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Electromagnetic intensity investigation of emitted non-ionizing radiation from base transcriptive stations in the urban region of southern Iran

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ABSTRACT

Their monitoring in urban regions is essential for policymakers and the population. In this study, the electromagnetic intensity (EMI) was measured around 30 stations of base transcriptive stations (BTS) at both distances lower than 20m and higher than 200m using real-time equipment SMP2-dual in summer and winter. Results have shown that EMI in summer (range: 2-6500 mW/m²) was more than in winter (1.5-5000), and the intensity of about 93% of samples exceeded WHO standards. EMI has consistently decreased with the increasing distance from BTS. There was a negative correlation between the temperature and EMI in summer and humidity and EMI for both distances. The mapping of EMI depicted the highest value of EMI across the central region from south to eastern north at a distance lower than 20 m in winter. The clustering of the EMI in this region was influenced by the geographical location of BTS.

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Introduction

Non-ionizing radiation as one of the electromagnetic waves (EMW) is widely used in human society. Among them, radiofrequency (RF) waves apply to communication, radar, electrical engineering, domestic and industrial processes, light sensors, and medical care (Jelodar et al. 2012; Muhibbullah et al. 2017; Tradacete et al. 2021; Kleinau et al. 2021; Zhao et al. 2022; Jayaraju et al. 2023).

Recently, the use of cell phones and mobile communication technology has been raised (Zhao et al. 2022) due to the facilitation of trade and wireless communication; thereby, base transcriptive stations (BTS) have been significantly established in urban areas to cover the efficient communication of vast regions (Huang et al. 2019; Kleinau et al. 2021). For example, it is estimated that there are more than 3 million 5G base stations worldwide. Despite the advantages of these

stations, they interact with the crossing media such as biological paths (Leyser and Wong 2009) and may finally lead to adverse health effects on human bodies. Although there is a lack of clear relationship between BTS and human health effects (Shahbazi-Gahrouei 2017), these EMW could disrupt the function of the immune, blood, neurology, endocrine, and reproductive systems, as well as the induction of pathologies syndrome and biochemical markers (Chrousos 2007; Khurana et al. 2010; Odacı et al. 2015; Taheri et al. 2017; Shahbazi-Gahrouei et al. 2019; Akbari et al. 2021; Balmori 2022; Rangkooy et al. 2023). Reported results by Shahbazi-Gahrouei (2017) and Amraee et al. (2021) have pointed out some psychobiological reactions such as chronic fatigue and sleep disorders in people who are living near BTS. These effects can change in different conditions. However, regardless of the initial intensity of these waves, the vicinity conditions of stations and the distance of the target from these point sources can be considered important factors in the intensity of radiation followed by human exposure. For example, the building may reflect and/or adsorb RF based on its structure and components (Xie et al. 2020; Lai et al. 2020; Zhao et al. 2022; Gu et al. 2023; Guo et al. 2023). Furthermore, the overlapping of emitted radiation from several stations can occur. This overlapping may originate from the sophisticated interaction between independent factors and the generation of electromagnetic fields. (Barudov and Ivanova 2020; Chaudhuri and Yun 2023; Nasserri et al. 2013; Pavlík et al. 2024). Hence, the utilization of non-linear modeling can clarify the relationship between them. However, there is a knowledge gap about this issue, and based on the best of our knowledge, there was no published data for the southern regions of Iran. Machine learning is a useful approach to simulate environmental contaminants including EMW. Till now, there have been simulated different contaminants by this technique (Abbasi et al. 2021, 2021; Mohammadpour et al. 2024, 2024). Therefore, the determination of RF intensity regarding urban factors and the distribution of their intensity are essential to manage and reduce their emission by policymakers following the identification of the influencing sources and real levels.

Considering the requirement of BTS for communication in living regions and mismanagement of urbanization, especially in developing countries due to the limited public awareness about the health effect of non-ionizing irradiation and the necessity of a sustainable environment (Popescu and Safta 2021), this study was performed to determine and monitor electromagnetic intensity (EMI) in southern Iran for the first time. Furthermore, this study aimed to interpolate and simulate the emitted intensity radiation from BTS using Geographical Information System (GIS) and machine learning.

Materials and methods

Study area and sampling methods

This study was performed in Behbahan (southern Iran) to detect the EMI around all BTS. The total stations were 30, and their characteristics are presented in [Tables 1 and 2](#). Samples were collected in both seasons, winter and summer. The power density of EMW around the antennas was measured in both the near field (less than 20 m) and the far field (more than 200m). Furthermore, the effect of buildings and their concrete structures and the climate conditions including temperature and humidity on the EMI were investigated. To improve the accuracy and reliability of data, sampling was repeated three times in each season. EMI was measured according to the STD1309-IEEE method using SMP2-dual real-time equipment (WAVECONTROL, Spain). Within sampling, the detector probe was placed above the ground (145 cm and with a slope of 34.3 degrees from the ground). The location of sampling points was recorded using the Global Positioning System. Then, EMI was read and documented regarding their Universal Transverse Mercator (UTM) coordinates.

Table 1. The EMW properties around BTS in winter.

UTM(X)	UTM(X)	Distance <20 m range (intensity)	Distance >20 m range (intensity)	Traffic	Temperature	Humidity
425938.2	3383440	2–2.500	1.5–2.0	1	17	63%
425412.6	3383578	500–600	400–500	1	17	63%
425397.2	3383734	600–700	500–600	1	18	61%
425031.8	3384165	850–950	750–850	1	18	60%
424664.2	3383604	200–300	000.1–000.2	1	19	55%
425883.7	3383645	300–400	100–200	1	20	52%
426139.6	3383925	650–750	600–700	1	21	48%
426458.1	3382451	1800–2500	850–1000	1	24	38%
427105.5	3382609	850–1000	450–550	1	24	40%
426196.8	3383087	800–900	300–450	1	23	42%
426979.8	3384385	1600–1800	800–900	3	23	43%
426802.1	3384524	300–400	4000–5000	3	22	45%
427821.2	3385147	900–1200	850–1050	2	22	47%
427966.9	3384794	3.5–7.0	10.0–25.0	3	22	49%
427980.1	3384484	700–800	650–750	3	21	51%
429758.3	3384100	800–900	600–700	1	17	62%
428737.9	3384273	250–350	200–300	1	18	60%
428543.3	3384827	600–700	1000–1200	2	18	58%
428509.6	3385035	550–650	500–600	3	19	56%
428573.1	3385885	1500–2500	700–800	1	20	53%
428082.5	3385942	1800–2000	1300–1500	1	20	52%
427842.9	3385806	1200–1300	1300–1400	2	20	54%
427946.2	3386391	500–600	450–550	1	21	51%
426951.9	3383138	350–450	450–550	1	17	63%
426819.4	3383319	1800–2000	800–1000	1	18	59%
426441.7	3385000	1500–2500	900–1200	1	19	57%
426057	3385335	250–350	150–250	2	20	53%
426119	3385501	900–1500	500–600	1	21	51%
425419	3386102	400–500	800–900	1	21	49%
425494.2	3385239	600–700	1600–2000	2	22	48%

EMW mapping in Geographical Information System

The data obtained from the aforementioned variables was entered into the checklist, and then the average EMI obtained from the stations was entered into GIS and simulated with interpolation models. Considering the distance of each sampled point from the BTS, the EMI was interpolated based on the inverse distance weighted method. The EMI average of each station was weighted based on the quality of the data. Additionally, missing values were removed from the dataset. The influencing factors in the weighted values were geographic factors, distance from BTS sources, and traffic intensity. The predictions of the interpolated models based on the distance from the BTS were compared with real data to validate the model.

EMI clustering by hierarchical clustering analysis

To analyze and cluster recorded EMI from two seasons across multiple locations, first, the collected data structure was arranged with each row representing a location and separate columns for each season's measurements. Then, missing values were deleted and normalized if they changed in a significantly vast range. Then, the database was merged for both seasons and hierarchical clustering with an Euclidean distance metric, and Ward's method was used. Furthermore, the type of location cluster was determined based on EMI levels. Finally, we visualized the clustering results with a dendrogram to identify distinct clusters and analyze these to understand EMI levels at different sites.

Statistical analysis

In this study, descriptive and analytical statistics were used. The EMI and its variation were reported as mean and standard deviation, respectively. The difference between categories was determined by

Table 2. The EMW around BTS in summer.

UTM(X)	UTM(X)	Distance <20 m range (intensity)	Distance >20 m range (intensity)	Traffic	Temperature	Humidity
425938.2	3383440	2500–3000	750–850	3	38	17%
425412.6	3383578	1800–2000	400–500	1	38	17%
425397.2	3383734	900–1000	500–600	1	38	16%
425031.8	3384165	1000–1100	1800–2000	1	39	16%
424664.2	3383604	2–2.5	0.005	1	39	16%
425883.7	3383645	150–200	550–650	1	39	16%
426139.6	3383925	2000–2500	1500–1700	1	39	16%
426458.1	3382451	1000–2000	500–600	1	39	16%
427105.5	3382609	900–1000	400–500	1	37	17%
426196.8	3383087	350–450	900–1000	1	39	16%
426979.8	3384385	1000–1500	450–500	3	39	15%
426802.1	3384524	200–300	100–200	3	39	15%
427821.2	3385147	1500–2000	350–450	2	40	14%
427966.9	3384794	10.0–20.0	20–40	3	38	17%
427980.1	3384484	2000–2500	1500–2000	3	38	17%
429758.3	3384100	1000–1500	1300–1500	2	38	16%
428737.9	3384273	700–900	600–700	1	38	16%
428543.3	3384827	1000–1200	1200–1400	2	38	16%
428509.6	3385035	700–900	600–800	3	38	15%
428573.1	3385885	2000–2500	6000–6500	1	38	15%
428082.5	3385942	600–800	2000–2500	1	38	15%
427842.9	3385806	2400–2700	2000–2300	2	38	15%
427946.2	3386391	600–700	800–900	1	42	12%
426951.9	3383138	400–700	1000–1200	1	43	11%
426819.4	3383319	1000–1300	900–1200	1	43	11%
426441.7	3385000	200–400	300–500	1	43	11%
426057	3385335	350–500	150–300	2	42	11%
426119	3385501	1800–2200	900–1300	1	42	11%
425419	3386102	500–800	600–900	1	42	11%
425494.2	3385239	500–700	1000–1300	3	42	11%

Mann–Whitney U test, and the statistical difference was 0.05. Furthermore, the relationship between EMI and independent variables was estimated using Spearman correlation. All tests were performed in Python (v 3.12), SPSS21, and Excel 2019.

Results and discussion

A summary of EMI in the studied region

In this study, the EMI was measured around 30 stations of BTS in Behbahan. Sampling was repeated at both distances lower than 20 m and higher than 200 m from BTS. The sampling station properties based on summer and winter seasons are expressed in Table 1 and Table 2.

As shown in Table 2, there has been a wide range for the intensity of EMW in summer (range: 2–6500) and winter (1.5–5000). It should be considered that the intensity of EMW at about 93% of total stations exceeded WHO standard (intensity = 100 mW/m²) for non-ionizing irradiation. In the previous studies, the measured EMI around hospitals in Arak (the center of Iran) and the residential regions of the western north of Iran was lower than the suggested safety range of the International Commission on Non-Ionizing Radiation Protection (Seif et al. 2022, Naderi et al. 2021). Therefore, it may be a concern for the health of public residential humans in this region, and further studies are essential to determine the separate wavelengths and apportion the effective sources of non-ionizing radiation.

Also, the intensity of EMI in summer was higher than in winter. Therefore, the EMI around 63% of total stations (distance lower than 20 m) in summer was more than in winter ($p = 0.07$). Furthermore, 70% of total stations in summer had an EMI higher than in winter (distance higher than 20 m) ($p = 0.1$). One reason for the higher EMI in summer could be that the higher temperature in summer facilitates the emission of EMW (IAe and Kidin 2005; Hadjicontis et al. 2007; Liu

Table 3. The correlation between independent variables and EMW intensity.

Distance	Summer			Winter		
	Temperature	Humidity	Traffic load	Temperature	Humidity	Traffic load
<20 m	-0.28	0.24	0.09	0.24	-0.26	-0.17
>20 m	-0.19	0.065	-0.19	0.27	-0.3	0.33

et al. 2020; Gao et al. 2022). Furthermore, temperature itself influences the ionization of air (Schekotov et al. 2021). Likely, these differences in results imply other environmental properties such as humidity, rate of air ionization, or land use (Manassas et al. 2012; Mat et al. 2020; Popescu and Safta 2021; Schekotov et al. 2021). In Greece, the higher EMI is found in urban areas compared to rural catchments (Manassas et al. 2012), but the stability of annual land use around the studied BTS caused more focus on the other variables. In the case of independent variables, it can be mentioned that the relative humidity in winter (mean: $52 \pm 0.07\%$) was more than in summer (mean: $15 \pm 0.02\%$) significantly ($p < 0.001$). Conversely, the higher mean temperature was surprisingly measured in summer (mean: $39.5 \pm 1.9^\circ\text{C}$) compared to winter (mean: $20 \pm 2.1^\circ\text{C}$) ($p < 0.001$). It should be noted that there has partially been a negative correlation between the humidity and EMI in summer for both distances. Similar to temperature in summer, a negative correlation was measured between humidity and intensity of EMW in winter (Table 1). As presented in Table 3, a decreasing trend of electromagnetic density was observed during a higher relative humidity (Dikun et al., 2015; Li et al. 2019). In addition to the lower accuracy of the radiation detector in higher relative humidity (Hou and Tsai 2019), possible reasons for these results may be the adsorption of some frequency of EMW and the change in conductivity under the variation of humidity (Totoreanu and Malaescu, 2012; Cheng et al. 2012; Martin 2016).

It can be concluded that the high humidity and temperature in winter and summer, respectively, may be effective in decreasing the EMI, while there has been an inductive trend for humidity and temperature in summer and winter, respectively. Considering global factors occurrence such as climate change as a worldwide disaster (Popescu and Safta 2021) that may cause humidity and global warming to increase, especially in southern Iran, the increasing trend of non-ionizing radiation may become a potential public health risk in this region (Martin 2016; Ansor et al., 2019). On the other hand, a higher correlation was observed in the traffic load and EMI in winter for distances more than 20 m ($R = 0.33$). It should be noted that similar results were confirmed by the determined correlation between temperature ($R = 0.27$) and humidity ($R = -0.3$) in winter. Tang et al. (2019) have expressed that the tourism regions had a higher intensity of non-ionizing radiation due to the density of the population and numerous mobile users as well as its associated facilities. Regardless of the directly sourced radiation from BTS, the measured EMI might be related to the radiation of cell phones and indirect wireless stations as natural and/or anthropogenic sources that are significantly located along the higher distances of radiation point sources and daytime (Manassas et al. 2012). Also, the intensity of mobile radiation closely correlates to the type of urban area, including traffic and population density (Tang et al. 2019).

Distribution of current density

Considering the low information about the source of EMW in the studied region and the appropriate accuracy of the interpolation algorithm (Zhang et al. 2015; Fuchs et al. 2017), this method was used to zoning EMI in the present study. As shown in Figures 1 and 2, there is a significant difference between the mapping of EMI based on the distance from BTS in both seasons due to the positive decreasing trend of EMW with the distance of non-ionizing radiation (Kalniņš et al. 1996). Furthermore, the highest EMI was detected across the central region from south to eastern north at a distance lower than 20 m. However, only one station in the central region has a high EMI at a distance of more than 200 m. By comparing Figures a and b, it is confirmed that this station had a safe range of EMI at distances lower than 20 m due to periodically decreasing EMI with the

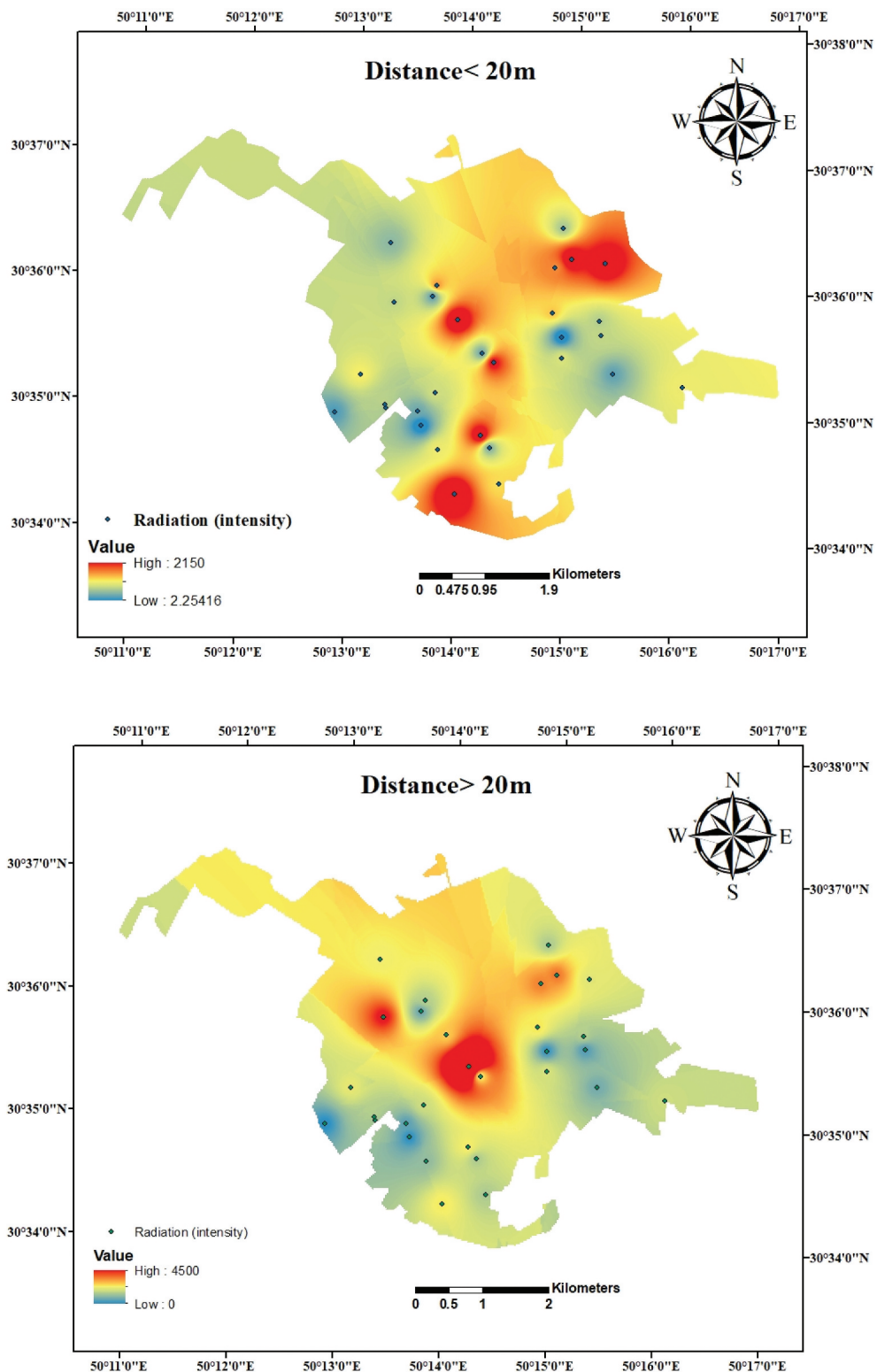


Figure 1. EMI distribution in winter based on the distance from BTS.

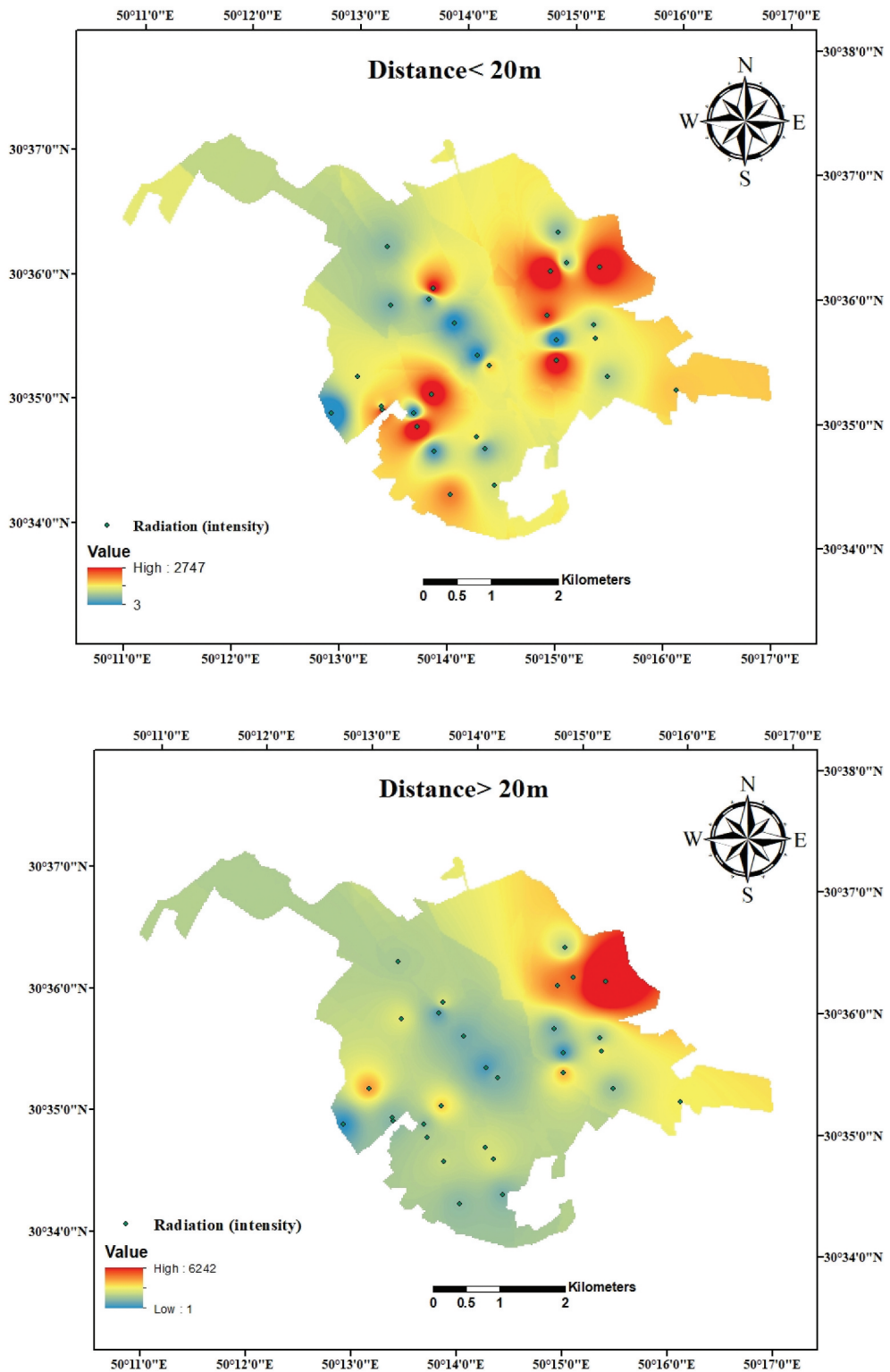


Figure 2. EMI distribution in summer based on the distance from BTS.

distance from sources (Popescu and Safta 2021; Liu and Bao 2021). This station is located in a densely populated region; thereby, this EMI can be related to wireless sources and cell phones (Manassas et al. 2012; Tang et al. 2019). Despite the collected data from winter, the lower area depicted high EMI at a distance lower than 20 m. Furthermore, the EMI in most stations was lower than the WHO standard except for one station in the northeast of this city. Therefore, these results can open a path for further studies to investigate the potential health risks of EMW, especially brain and sleep disorders in the resident population near these stations.

EMI clustering

The associated dendrograms of EMI based on the hierarchical clustering analysis (HCA) approach are presented in Figure 3. Regarding the conducted simulation by HCA, several groups were identified among the emitted EMI around BTS. For distances higher than 200 m from BTS, three subgroups are located in the same geographical direction, such as stations 26 and 13 in the center of the city, stations 21 and 22 in the western east, and stations 7 and 15 in the central area. These results can confirm that they originated from similar sources. In the case of distances lower than 20 m, HCA identified three groups. Group 1: stations 28, 13, 15, and 7 in the northern and the central regions of Behbahan. Group 2: stations 25, 11, 26, and 21 are located in the south, center, and eastern north of the city. Group 3 includes three subgroups that are distributed in a uniform direction.

Considering the geographical location of stations 15 and 7 (central region) in Group 1, stations 12 and 6 (central region) in Group 3 at a distance lower than 20 m, as well as the three subgroups at a distance higher than 20 m [(S26 and S13), (S21 and S22), (S7 and S15)], the environmental factors can be a considerable aspect. The results from the HCA pointed out that the emission of EMW in this region is influenced by geographical parameters. Therefore, the adaptation of urban areas and buildings based on geological and geographical conditions is essential to improve the sustainability of the environment and decrease its related health effects. Furthermore, further studies for the determination of potential health effects including brain disorders in each cluster are suggested.

Conclusion and future suggestion

In this study, the EMI was measured around 30 stations of BTS (distance was lower than 20 m and higher than 200 m) in southern Iran. Results have shown that EMI in summer (range: 2–6500) was more than in winter (1.5–5000), and their intensity for 93% of total stations exceeded WHO standards. In the case of independent variables, it can be mentioned that there was a partial negative correlation between the humidity and EMI in winter for both distances. Similar to temperature in summer, a negative correlation was measured between humidity and intensity of EMW in winter. Furthermore, a higher correlation was estimated between the EMI and independent factors including traffic load, temperature, and humidity in winter for distances higher than 20 m. Based on the mapping of EMI, the highest value was detected across the central region from south to eastern north at a distance lower than 20 m in winter. However, the lower area was depicted as a high EMI in distances lower than 20 m, and their value in most stations was lower than the WHO standard. Considering HCA, EMW might originate from similar sources and EMI could closely relate to the geographical parameters. Therefore, the emission of these non-ionizing radiations can be considered a potential health risk in southern Iran, and adaptation of this region based on the environmental conditions is essential. In addition to the operation of BTS regarding geographical properties of a region and distance from other stations, improvement of safety guidelines for non-ionizing radiation is suggested based on topography and climate variables as well as anthropogenic factors such as systematic planning to design and install the communication stations in the city regions. On the other hand, localization of safety guidelines based on the specific conditions of each country and city can be a considerable alternative.

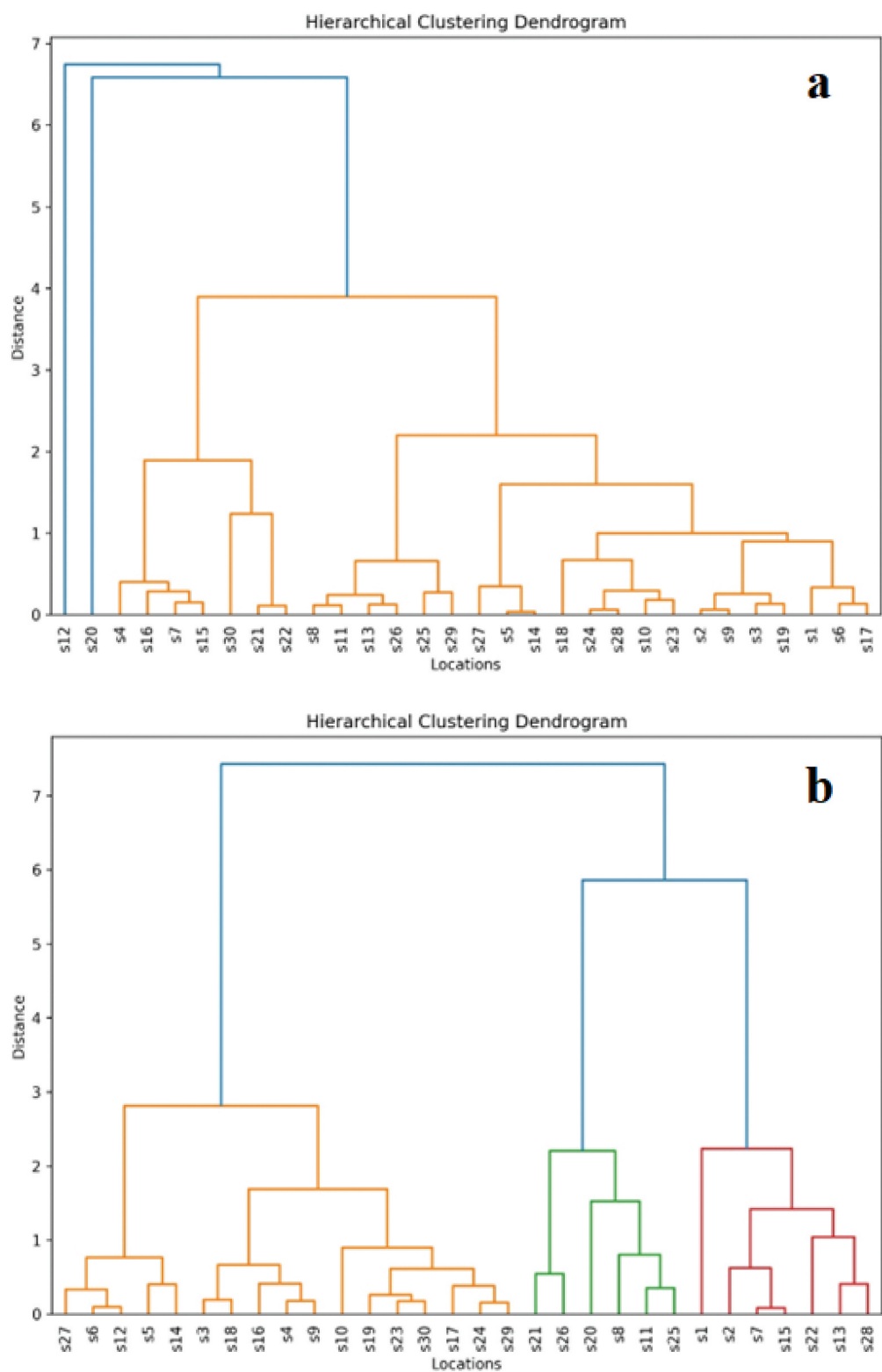


Figure 3. EMI clustering by HCA. (a) Distance higher than 20 m and (b) distance lower than 20 m.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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