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How is Sleep Quality and Noise Sensitivity of Residents Living in Proximity to Largest Wind Farm of Iran?

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ABSTRACT

Introduction: Noise emitted by wind farms has many potential negative impacts on the health of nearby residents, some of which are sleep disturbance, noise sensitivity and consequently negative effects on behavioral reactions. The main aim of this research is to investigate the effect of wind turbines on the sleep quality and noise sensitivity of the residents of three areas located close to the largest wind farm of Iran.
Method: This study has been implemented in 2 phases: 1) in the first phase, A-weighted sound pressure levels measurements have been done in the houses, the distance of respondents' residence location from the wind farm has been determined with GPS, 2) in the second phase, Pittsburgh Sleep Quality Index (PSQI) and Weinstein's Noise Sensitivity Scale (WNS) questionnaires were filled out by 180 of nearby residents. Data analyses have been done with SPSS16 software.
Results: Decreasing the distance of the respondents' residence from the wind farm leads to higher sound pressure levels and hence higher sleep quality index ($Pv<0.05$). Residents living in less than 800m away from wind farm are averagely exposed to 45dBA, so the sleep quality index of 90% of them has been more than 5. About 42% of the respondents, mostly females, have poorer sleep quality. A decrease in the distance of the residence from wind farm causes more noise sensitivity ($Pv<0.05$), females are clearly more sensitive to noise (40 %) than males (30 %)
Conclusion: On the basis of the results achieved, decreasing the distance causes more exposure to sound pressure levels emitted by wind turbines, which in turn leads to less sleep quality and more noise sensitivity of the residents near the largest wind farm of Iran.
KEY WORDS: Sleep Quality, Noise Sensitivity, Wind Farm

INTRODUCTION

The installation of wind turbines as relatively new sources of energy, which convert wind energy to electricity, has been remarkably developed in recent years. Experts have discussed the infrasound of wind turbines a lot. There are some impacts on receptors because of the wind turbine noise[1,2]. Low frequency noise of these turbines threatens the health of the people living nearby and its energy causes annoyance and sleep disturbance for some residents[1, 3, 4]. Based on a research made by Miedema and Vos in 2003, noise sensitivity has a significant relationship with the residents' annoyance[5]. Loren D Knopper et al. study in 2011 showed that exposure to the noise emitted by wind turbines would decrease people's health and would directly cause annoyance, sleep disturbance and decreased quality of life. It also causes sensitivity to noise and has negative impacts on behavioral reactions. Noise from wind turbines has also secondary impacts including stress-related diseases and decreased quality of life as a result of sleep disturbance[1]. According to Renewable Energy Approval (REA) regulations the minimum setback distance required between a receptor location (center of dwelling) and the base of the closest wind turbine should be 550m, which states that the potential impacts of wind farm noise would decrease in longer distances, and the noise level would be kept at 40dBA, which is the threshold of the occurrence of negative impacts[6]. According to the literature review there is no research implemented in Iran about wind turbine noise impact on nearby residents, so in the current study, Manjil wind farm as the largest wind farm of Iran, which has the minimum distance from residential areas has been selected as the study area (residents' dwellings from wind farm is 300 to 1500m). Considering the wide range of research topics in the field of the wind turbines impacts, the main objectives of this study are to measure the sound pressure levels of Manjil wind farm (largest wind farm of Iran) and its effects on sleep quality and noise sensitivity of the residents living in the three neighboring areas.

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MATERIALS AND METHODS

This research has been implemented on the people living in the vicinity of the largest wind farm of Iran in Manjil located in north of Iran with UTM coordinates X:356407,01 and Y: 4066138,95 (Figure. 1). Since Manjil is suitable to generate electricity with wind turbines because of its high average wind speed (max: 25m/s);the largest wind farm in Iran and also in the Middle East has been installed with 52 wind turbines. The wind farm area is some 1653116 m^2. As illustrated in Figure1, there are 3 residential areas located in less than 300m away from the wind farm, the residents of which are continuously exposed to the noise emitted by wind turbines. Therefore the respondents have been selected from these three areas. In order to define the statistical population and determine the appropriate number of questionnaires as the sample size, a preliminary survey has been conducted, 60 questionnaires have been distributed and filled out, and the sample variance was estimated with a 95%-confidence interval. The sample size was calculated to be 164 using relevant statistical formulae, which is added by 16 to increase the confidence interval. In total, 180 questionnaires were filled out by male and female participants equally (90 males and 90 females) in order to compare the groups with more precision. The average distance of randomly selected residents' dwellings from the wind farm was 300 to 1500m.

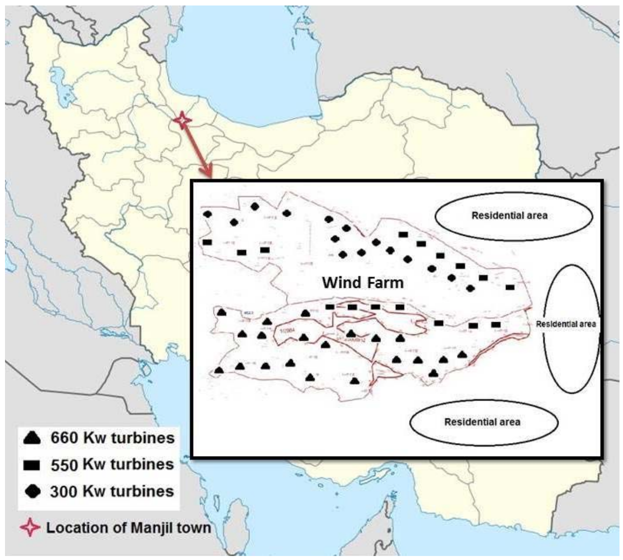

Figure 1. Location of Manjil in Iran and three residential areas to Manjil wind farm

Considering the defined aims of the study, data was collected in two phases:

Phase I: *Noise measurement in the residential areas*

The A-weighted sound pressure levelsat noise receptor locations have been measured with TES- 1358 Sound Analyzer Sound Level Meter. The sound level meter was calibrated to 94 dBA at 1000 Hz. The device microphone (Protected with wind shield) was positioned at the height of 1.5 m. In order to improve the measurement accuracy, A-weighted sound pressure levels (as perceived by the human ear) have been measured 3 times [9]. As the investigation of impact of distance on sleep quality and noise sensitivity was emphasized in this research, the respondents' geographical position and their distance from the wind farm have been recorded by GPS. The analyses of data achieved from the questionnaires and field measurements have been carried out with SPSS 16.

Phase I: *Subjective Survey*

The questionnaire method has been chosen in order to assess the sleep quality and noise sensitivity of the people living in close proximity to the wind farm, so Pittsburgh Sleep Quality Index (PSQI) and Weinstein's Noise Sensitivity Scale (WNS) questionnaires have been applied. All the questionnaires were filled out directly by trained interviewers. All the respondents were in good mental and physical conditions. Besides the questionnaires necessary fields, some other important data including age, gender, daily time spent indoors, daily sleep duration and length of residence were also collected. The questionnaires applied in this research have been approved by related experts. The Pittsburgh Sleep Quality Index (PSQI) is an effective tool to assess the quality and patterns of sleep in older adults, which differentiates "poor" from "good" sleep by measuring seven areas: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction over the last month. The client self-rates each of these seven areas of sleep. Scoring of answers is based on a scale of 0 to 3, whereby 3 shows very bad. An overall sum of "5" or greater indicates a "poor" sleeper. The PSQI has internal consistency and a reliability coefficient (Cronbach's alpha) of 0.83 for its seven components. Several studies using the PSQI in a variety of older adult populations throughout the world have supported high validity and reliability[7]. The Weinstein's Noise Sensitivity (WNS) Scale has been largely used in noise sensitivity studies. This questionnaire consists of 21 items, which are presented on a 6-point scale rating from "agree strongly" (1) to "disagree strongly" (6). Weinstein (1978) stated that the Kuder-Richardson reliability of his noise sensitivity questionnaire was 0.83 [8]. The noise sensitivity questionnaire has a reliability coefficient (Cronbach's alpha) of 0.83 for its items.

In order to implement the statistical analysis needed to confirm the results, the proper statistical test for the analysis should be determined firstly, so, the normality of each of the variables was initially tested using the Kolmogorov-Smirnov test (KS-test) with a margin of error greater than 0.05. After ensuring the normal distribution of the data, chi-square test (χ^2), bivariate correlations test and one-way ANOVA test were used to analyze the quantitative and qualitative data that have been collected in this study with SPSS16 software.

RESULTS

In the current research, 180 questionnaires have been filled out by respondents. According to kolmogorov-smirnov test results, all variables have normal distributions, which are significant at the >0.05 error level, so parametric tests have been applied to analyze the data.

Phase I:

More distance between wind turbines and the houses leads to lower noise exposure which on the basis of the results changes the sleep quality of residents. Figure.2 illustrates sound pressure level at the residents' houses considering their distance from the wind farm and the residents sleep quality index.

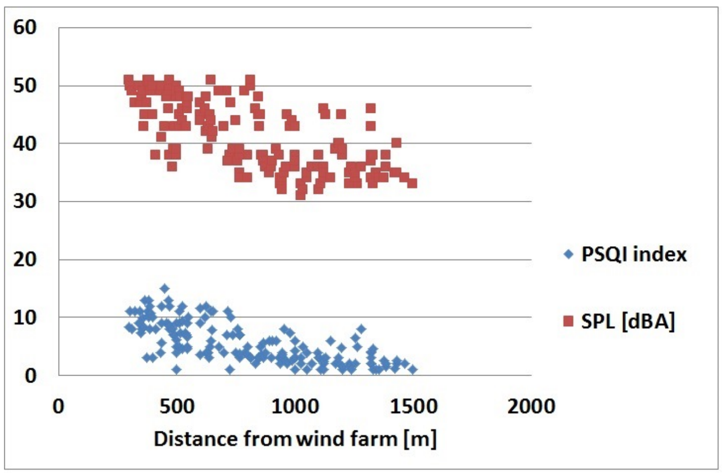

Figure 2. PSQI index and Sound pressure levels at the residents' houses to their distance from wind farm

Figure2 shows that sound pressure levels emitted by wind turbines have a significant, inverse relationship with the residents distance from wind farm (Pv<0.05). Considering the distance of the selected houses from the wind farm, which ranges from 300 to 1500m and also measured sound pressure levels which are 31 to 51dBA, sound pressure levels decrease with the distance increase(Pv<0.05). The sound pressure levels of wind turbines decrease averagely by 2.1dBA per 100m from wind farm in 1000 m away. In farther distances the sound pressure levels decrease averagely by 1.1dBA per 100m, so, based on the findings, distance from the wind farm has an inverse relationship with sound pressure levels. Averagely, minimum sound pressure levels (31dBA) were recorded in 1500m and maximum sound pressure level (51dBA) in 300m away from wind farm. Average sound pressure level has been 45dBA (SD=4.7) measured in approximately 800m away from the wind farm. As it is illustrated in figure 3, the relationship between residents' distance from the wind farm and sleep quality index is significant (correlation coefficient= -0.698, Pv<0.05). Overall, sleep quality score of almost 90% of the residents living in less than 800m away from the wind farm has been >5, which fell within a categorically defined range for "poor" sleepers. The results of correlation test show that there is a significant relationship between noise emitted by wind turbines and residents' sleep quality (correlation coefficient= 0.334, Pv<0.05), so a decrease in wind turbine noise leads to an improvement in their sleep quality.

Phase II:

Since the general information about respondents may influence the results, their demographic characteristics including age, gender, daily sleep duration along with the daily time spent indoors and also Pittsburgh Sleep Quality Index (PSQI) scores have been recorded for both males and females separately and summarized in Table1.

Table1. Frequency distribution of Demographic characteristics and Pittsburgh Sleep Quality Index (PSQI) scores in males and females

Variables	Category	Males	Females	Total
gender	-	90(50%)	90(50%)	180
Age group (years)	24-16	14(15.6%)	14(%15.6)	28
	34-25	34(37.7%)	18(%20)	52
	44-35	26(%28.9)	20(%22.2)	46
	54-45	8(8.9%)	22(24.4%)	30
	64-55	8(8.9%)	16(17.8%)	24
Daily time spent indoors (hours)	<10	14(15.6%)	6 (6.7%)	20
	10-14	44(48.8%)	18(20%)	62
	14-18	26(28.9%)	46(51.1%)	72
	>18	6(6.7%)	20(22.2%)	26
Daily sleep duration (hours)	<5	11 (%12.2)	(%7.7)7	18
	5-10	46(%51.1)	37(%41.1)	83
	10-15	28(%31.1)	42(%46.7)	70
	>15	5(%5.6)	4(%4.5)	9
Category of PSQI Index	<5(good)	(75.5%)68	36(40%)	104(58%)
	≥5(poor)	(24.5%)22	54(60%)	76(42%)

Some 73% of females and 40% of males spent more than 14h indoors daily. Females averagely spent more time indoors (15.2h) than males (13.3h), so daily time spent indoors has a significant relationship with gender (pv<0.05). Average age of females was 40.8 years and males' average age was 35.8 years, so average age of females is more than males (pv<0.05). Males' sleep duration was averagely 9 hours and females10 hours daily. According to data analysis, there is no significant relationship between sleep duration and gender (Pv>0.05). All the respondents had been living in Manjil more than 10 years and were natives. As it is shown in Table1, sleep quality of 58% of the respondents has been reported to be "good". The results of chi-square test (χ^2) showed that PSQI Index has significant relationship with gender (pv<0.05). 76 of the respondents had poor PSQI Index, 22 of which were males and 54 were females. Almost 24.5% of males and 60% of males had poor PSQI Index. Data suggested that males PSQI Index was generally better compared with females. Minimum and maximum scores of PSQI were 1 and 11 for males and 2 and 15 for females respectively.

The residents' noise sensitivity is the result of environmental noise and may cause sleep disturbances since sensitivity to noise affects the sleep quality. Figure3 illustrates the noise sensitivity of males and females.

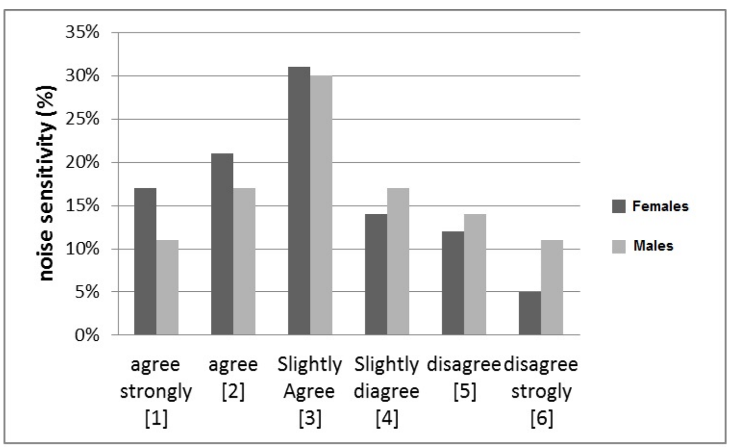

Figure 3. Noise sensitivity in males and females

Based on chi-square test (χ^2) results conducted to see if there is any relationship between gender and noise sensitivity (Pv<0.05), so H1 was accepted, and it was evident that gender and noise sensitivity are significantly related. Males and females have different sensitivity to noise, and the results showed that females are more sensitive to noise comparing to males. Figure 3indicates that some 40% of females and 30% of males are sensitive to the noise emitted by wind turbines. Data analysis showed a significant relationship between sleep quality index and noise sensitivity (Pv<0.05). Therefore, it could be deduced that residents who are more sensitive to noise have poorer sleep quality.

Since all data have a normal distribution, the relationships between quantitative and qualitative data were tested by one-way ANOVA, the relationship between two quantitative variables was determined by Pearson's test and the relationship between two qualitative variables was tested by chi-square test (χ^2). Table 2summarizes the statistical tests correlation coefficients with Pv<0.05.

Table2. Correlation coefficients of studied variables

	PSQI	Age	Gender	Distance	LA (dBA)	Daily sleep duration (hours)	Daily time spent indoors (hours)	sensitivity to noise
PSQI	1	0.307*	0.859*	-0.698*	0.334*	-0.206*	-0.476*	-.576*
Age	-	1	0.341*	-	-	0.050	0.093	0.412*
Gender		-	1	-	0.091	0.124	0.754*	0.435*
Distance	-	-	-	1	-0.674*	0.179*	0.040	0.389*
LA (dBA)	-	-		-	1	-0.420*	0.105	0.653*
Daily sleep duration (hours)	-	-		-	-	1	0.137*	0.414*
Daily time spent indoors (hours)	-	-		-	-	-	1	0.370*
sensitivity to noise	-	-		-	-	-	-	1

*Pv<0.05

On the basis of the data achieved from Table2, the age attribute has a significant relationship with sensitivity to noise and sleep quality (Pv<0.05). Females are more sensitive to noise than males and have a poorer sleep quality too. There is also a significant relationship between sound pressure levels emitted by wind turbines and distance from them (Pv<0.05), the greater the distance the lower sound pressure levels and also higher sleep quality index average (Pv< 0.05). People who have a good sleep quality would not easily wake up during night and are less sensitive to noise (Pv<0.05). In a general view, people who spent more time indoors, have better sleep quality and sleep more along the day. Sound pressure levels increase in the locations closer to the wind farm, which lead to more sensitivity to noise emitted by wind turbines and less daily sleep.

DISCUSSION AND CONCLUSION

Wind farms have a considerable growth as a result of a greater demand for electricity throughout the world. On the other hand, noise emitted by wind turbines has many impacts on health and life of the people living nearby. The average sound pressure level emitted by wind turbines is more than 40dBA in residential areas closer to the wind farm, which would negatively affect the residents[1]. The current study also suggests that the neighboring residents' sleep quality decreases and they are more sensitive to noise. Michel A Nissebaum et al. in 2012 has conducted a research on the effects of wind turbine noise on nearby residents' health and sleep in Mars Hill and Vinalhaven where the general health and sleep quality of two groups of residents (a. living close to wind turbines and b. living further away from them) were compared. Their results showed that participants living between 375 and 1400 m had a worse sleep compared to those living between 3.3 and 6.6KM. According to their results, the sound pressure levels have decreased with distance, while the sleep quality has increased. Perhaps a shorter distance between the residents and the wind farm is the reason of their lower sleep quality [10]. The findings of the our research on participants living in the range of 1500m from the wind farm also showed that the sleep quality decreases with their distance from the wind turbines and some 42% of participants have poor sleep quality. The similarity of these findings is the result of the fact that sound pressure levels of wind turbines at the receptors decrease with distance, so they hear less noise. Pedersen et al. investigated the noise sensitivity of people living close to wind turbines, which suggests that the lowest proportion of noise sensitivity was found among respondents who always lived at their current residence[11]. The current study also showed that participants, who spent more time indoors, are less sensitive to noise and have better sleep quality due to adaptation to noise which leads to less negative responses to noise. According to Bakker, Roel H et al. research in 2012 in the Netherlands, an increase in wind turbine sound pressure levels would result in more sleep disorders. Their research revealed that for almost 48% of the studied residents near the wind farm are exposed to >45 dB sound pressure level, and sleep disorders have been reported [12].This research also found similar results, which approve that an increase in noise exposure would consequently decrease sleep quality and increase sleep disturbances. Although these disturbances may be the result of different sources of environmental noise, but since the wind turbine has low frequency noises with high propagation and high annoyance, it would cause more sleep disturbances. According to the findings of Pedersen Eja research 2004, environmental noise emissions by different sources like wind turbines, aircraft and road traffic result in residents annoyance. Almost 85% of the studied people exposed to 35-37.5dBA wind turbine noise, reported the wind turbine as the most annoying factor among different sources, which causes sleep disturbances. The findings of the current research showed that residents closer to the wind farm were exposed to 45dBA sound pressure level emitted by wind turbines and also stated that they have sleep disturbances due to poor sleep quality and noise sensitivity. The difference between the sound pressure levels and the consequences in these studies is probably due to the difference between the nature of environmental noise and wind turbine noise, which has affected the residents more because of its low frequency[4]. A review of the scientific literature has been conducted by Loren D Knopper and Christopher A. Ollson in 2011 on the wind turbines' health impacts. They found that noise emitted by wind turbines would not cause hearing loss, but since it is low frequency and people are exposed to it day and night, it has been annoying for some people, and it caused headaches, dizziness and sleep disturbances[1]. It is also found in the current study that level of annoyance increases with sound pressure levels of wind turbines, while Pedersen, Eja research in 2007 in Sweden states that age and gender have no influence on wind turbine noise annoyance[13].This study shows that sleep quality decreases as a result of wind turbine noise annoyance, and also revealed that age has an impact on sleep quality. There are also different effects on males and females in this regard; females have poorer sleep quality in comparison with males. Considering the more hours spent at home by women and also their higher average age, it could be concluded that women are probably more exposed to wind turbine noise and due to their higher average age it would disturb them more before sleep compared to men. Females are also more sensitive to noise. The reason why sound pressure levels has influenced the annoyance level and sleep quality in both studies is that wind turbine noise decreases the comfort and concentration of the residents and cause sleep disorders, headaches, dizziness, drowsiness, etc., all of which result in poor sleep quality. The difference between these studies is possibly the result of the fact that men work outside and so they are more tired than women, so they are conscious of environmental noise less than women before sleep, hence they fall asleep easier. The other reason behind the difference is that the average age of women is higher than men, which affects noise sensitivity and sleep quality in this research. According to the findings of the current study, wind turbine noise has a significant relationship with sleep quality decrease and noise sensitivity increase, so its negative impacts would be harmful for nearby residents' health and quality of life. Considering that people's health is the first priority in all activities, more comprehensive researches on the impacts of wind turbine noise on the people living in close proximity to the wind farms in Iran is highly recommended.

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Conflicts of interest

The authors declare that there are no conflicts of interest in this study.

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