JOURNAL OF RADIATION INDUSTRY

Technical article

17(3) : 299-307 (2023)
https://doi.org/10.23042/radin.2023.17.3.299

A Study of Wind Characteristics around Nuclear Power Plants Based on the Joint Distribution of the Wind Direction and Wind Speed

Yunjong Lee[1,*]

[1]Advanced Radiation Technology Institute, Korea Atomic Energy Research Institute, 29, Geumgu-gil, Jeoneup 56212, Republic of Korea

Abstract Given that toxic substances are diffused by the various movements of the atmosphere, it is very important to evaluate the risks associated with this phenomenon. When analyzing the behavioral characteristics of these atmospheric diffusion models, the main input data are the wind speed and wind direction among the meteorological data. In particular, it is known that a certain wind direction occurs in summer and winter in Korea under the influence of westerlies and monsoons. In this study, synoptic meteorological observation data provided by the Korea Meteorological Administration were analyzed from January 1, 2012 to the end of August of 2022 to understand the regional wind characteristics of nuclear power plants and surrounding areas. The selected target areas consisted of 16 weather stations around the Hanbit, Kori, Wolsong, Hanul, and Saeul nuclear power plants that are currently in operation. The analysis was based on the temperature, wind direction, and wind speed data at those locations. Average, maximum, minimum, median, and mode values were analyzed using long-term annual temperature, wind speed, and wind direction data. Correlation coefficient values were also analyzed to determine the linear relationships among the temperature, wind direction, and wind speed. Among the 16 districts, Uljin had the highest wind speed. The median wind speed values for each region were lower than the average wind speed values. For regions where the average wind speed exceeds the median wind speed, Yeongju, Gochang, Gyeongju, Yeonggwang, and Gimhae were calculated as 0.69 m s^{-1}, 0.54 m s^{-1}, 0.45 m s^{-1}, 0.4 m s^{-1}, and 0.36 m s^{-1}, respectively. The average temperature in the 16 regions was 13.52 degrees Celsius; the median temperature was 14.31 degrees and the mode temperature was 20.69 degrees. The average regional temperature standard deviation was calculated and found to be 9.83 degrees. The maximum summer temperatures were 39.7, 39.5, and 39.3 in Yeongdeok, Pohang, and Yeongcheon, respectively. The wind directions and speeds in the 16 regions were plotted as a wind rose graph, and the characteristics of the wind direction and speed of each region were investigated. It was found that there is a dominant wind direction correlated with the topographical characteristics in each region. However, the linear relationship between the wind speed and direction by region varied from 0.53 to 0.07. Through this study, by evaluating meteorological observation data on a long-term synoptic scale of ten years, regional characteristics were found.

Key words: Wind direction, Wind speed, Automated Synoptic Observing System (ASOS), Correlation analysis, Wind rose

1. INTRODUCTION

The Korean Peninsula is located between 33° and 43° north latitude, and climate characteristics are also influenced by this latitude difference. There is a difference in climate between the East Sea slope and the West Sea slope,

http://www.ksri.kr/

Copyright © 2023 by
Korean Society of Radiation Industry

***Corresponding author.** Yunjong Lee
Tel. +82-63-570-3270 E-mail. yjlee@kaeri.re.kr

Received 21 August 2023 **Revised** 20 September 2023 **Accepted** 21 September 2023

which are bordered by the Hamgyeong and Taebaek mountain ranges, respectively along the east coast [1]. Korea is affected by westerlies caused by the Earth's rotation. Also, depending on the season, the country is also affected by monsoons. In summer, the southeast monsoon develops due to high pressure in the North Pacific Ocean, which is hot and humid. In winter, the northwest monsoon wind develops as cold and dry high pressure develops in the air mass of Siberia [2].

The atmosphere consists of the troposphere, the stratosphere, the mesosphere, and the thermosphere. Among the winds that blow within the troposphere, there is an air current that blows from west to east around the pole in areas excluding the lower layers of the equator and the poles. The zone where this wind is outstanding is called the westerly wind zone [3].

Monsoons are caused by differences in the specific heat between the continents and the oceans. Continents have less specific heat than oceans, meaning that they warm up and cool more rapidly than oceans. As a result, in summer, continents have warmer temperatures than oceans, and a low pressure zone forms in the continental region. In Korea, this phenomenon is termed the southeast monsoon, and when weather maps are drawn based on the Korean Peninsula, high pressure in the North Pacific is located in the southeast and low pressure is located in the north. In Southeast Asia and South Asia, the term used is the southwest monsoon, and it blows mainly between May and October, during the rainy season [4].

In addition, typhoons are accompanied by storms with a maximum wind speed of at least 17 m s^{-1}, causing wind and flood damage. Wind directions and speeds according to these regional and seasonal factors affect the diffusion of radioactive materials.

In winter, the land is cooler than the ocean and a high pressure zone forms on the land. This is called the northwest monsoon. This occurs because the land cools more rapidly than the sea, whereas the ocean does not cool rapidly owing to its high specific heat. The higher the density of air over land is, the higher the high pressure is in the summer. As a result, the atmospheric pressure gradient in winter is higher than that in summer, and the average wind speed of the northwest monsoon in winter is higher than that of the southeast monsoon in summer [5].

If toxic chemicals or radioactive materials that leak from nuclear power facilities spread via such atmospheric movements, a resident impact assessment can serve to determine the degree of risk. To do this, the behavioral characteristics of the leaking material must be analyzed. As a method to quantify the properties of diffusion through the dilution and dispersion of radioactive materials released into the atmosphere, an atmospheric diffusion model using actual measurements of emission inventories and points of interest at nuclear facilities is used. The main input data for the atmospheric diffusion model of these toxic substances is meteorological data, and the estimated atmospheric dispersion coefficient (ADF) calculated using the atmospheric diffusion model is used to evaluate the radiation dose. Calm conditions and low wind speeds have very important effects on the ADF [6].

In order to warn residents of danger in advance of the spread of radioactive materials, a radiation emergency planning zone has been established and operated. It is divided into what are termed an urgent protective action planning zone and a precautionary action zone. This strategy is centered on nuclear power plants, with an average of 3 to 5 km for the emergency protection action planning zone and an average of 20 to 30 km for the urgent protective action planning zone [7].

As the technical basis of the emergency plan established for radiation emergency disaster prevention, the content used as the current basis described in NUREG0396 is outdated, and there is an opinion that a reevaluation of risks related to radiation accidents at nuclear power plants is necessary [8,9].

Currently, Korea operates 18 out of 24 units. The country's nuclear capacity is 23,250 kw, and 17833Mwe of that is from nuclear power generation [10].

In this study, atmospheric characteristics were analyzed using data from January 1, 2012 to the end of August of 2022 among the meteorological data provided by the Korea Meteorological Administration in order to understand the regional characteristics of atmospheric meteorology so that possibly scenarios for emergency disaster prevention can be created.

Sixteen weather stations around the Hanbit, Kori, Wolsong, Hanul, and Saeul nuclear power plants currently in operation in Korea were selected and analyzed based on the temperature, wind direction, and wind speed data provided by the Korea Meteorological Administration.

The annual temperature, wind speed and direction data for this area over a period of ten years were analyzed. The

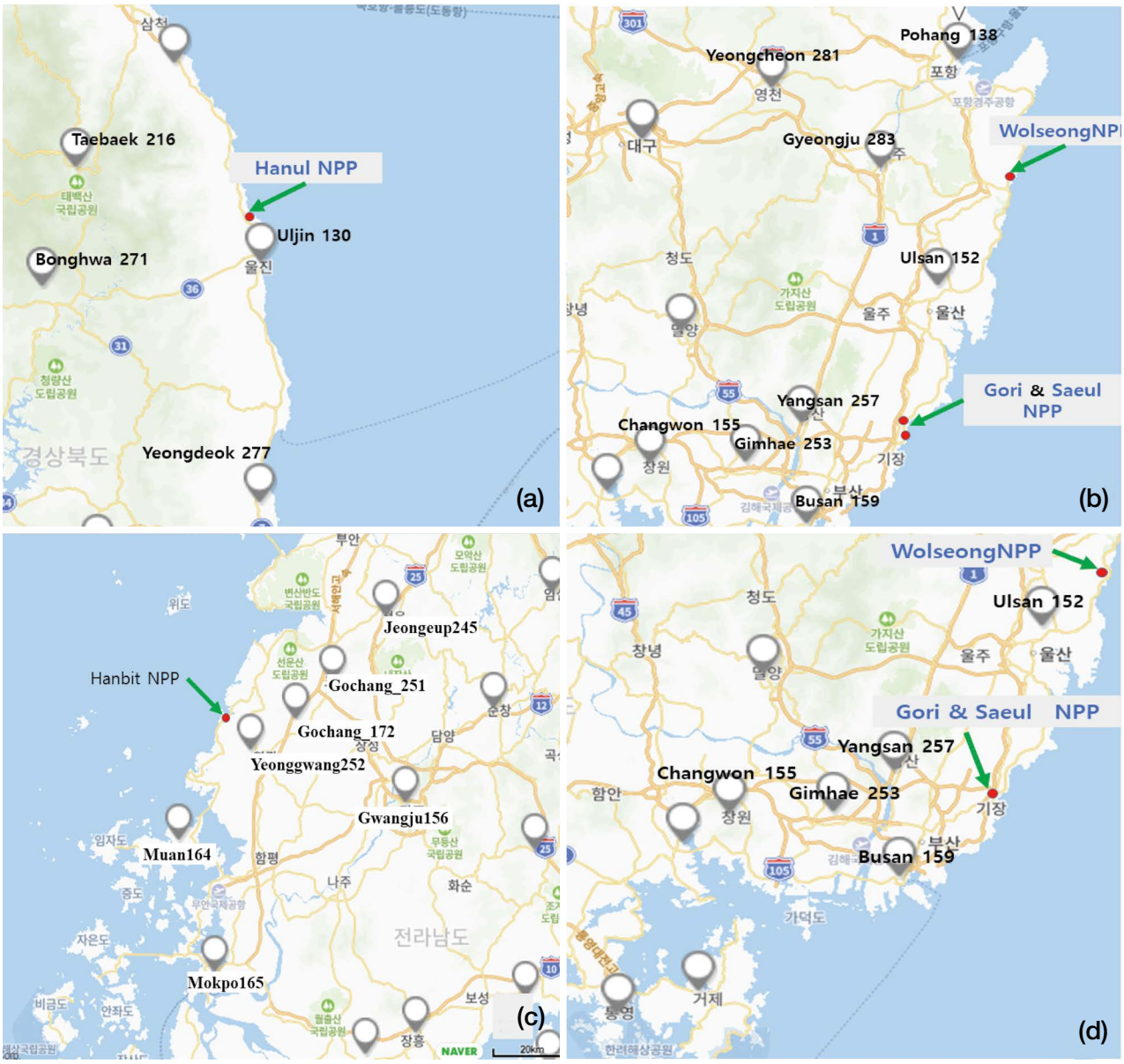

Fig. 1. Sixteen meteorological observatory points of the Korea Meteorological Administration around the Hanbit, Kori, Wolsong, Hanul, and Saeul Nuclear Power Plants: (a) Hanul, (b) Wolsong, (c) Yeonggwang, and (d) Kori and Saeul.

correlations among the temperature, wind direction and wind speed were also analyzed. Through this, we attempted to uncover the characteristics of the atmosphere around each of the power plants.

2. MATERIALS AND METHODS

2.1. Region selection

Sixteen meteorological stations were selected based on representative nuclear power plant operation areas, as shown in Fig. 1. For the Hanbit nuclear power plant, data from Yeonggwang 252, the site of the power plant, and Gochang 172 and Gochang 251 installed at Gochang-gun, Hanjeon, were analyzed. For the Saeul nuclear power plant adjacent to the Kori nuclear power plant in the Gyeongnam region of Busan, Changwon 155, Ulsan 152, Yangsan 257, and Gimhae 253 adjacent to Busan 159 were targeted. For the Wolsong Nuclear Power Plant, data were analyzed for three sites: Yeongcheon 281, Pohang 138, and Gyeongju

283. Lastly, for the Hanul Power Plant, data from the Yeongdeok 277, Yeongju 272, Bonghwa 271, and Taebaek 216 meteorological stations adjacent to Uljin 130 in Uljin were analyzed.

2.2. Meteorological observation data

The meteorological data open portal operated by the Korea Meteorological Administration provides synoptic observation data (Automated Synoptic Observing System (ASOS)) for 103 locations across the country [11].

Synoptic-scale winds refer to ground observations conducted at the same time at all stations at a fixed time. This refers to daily weather phenomena. Synoptic from the Greek language means synthesized or simultaneous [12].

The data provided are the temperature, precipitation, wind, atmospheric pressure, humidity, insolation, sunshine levels, snow levels, clouds, visibility, ground conditions, ground/supernormal temperature, any weather phenomena, evaporation amounts, and number of phenomena, among other information. Weather data are provided on an annual basis with temperature, wind speed and wind direction data provided on an hourly basis every day. In total, 1,494,654 data points were analyzed. The analysis was based on data from an average of 93,416 cases for each region.

2.3. Temperature and wind speed

As for the temperature data, the average temperature for the entire dataset and the standard deviation of the temperature were calculated based on data collected from January 1, 2012 to the end of August 2022.

Wind is the movement of air caused by differences in the temperature and pressure between two places. Wind is one aspect of atmospheric circulation. Wind is the flow of air that moves in parallel from high-density high-pressure areas to low-density low-pressure areas [13].

Hence, the maximum wind speed, mode, median wind speed, 95th percentile value, 99th percentile value, and the average wind speed were calculated based on the wind direction and wind speed data measured by the Korea Meteorological Administration.

2.4. Wind rose

The wind rose is a radial graph showing the frequency of the appearance of wind in each direction over a certain period at the observation point.

The percentage (%) of the frequency is expressed as the length of the azimuth line on the azimuth plate corresponding to each wind direction.

The azimuth angles used here are 0, 22.5, 45, 67.5, 90, 112.5, 135, 157.5, 180, 202.5, 225, 247.5, 270, 292.5, 315, and 337.5 degrees, and the frequency of appearance is indicated in the longitudinal direction centered on 16 azimuth angles.

The wind rose was generated using the Origin Pro 2022 software program.

3. RESULTS AND DISCUSSION

As shown in Tables 1 and 2, the maximum, minimum, central, 95th percentile and 99th percentile values and the average values for the basic information about the temperature and wind speed in each region were aggregated. The analysis results for each power plant by region are discussed below.

3.1. Hanbit NPP

The Hanbit nuclear power plant has a maritime climate because it faces the West Sea. In spring and autumn, sea breezes are affected by the characteristics of the coast. In winter, when the cold continental high pressure expands, gusts of wind and showers may cause snow and heavy snowfall.

To the east is the Sobaek Mountains, bordering the Yeongnam region, and to the north are the Chungcheong region and the Geumgang River. On the other hand, Jeollanam-do and the northern regions are bordered by the Noryeong Mountains.

The average temperature is 13.38°C, the average highest temperature in August is 36.5°C, and the average minimum temperature is −17.3°C in January, the coldest month. The annual average wind speed is 2.10 m s^{-1}, and the monthly average wind speed is highest in February at 2.53 m s^{-1}.

Fig. 2 is an aggregated graph based on the temperature data measured at Yeonggwang 252.

Fig. 3 was created by accumulating wind speeds in all regions. Although there are regional variations in each region, most of them show the same distribution.

3.2. Kori and Saeul NPP

The Gyeongnam region, where the Kori and Saeul nuclear power plants are located, is located in the southeast of the

Table 1. Distribution of temperature in the areas around the nuclear power plants - Calculated based on data from January 1, 2012 to the end of August 2022

		Hanbit			Wolsong			Kori					Hanul				
		Yeonggwang 252	Gochang 172	Gochang 251	Yeongcheon 281	Pohang 138	Gyeongju 283	Changwon 155	Ulsan 152	Yangsan 257	Busan 159	Gimhae 253	Uljin 130	Yeongdeok 277	Yeongju 272	Bonghwa 271	Taebaek 216
Temperature (°C)	Maximum	36.5	37.3	36.9	39.5	39.3	39.2	38.3	38.4	38.1	36.6	37.8	37.5	39.7	37.8	36.8	35.3
	Minimum	−17.3	−16.8	−17.5	−15.6	−12.7	−13.2	−13.8	−12.2	−10.8	−12.2	−13.8	−15.6	−14.1	−20.6	−27.1	−21.5
	Mode	21.2	23.3	21.2	21.7	21.9	18.9	19.9	19	21.6	20.2	21.5	18.4	20.4	22.7	21	18.1
	Median	14	14.3	14.4	14.2	15.9	14.3	15.5	15.6	15.9	16.3	15.9	14	14.3	12.8	11.1	10.4
	Average	13.43	13.53	13.65	13.42	15.03	13.63	14.73	14.73	15.12	15.36	15.06	13.19	13.58	12.01	10.37	9.51
	Standard deviation	±10.11	±10.16	±10.26	±10.47	±9.45	±10.19	±9.29	±9.23	±9.54	±8.61	±9.40	±9.00	±9.50	±10.67	±10.92	±10.56

Table 2. Distribution of wind speed in the areas around the nuclear power plant - Calculated based on data from January 1, 2012 to the end of August of 2022

Wind \ Regions		Hanbit			Wolsong			Kori					Hanul				
		Yeonggwang 252	Gochang 172	Gochang 251	Yeongcheon 281	Pohang 138	Gyeongju 283	Changwon 155	Ulsan 152	Yangsan 257	Busan 159	Gimhae 253	Uljin 130	Yeongdeok 277	Yeongju 272	Bonghwa 271	Taebaek 216
Wind speed ($m\ s^{-1}$)	Maximum	15.50	20.60	12.60	10.40	14.40	15.50	16.90	12.20	11.50	18.50	17.20	21.00	15.60	12.10	9.90	10.20
	Mode	0.00	0.00	0.00	0.60	2.30	1.30	0.00	1.30	0.90	2.60	1.00	2.10	2.00	1.10	0.50	0.10
	Median	1.70	2.10	1.40	1.50	2.50	2.00	1.50	1.90	2.10	2.90	1.70	2.40	2.40	1.80	1.20	1.40
	Percentile 95	5.30	6.60	4.30	4.60	5.00	5.70	4.00	4.60	5.10	6.40	4.80	5.10	6.50	6.60	3.50	3.80
	Percentile 99	7.20	9.10	5.90	5.90	6.50	7.30	5.10	6.10	6.30	8.70	6.30	7.00	8.50	8.20	4.70	5.00
	Average	2.10	2.64	1.70	1.82	2.62	2.45	1.69	2.16	2.33	3.18	2.06	2.59	2.82	2.49	1.43	1.58

Korean Peninsula. It is bordered by Gyeongbuk to the north and Jeonnam to the west, and bordered by the South Sea and the East Sea to the south and east, respectively. To the east, the relatively gentle dyke of the Taebaek Mountains is located, the Nakdonggang River is located in the central part, and the relatively rugged Sobaek Mountains are located to the west.

In the eastern mountainous area, high mountains such as Cheonwangsan (1,189 m above sea level), Gajisan (1,240.9 m above sea level), and Sinbulsan (1,159 m above sea level) are located.

The mountainous area to the west is steep and consists of relatively high peaks such as Deogyusan (1,614 m above sea level), Jirisan (1,915 m above sea level), and Baegunsan (1,279 m above sea level), and basins exist in the mountainous area.

The east coast has a monotonous coastline, and the south coast is a subdued rias coast, forming an archipelago with small and large bays and islands.

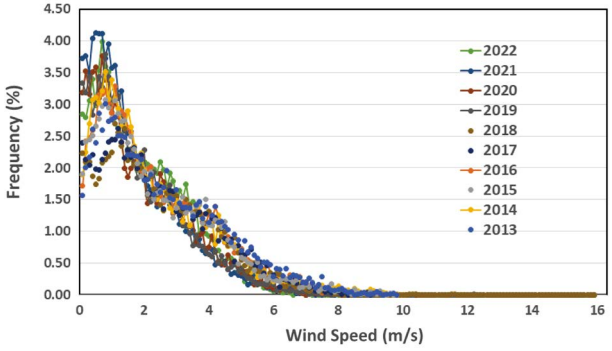

Fig. 2. Current status of wind speeds in the Yeonggwang region from 2013 to 2022.

The Busan region consists of the eastern hills and the western plains centering on the Geumjeong mountain range (Geumjeong Mountain 801.5 m) and the Geumnyeon mountain range (Geumnyeon Mountain 415 m). The Sineisan mountain range surrounds the Nakdong river delta from north to southwest and consists of large and small mountains. The annual average temperature is 15.36°C. The average maximum temperature in August is 36.60°C, and the average minimum temperature in January, the coldest month, is −12.2°C. A northeast wind blows mainly from March to October, and the annual average wind speed is 3.18 m s^{-1}. The average monthly wind speed is highest in April at 3.55 m s^{-1}.

The Ulsan region is located in the east of Gyeongsangnam-do where the Taebaek Mountains end, with 1,200 m high mountains to the north and west and a basin surrounded by 700 m mountains to the southern area. The annual average temperature is 14.73°C. The average maximum temperature in August is 38.40°C, and the average minimum temperature in January, the coldest month, is −12.20°C. From October to January, mainly a northwest wind blows; the annual average wind speed is 1.9 m s^{-1}, and the average monthly wind speed is the highest in February at 2.4 m s^{-1}.

3.3. Wolsong NPP

The Pohang area is bordered by the Taebaek Mountains in a row with a steep mountain pass over 1,000 m to the northwest and the East Sea to the east. The Hyeongsan River flowing through the center of the city flows into Yeongil Bay,

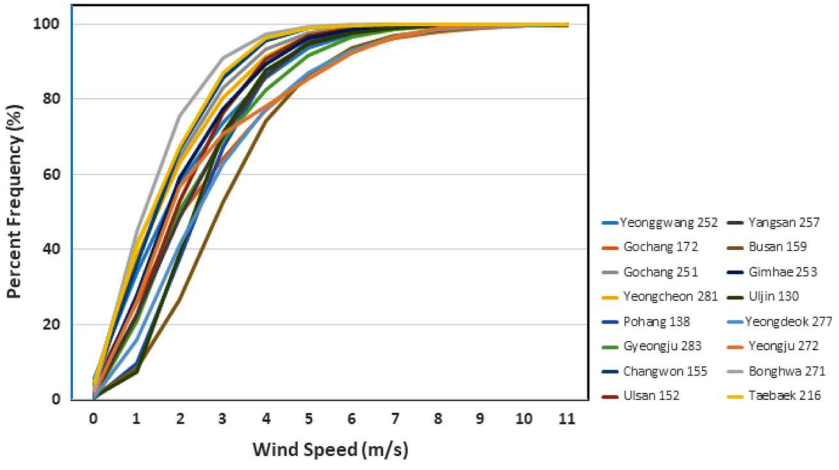

Fig. 3. Cumulative wind speed ratio according to meteorological observatories.

forming a wide alluvial plain.

The west side of the city is hilly. Most of the northern area is used as farmland, and the middle area is being urbanized as an area adjacent to a port. The current urban area is developed to the south, and flat land has been developed to the south of the Hyeongsan River, commonly used as farmland. The annual average temperature is 15.03°C. The average maximum temperature in August is 39.30°C, the hottest month.

The coldest month, January, has an average minimum temperature of −12.70°C.

From December to January, mainly a southwest wind blows; the annual average wind speed is 1.9 m s^{-1}, and the average monthly wind speed is the highest in March at 2.91 m s^{-1}.

3.4. Hanul NPP

In the Gyeongsangbuk-do region, the Taebaek Mountains form a steep slope with the East Sea to the east, and the Sobaek Mountains branching from the Taebaek Mountains are formed from the northeast to the southwest. Sobaek main mountains such as 1,394 m above sea level and Munsusan (1,206 m above sea level) and Taebaeksan (1,567 m above sea level) are located.

In the central part of Gyeongsangbuk-do, the Nakdong River passes through the inland region of Gyeongnam, and the south, which borders Gyeongsangnam-do, consists of high mountains such as Gayasan (1,430 m above sea level) and Biseulsan (1,084 m above sea level). The east coast has a monotonous coastline.

Uljin is located near the border between Gyeongsangbuk-do and Gangwon-do. Uljin, where the Hanul Nuclear Power Plant is located, belongs to the east coast of northern Gyeongsangbuk-do, and the East Sea and Taebaek Mountains form a steep slope. The annual average temperature is 13.19°C. The average maximum temperature in August is 37.50, and the average minimum temperature in January, the coldest month, is −15.60°C. A southwest wind blows mainly from November to January; the annual average wind speed is 1.9 m s^{-1}, and the average monthly wind speed is highest in March at 3.0 m s^{-1}.

3.5. Correlation analysis between the wind speed and wind direction

Table 3 shows the percentage fractions for the wind direction by region. As shown in Table 4, a correlation analysis was conducted to analyze the linear relationship between

Table 3. Wind directions and ratio table around nuclear power plants

Region	Wind direction (degrees)																
	Clam	2	5	7	9	11	14	16	18	20	23	25	27	29	32	34	36
Yeonggwang 252	1.60E-01			1.08E-05			1.08E-05			1.E-01			1.E-05			2.E-05	1.E-05
Gochang 172	1.18E-01									6.E-02					1.E-05		
Gochang 251	2.11E-01		1.08E-05		2.16E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	4.E-02	1.E-05	2.E-05	4.E-05	2.E-05	5.E-05	1.E-05	2.E-05
Yeongcheon 281	1.63E-01									6.E-03				1.E-05			
Pohang 138	1.64E-02		1.07E-05							9.E-02							
Gyeongju 283	5.12E-02	1.07E-05	1.07E-05					1.07E-05	1.07E-05	7.E-02							
Changwon 155	1.48E-01								1.07E-05	8.E-02	1.E-05				1.E-05		
Ulsan 152	6.66E-02	2.14E-05								7.E-02							
Yangsan 257	7.35E-02		2.14E-05	2.14E-05					1.07E-05	3.E-02	1.E-05	3.E-05					
Busan 159	3.08E-02									5.E-02							1.E-05
Gimhae 253	8.86E-02					1.07E-05			1.07E-05	1.E-02				1.E-05	4.E-05	5.E-05	1.E-05
Uljin 130	1.49E-02									2.E-02							
Yeongdeok 277	5.12E-02									9.E-02							
Yeongju 272	8.23E-02						1.07E-05		1.07E-05	2.E-02					2.E-05		
Bonghwa 271	1.79E-01									4.E-02	1.E-05					1.E-05	1.E-05
Taebaek 216	2.30E-01									4.E-02	1.E-05					1.E-05	

Region	50	70	90	110	140	160	180	200	230	250	270	290	320	340	360
Yeonggwang 252	6.E-02	4.E-02	5.E-02	5.E-02	5.E-02	4.E-02	4.E-02	3.E-02	4.E-02	4.E-02	6.E-02	2.E-02	4.E-02	6.E-02	1.E-01
Gochang 172	7.E-02	5.E-02	5.E-02	5.E-02	5.E-02	6.E-02	5.E-02	4.E-02	4.E-02	4.E-02	4.E-02	7.E-02	9.E-02	7.E-02	6.E-02
Gochang 251	3.E-02	3.E-02	3.E-02	4.E-02	6.E-02	6.E-02	5.E-02	4.E-02	4.E-02	4.E-02	4.E-02	5.E-02	8.E-02	8.E-02	8.E-02
Yeongcheon 281	2.E-02	6.E-02	1.E-01	8.E-02	3.E-02	1.E-02	9.E-03	1.E-02	3.E-02	5.E-02	1.E-01	2.E-01	8.E-02	2.E-02	6.E-03
Pohang 138	9.E-02	3.E-02	2.E-02	8.E-03	6.E-03	7.E-03	1.E-02	5.E-02	2.E-01	2.E-01	9.E-02	5.E-02	5.E-02	3.E-02	6.E-02
Gyeongju 283	5.E-02	2.E-02	1.E-02	2.E-02	3.E-02	5.E-02	2.E-01	1.E-01	5.E-02	4.E-02	4.E-02	9.E-02	1.E-01	5.E-02	7.E-02
Changwon 155	1.E-01	3.E-02	2.E-02	3.E-02	6.E-02	8.E-02	7.E-02	5.E-02	4.E-02	5.E-02	6.E-02	4.E-02	3.E-02	4.E-02	6.E-02
Ulsan 152	5.E-02	5.E-02	4.E-02	3.E-02	4.E-02	3.E-02	2.E-02	5.E-02	3.E-02	3.E-02	4.E-02	8.E-02	1.E-01	1.E-01	9.E-02
Yangsan 257	9.E-02	1.E-01	6.E-02	3.E-02	3.E-02	3.E-02	4.E-02	1.E-01	2.E-01	8.E-02	4.E-02	4.E-02	4.E-02	2.E-02	2.E-02
Busan 159	2.E-01	8.E-02	5.E-02	4.E-02	2.E-02	1.E-02	3.E-02	8.E-02	7.E-02	7.E-02	8.E-02	6.E-02	5.E-02	6.E-02	4.E-02
Gimhae 253	8.E-03	1.E-02	2.E-02	6.E-02	9.E-02	6.E-02	4.E-02	2.E-02	2.E-02	4.E-02	4.E-02	1.E-01	3.E-01	8.E-02	3.E-02
Uljin 130	2.E-02	2.E-02	5.E-02	3.E-02	5.E-02	4.E-02	4.E-02	6.E-02	1.E-01	2.E-01	2.E-01	9.E-02	7.E-02	4.E-02	3.E-02
Yeongdeok 277	5.E-02	3.E-02	3.E-02	2.E-02	3.E-02	1.E-01	1.E-01	6.E-02	4.E-02	7.E-02	1.E-01	9.E-02	3.E-02	2.E-02	4.E-02
Yeongju 272	2.E-02	2.E-02	1.E-02	3.E-02	7.E-02	1.E-01	5.E-02	2.E-02	1.E-02	1.E-02	3.E-02	2.E-01	3.E-01	9.E-02	2.E-02
Bonghwa 271	3.E-02	2.E-02	2.E-02	2.E-02	5.E-02	8.E-02	5.E-02	5.E-02	5.E-02	3.E-02	3.E-02	6.E-02	8.E-02	1.E-01	7.E-02
Taebaek 216	6.E-02	7.E-02	3.E-02	2.E-02	1.E-02	2.E-02	5.E-02	8.E-02	1.E-01	8.E-02	4.E-02	3.E-02	4.E-02	4.E-02	4.E-02

Table 4. Correlation analysis results between the wind speeds and wind directions at 16 points

	Yeonggwang 252	Gochang 172	Gochang 251	Yeongcheon 281	Pohang 138	Gyeongju 283	Changwon 155	Ulsan 152
Correlation value of wind speed and wind direction	0.53	0.36	0.51	0.51	−0.13	0.25	0.07	0.14
	Yangsan 257	Busan 159	Gimhae 253	Uljin 130	Yeongdeok 277	Yeongju 272	Bonghwa 271	Taebaek 216
Correlation value of wind speed and wind direction	0.16	0.27	0.29	0.23	0.10	0.47	0.35	0.40

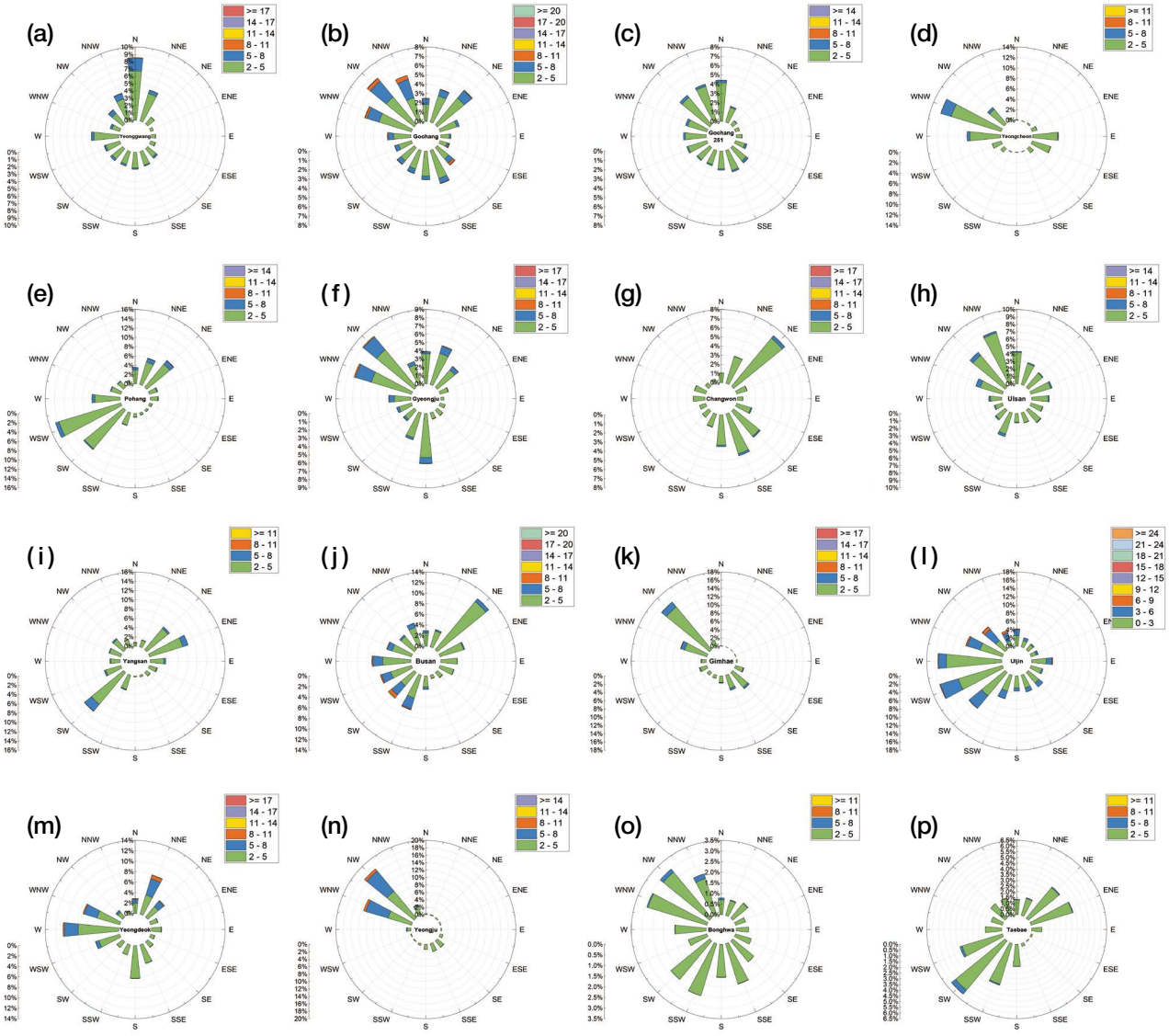

Fig. 4. Wind rose graph for 16 areas around nuclear power plants: (a) Yeonggwang 252, (b) Gochang 172, (c) Gochang 251, (d) Yeongcheon 281, (e) Pohang 138, (f) Gyeongju 283, (g) Changwon 155, (h) Ulsan 152, (i) Yangsan 257, (j) Busan 159, (k) Gimhae 253, (l) Uljin 130, (m) Yeongdeok 277, (n) Yeongju 272, (o) Bonghwa 271, and (p) Taebaek 216.

the wind speed and the wind direction.

In the correlation analysis, the correlation coefficient values ranged from 0.53 to 0.07. The wind direction for the wind speed was mostly positive, and Yeonggwang 252 was highest at 0.53. The lowest area was Changwon 155, which recorded a value of 0.07. Calculations showed that the region adjacent to the east coast was low and the west coast or inland regions had a high linear relationship. Table 3 shows the percentage fractions for the wind direction by region.

3.6. Wind rose

As shown in Fig. 4, a wind rose chart with 16 points was created through the Origin Pro 2022 program. The frequency of the appearance of each wind direction at each observation point was converted into percentage (%); these are expressed as the length of the bearing line on the bearing plate corresponding to each wind direction.

4. CONCLUSION

Among the 16 districts, Uljin had the highest wind speed. The median wind speed values for each region were lower than the average wind speed values. For regions where the average wind speed exceeds the median wind speed, Yeongju, Gochang, Gyeongju, Yeonggwang, and Gimhae were calculated as 0.69 m s^{-1}, 0.54 m s^{-1}, 0.45 m s^{-1}, 0.4 m s^{-1}, and 0.36 m s^{-1}, respectively.

Looking at the temperature distribution, the average temperature of the 16 regions was calculated and found to be 13.52°C, the median temperature was 14.31°C, and the mode temperature was 20.69°C. The average regional temperature standard deviation was calculated as 9.83 degrees. The maximum summer temperatures were 39.7, 39.5, and 39.3 in Yeongdeok, Pohang, and Yeongcheon, respectively.

The wind direction and speed of the 16 regions were plotted as a wind rose graph, and the characteristics of the wind direction and speed of each region were investigated. It was found that the dominant wind direction is correlated with the topographical characteristics in each region.

However, the linear relationship between the wind speed and direction varied by region from 0.53 to 0.07.

Through this study, by evaluating meteorological observation data on a long-term synoptic scale spanning ten years, regional characteristics were elucidated.

ACKNOWLEDGMENTS

This paper is research conducted with the support of the National Research Foundation of Korea (NRF) with funding from the government (Ministry of Science and ICT) (NRF-2020M2D2A2062571).

REFERENCES

1. Disaster Recovery, Busan City Hall Homepage, 2022. 9. 10. https://www.busan.go.kr/depart/disasterhistory0102
2. Jeong JH and Cho LN. 2010, Trend of the Westerlies over the Korean Peninsula. *J. Clim. Res.* **5**(1):68-77.
3. Kang B, Jung C, Park Y-S and Kong G-Y. 2021. Minimum Wind Speed of Dragging Anchor for Ships in Jinhae Bay Typhoon Refuge. *J. Korean Soc. Mar. Environ. Saf.* **27**(4):474-482. https://doi.org/10.7837/kosomes.2021.27.4.474
4. Seol D. 2013. Seasonal wind changes on the west coast of Korea. Proceedings of the Korean Society of Navigation and Maritime Affairs 2013 Fall Conference Proceedings 2013.09. pp. 19-20.
5. Government e-learning platforms. 2022. 8. 12. Korea Meteorological Administration. http://kma.nhi.go.kr/
6. Hongwei H, Dan F, Rentai Y and Xignajun X. 2011. Comparison of atmospheric dispersion factor in complex terrain. *Prog. Nucl. Sci. Technol.* **1**:452-455.
7. Moon JH. 2020. Suggestions to Improve the Effectiveness of National Radiological Emergency Response System. *JNFCWT* **18**(2):195-206. https://doi.org/10.7733/jnfcwt.2020.18.2.195
8. EPRI_1015105: Risk-Informed Evaluation of Protective Action Strategies for Nuclear Plant Off-Site Emergency Planning. EPRI, Palo Alto, CA and NEI, Washingon, D.C.: 2007. 1015105
9. Collins HE and Grimes BK. 1978. Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants. U. S. Nuclear Regulatory Commission and U. S. Environmental Protection Agency Task Force on Emergency Planning.
10. Open Nuclear Operations Information, Korea Hydro & Nuclear Power Homepage, July 12, 2022. https://npp.khnp.co.kr/index.khnp
11. Data of Automated Synoptic Observing System, Sep. 3, 2022. https://data.kma.go.kr/data/grnd/selectAsosRltmList.do?pgmNo=36
12. Scale of atmospheric circulation, Korea Meteorological Administration, Sep. 1, 2022 18:34. https://blog.naver.com/PostView.nhn?isHttpsRedirect=true&blogId=kma_131&logNo=221276236381
13. Wind, From Wikipedia, the free encyclopedia. 2022.8. 12. 14:57, https://en.wikipedia.org/wiki/Wind