, Mg^{2+}) have significant positive correlations with each other during the wet season, and also have significant positive correlations with wastewater-impacted indicator parameters such as NH_4^+ and $P.O_4^{3-}$ during the dry season. These correlations can be illustrated due to the salts' strong effect on river water quality [53, 54]. The strong influence of salts on water quality in our study is consistent with Haldar *et al.* [27], who evaluated the Spatio-temporal variations in chemical-physical water quality parameters Khulna, the delta city of Bangladesh. Furthermore, the significant positive correlation between $NO_3^-$and $P.O_4^{3-}$ indicates that the NO_3^- concentrations are likely due to the leaching from agricultural land, which is similar to Barakat *et al.* [52]. Also, the non-correlation between COD and BOD, and the high COD values compared to BOD values, show that the major part of organic material is not biodegradable. Similar results with the present research were found in the study of Barakat *et al.* [52], who reported that the COD could be related to the leaching and transport of domestic sewage, natural and agricultural pollutants. Using SAR values, river waters are classified for irrigational purposes. SAR < 10 of water is considered as excellent (sodium hazard class S-I), SAR = 10–18 of water is considered as good (class S-2), SAR = 19–26 of water is considered as doubtful/fair poor (class S-III), and SAR > 26 is considered unsuitable (class S-IV) [29]. The SAR values of the Ardak River range from 0.279 to 0.882 in the dry season and 0.429 to 1.28 in the wet season. Regarding Richard's classification, all the samples were categorized as 'excellent' for irrigation purposes [42]. Furthermore, the spatial distribution of the SAR values for both the seasons along the sampling stations has been prepared (Figures 2, c, and d).

Regarding U.S. Salinity Laboratory, RSC values of less than 1.25 meq/L is safe for irrigation, RSC values of 1.25–2.5 meq/L is marginally suitable, and RSC values greater than 2.5 meq/L is unsuitable for irrigation [46]. In this research, the RSC values of water samples range from − 8.15 to - 3.89 meq/L in the dry season and from − 3.0 to - 1.17 meq/L in the wet season. RSC values of all water samples are less than 1.25 meq/L, indicating 'safe' water qualities for irrigation purposes. The reason why the RSC values of water samples are negative is that the Magnesium and calcium have not been precipitated out [42]. ArcGIS 10.3 (Figures 2, e, and f) created RSC values' spatial distribution for both seasons.

Because of the adverse effects of high Mg^{2+}concentration in the water on the soil quality and crop yield, magnesium hazard (M.H.) was also assessed for all water sampling stations. The MH values vary from 16.06 to 72.50% in the dry season and 37.30 to 42.90% in the wet season. M.H. values above 50% are not suitable for irrigation purposes and adversely affect the crop yield [46]. In the study area, except P2 sampling station in the dry season, which has M.H. value above 50% (72.50%) and is not suitable for irrigation, all the other M.H. values of water samples in both seasons are below 50%. The highest Mg^{2+} the level was measured in the P2 sampling station, supplied by untreated wastewater from Boghmech Village and dolomite and the upstream or P2 station. Based on the research carried out by Potasznik & Szymczyk [55] on the calcium and magnesium concentrations in the surface waters, it was found that large quantities of Magnesium are released to water resources from sedimentary rocks, mainly dolomite, which was dominant in the watershed. The spatial distribution of M.H. values for both dry and wet seasons are shown in Figure 3 (a and b).

Table 3) Pearson correlation matrix of water parameters in the dry season

	Coliform	BOD	NO_3	DO	EC	COD	NH_4	PO_4	Turbidity	TH	pH	AS	PB	CD	Ca	Mg	Na	HCO_3
Coliform	1																	
BOD	.339	1																
NO_3^-	-.894*	-.715	1															
DO	.345	-.176	-.253	1														
EC	.463	-.353	-.109	-.174	1													
COD	-.132	-.200	.283	-.857	.613	1												
NH_4^+	.339	-.577	.074	-.046	.965**	.538	1											
PO_4^{3-}	.383	-.443	-.007	-.271	.964**	.717	.946*	1										
Turbidity	-.623	-.628	.729	.310	-.101	-.234	.104	-.173	1									
TH	.613	-.192	-.298	-.106	.980**	.518	.911*	.914*	-.210	1								
pH	-.661	.312	.295	-.083	-.956*	-.387	-.930*	-.905*	.164	-.972**	1							
AS	-.678	-.325	.616	-.141	-.597	-.017	-.465	-.379	.153	-.720	.651	1						
P.B.	-.734	.031	.575	-.622	-.108	.392	-.128	-.156	.438	-.191	.371	.066	1					
CD	.530	.514	-.698	.522	-.474	-.668	-.529	-.461	-.540	-.334	.225	.060	-.745	1				
Ca^{2+}	.233	.782	-.596	.389	-.690	-.759	-.785	-.796	-.263	-.534	.531	-.110	-.199	.765	1			
Mg^{2+}	.375	-.476	.012	-.190	.987**	.652	.983**	.986**	-.051	.940*	-.932*	-.465	-.113	-.515	-.786	1		
Na^+	-.433	-.664	.692	-.397	.586	.650	.672	.584	.561	.439	-.373	-.072	.584	-.975**	-.861	.641	1	
HCO_3^-	-.097	-.269	.132	.817	-.234	-.763	-.076	-.391	.747	-.218	.105	-.146	-.061	.065	.277	-.252	-.013	1

* p<0.05; ** p<0.01

Table 4) Pearson correlation matrix of water parameters in the wet season

	Coliform	BOD	NO_3	DO	EC	COD	NH_4	PO_4	Turbidity	TH	pH	AS	PB	CD	Ca	Mg	Na	HCO_3
Coliform	1																	
BOD	.842	1																
NO_3^-	-.354	.001	1															
D.O.	.253	.014	-.248	1														
EC	.175	.360	-.073	-.877	1													
COD	.596	.394	-.648	.775	-.391	1												
NH_4^+	.520	.801	.457	-.440	.577	-.228	1											
PO_4^{3-}	.020	.365	.926*	-.180	.020	-.443	.714	1										
Turbidity	-.054	.077	.057	.759	-.705	.597	-.290	.063	1									
T.H.	.207	.252	-.466	-.697	.910*	-.110	.267	-.386	-.619	1								
pH	-.468	-.610	.461	.415	-.777	-.247	-.418	.259	.228	-.869	1							
AS	-.609	-.243	.511	.215	-.441	-.075	-.210	.333	.738	-.525	.340	1						
PB	-.943*	-.898*	.395	-.290	-.180	-.719	-.482	.026	-.166	-.251	.613	.390	1					
CD	.255	-.095	-.935*	.539	-.259	.791	-.635	-.896*	.269	.156	-.238	-.247	-.339	1				
Ca^{2+}	.373	.394	-.514	-.603	.887*	.020	.337	-.371	-.572	.984**	-.918*	-.588	-.414	.208	1			
Mg^{2+}	.022	.150	-.295	-.825	.943*	-.305	.283	-.275	-.647	.974**	-.797	-.395	-.072	-.014	.926*	1		
Na^+	-.054	.381	.643	-.788	.701	-.657	.808	.693	-.385	.359	-.338	.090	.039	-.830	.324	.495	1	
HCO_3^-	-.241	-.023	.291	-.995**	.854	-.811	.461	.225	-.795	.652	-.353	-.247	.308	-.584	.561	.782	.792	1

* $p<0.05$; **$p<0.01$

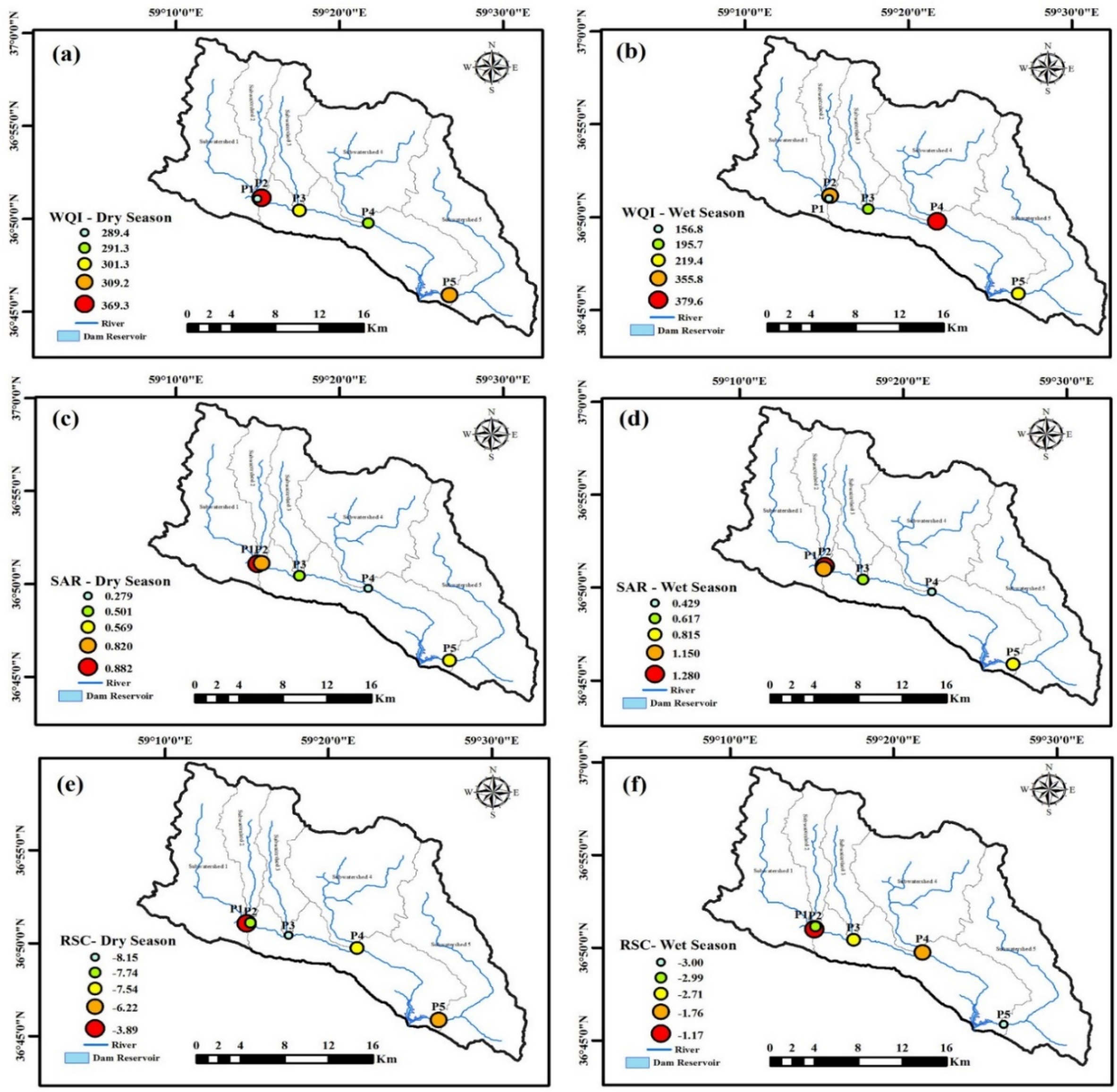

Figure 2) **a** and **b**: Spatial distributions of water quality index (WQI), **c** and **d**: Sodium adsorption ratio (SAR), **e** and **f**: residual sodium carbonate (RSC)

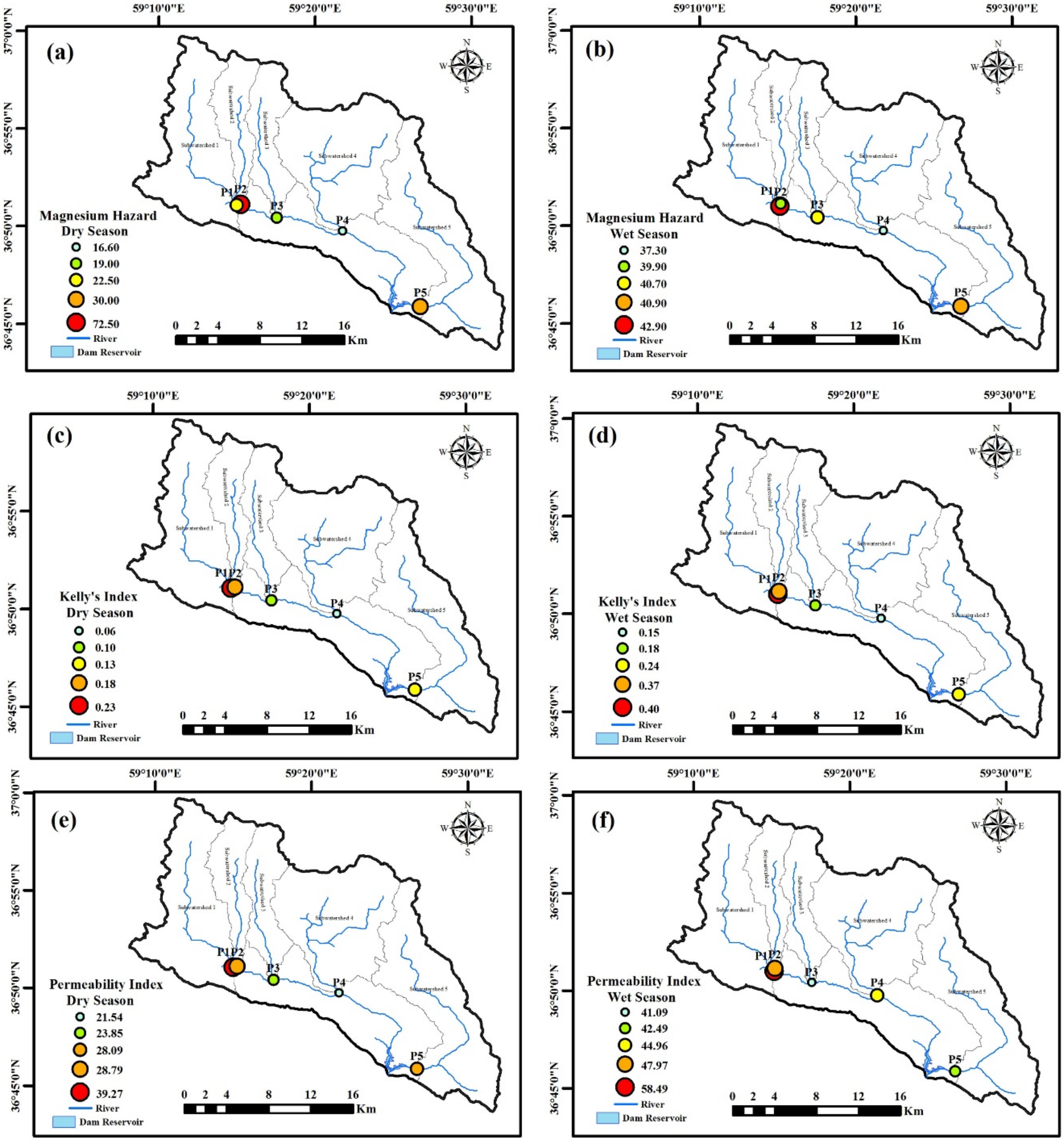

Figure 3) a and **b**: Spatial distributions of magnesium hazard (M.H.), **c** and **d**: Kelly's index (K.I.), **e** and **f**: permeability index (P.I.)

Kelly's index exhibits relative sodium quantity against Magnesium and calcium and helps researchers to determine the water quality suitability for agriculture. The Kelly's index values of less than one (K.I. <1) are suitable for irrigational purposes, greater than one (K.I.>1) shows excess sodium in water and not suitable for irrigation, and values less than two (K.I. <2) signifies sodium deficiency in water and is not proper for irrigation purposes [42]. In this research, Kelly's index values vary from 0.06 to 0.23 in the dry season and from 0.15 to 0.40 in the wet season. The results indicate that all water samples in both seasons are safe for irrigation purposes. Besides, the spatial variations of K.I. values are shown in Figure 3 (c and d).

Water is categorized into three classes based on P.I. values. Class I (P.I.> 75%) is considered as suitable for irrigation purposes, class II (PI=25–75%) is considered as moderately suitable for irrigation purposes, and class III (P.I. <25%) is unsuitable for irrigation purposes [28]. Permeability index (P.I.) values of water samples in Ardak Watershed vary from 21.54% to 39.27% in the dry season and from 41.09% to 58.49% in wet season. According to the results, P3 and P4 stations in the dry season with P.I. values of 23.85% and 21.54%, respectively, fall into the class III (P.I. <25%) and are unsuitable for irrigation. The highest calcium levels were measured in P3 and P4 sampling stations that received pollutants from agricultural upstream influenced calcium concentration in the water. The recipient untreated municipal wastewater also affected calcium levels, which points to anthropogenic factors' significant effects. However, other water samples in both seasons fall in class II (PI=25–75%) that is considered moderately suitable for irrigation purposes [42]. Regarding the P.I. analysis, the wet season's river water is better than the dry season, possibly due to the larger amount of fresh rainwater. The spatial distribution of P.I. values along the sampling stations is shown in Figure 3 (e and f).

Conclusion

In this research, the water quality of the Ardak River and its suitability for drinking and irrigation water were evaluated. The Ardak River is the main river recharging the Ardak Dam Lake. To assess the water quality of the Ardak River, 5 sampling stations were determined, and 20 water quality parameters were chosen for seasonal monitoring and analysis. Water quality parameters fecal coliform, BOD, NO_3^-, D.O., E.C., COD, NH_4^+, $P.O_4^{3-}$Turbidity, T.H., pH, As, Pb, and Cd were used to calculate WQI values to assess river water's drinking suitability. The calculated WQI values are between 156.77 and 379.59 in the study area. The results indicated nonpoint and point sources of pollution and the temporal variations controlled by precipitation and evaporation. The influences of water quality parameters on the WQI were evaluated, and the obtained outcomes indicate that the highest mean effective weight values belong to the fecal coliform and $P.O_4^{3-}$ parameters compared to the other parameters, which indicates the significant influence of anthropogenic activities on river water quality. Various indices and parameters were used to assess river water quality for irrigation purposes. The results indicate that the river water quality is generally moderately suitable to safe and suitable with exceptions at P2, P3, and P4 sampling stations in the dry season, unsuitable for irrigation purposes. Using river water in these sites during the dry season may cause adverse effects on soil quality and crop yield of agricultural lands. The spatial distribution maps effectively present information and help decision-makers better visualize river water quality conditions in the study area. Physicochemical analysis results show that the fecal coliform, BOD, E.C., and $P.O_4^{3-}$ values in all the sampling stations and during both seasons are over the WHO (2008) limit values. Therefore, the main pollutant sources of the Ardak River can be animal husbandry, intensive agricultural activities discharge at the bank of the river, and wastewater discharging from rural areas in the study area such as Boghmech, Talghur, Mianmargh, and Abghad villages. Due to the negative effects of anthropogenic pollutants, the water quality of the Ardak River is deteriorating and may cause detrimental effects on the health of people who use water of Ardak Dam Lake for drinking and irrigation purposes. Consequently, vital protection measures such as the management of domestic waste and wastewater and the improvements in agricultural practices should be taken by managers and decision-makers in the Ardak Watershed related to planned usage of the river.

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