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Psycho-Acoustic Survey on Wind Turbine Noise and Its Environmental Impact

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Abstract: India holds the fourth position in terms of installed wind power with an installed capacity of 40.788GW in July 2022. The country has set itself a national target of 60 GW by 2022. Wind energy still leaves small-scale impacts on the environment and human health. Advanced technologies emerged to make quitter turbines, still, the noise emitted is a cause of concern, especially in the habitats close to the installations. The present study aimed to assess the sensation of annoyance due to the wind turbine's (WT) noise. in the adjoining inhabited area. An interactive questionnaire survey is conducted in six villages from the three districts in the state of Tamil Nadu. The study group comprised 47 subjects belonging to different age groups profession. The basic objective of conducting the health survey is to understand the influence of wind turbine noise (WTN) on the lifestyle of the common masses residing in the surrounding wind farms. While framing the legislation, noise annoyance due to WTN should be considered with utmost importance, since WTN is more distressing than common sources of noise. From the social and psycho-acoustical survey, it was found that sleep disturbance due to ambient noise is more concern, and also the adult population who participated in the survey attributed the loss of rainfall as the main problem faced due to the advent of the WTs and the Noise from the WTs.

Keywords: noise, annoyance, psycho-acoustical, sleep, disturbances, rainfall, wind turbines.

I. INTRODUCTION

The promising utilization of natural resources in the form of renewable energy is wind energy generation. Although, noise problems arise due to the sound produced by the wind turbine. The mechanical and aerodynamic sources of noise are generated from the wind turbine. In the present day, quieter wind turbine technologies are evolved but the noise from some sources is still in concern. The only environmental impact caused by wind energy technology is noise emission from the wind turbine [1]. The majority of objections are noise emissions from wind turbines cause a nuisance to the people dwelling in the residence/village/town nearer to the wind turbine installed area. The noise response by individuals can be varied and wide [2]. Hence the assessment of the separation distance between wind turbine noise and receptors is an important one, thus the viability of wind farms and their size are identified. These objections from the residents about the noise emission generated from the wind turbine are met by the regulations of the country. The wind turbine noise regulations differ for the different countries [3]. The mechanical sources of noise are generated from the generators, hub, transmission chains, moving parts like gear and bearings, etc. the mechanical noise is in the form of vibration signal with low frequencies of 100Hz to 500Hz. The low-frequency noise broadband and tonal components are identified in a wind turbine nacelle which is mechanical noise [4][5]. The aerodynamic noise from wind turbines is naturally broadband, which means the range of its frequency spectrum is wide from infrasound to ultrasound (< 20 Hz to >20 kHz), and typically there are no specific tonal components [6]. Some works specify that the audible noises from wind turbines are in the frequencies between of 500Hz to 1000Hz [7]. Noise modulations in a residential area with a large wind turbine show that the external noise frequencies dominate the range of 200 Hz to 2000 Hz. Normally, the low-frequency noise is not audible to humans and its frequency is up to 20Hz, this is called infrasound [8]. Though not all European regulations follow the secure noise limits/ guidelines, in some countries, regulations for noise emission define the limits for the amount of noise that people are exposed to. The acoustic noise generated from a wind turbine is associated with an opposing impact on the environment. So, the world health organization estimates the environmental impact of noise from a wind turbine at high, moderate, and low frequencies. They obtain that low frequency and infrasound noise affect human well-being. The noise level of 32dB(A) affects the nervous system and 40dB(A) makes discomfort to people [9]. This may also cause health impacts on the nearby residents. Concern about the noisy health effects caused by wind turbines Moderna wind turbine eras began in the early 1970s. Studies on WT noise propagation provide striking steadiness among the research on the association between feeling annoyed and tensed or stressed.

The noise limits differ in daytime and night times based on the country's regulations. The setback distance for the settlement near the wind farm also differs for every nation.

Quality of life which describes an individual's state of dwelling represents a cornerstone of human health. The World Health Organization highlights the deterioration of human health as a notable decline in the quality of life due to environmentally induced noise. The audible and non-audible noise from the wind turbine is related to the health effects [10]. An Ontario Environmental Review Decision has stated that the harm caused by wind turbines on human health is serious even though the impact is generally indirect. These indirect health issues include anxiety and anger induced by stress and strain developed due to the presence of a wind turbine [11]. Stantec Consulting Ltd stated that people notice the sound linearly from the wind turbine during the increasing noise levels. people tend to notice sound from wind turbines almost linearly with increasing SPL, roughly from 5-15 % noticeable noise at 29dB (A) to 45-90% at 41 dB (A). Flindell et *al* [12] distributed questionnaires to 627 households near the wind turbine in areas with 16 installed turbines. Approximately the response rates were ranged from 60% to 78% (< 30 dB(A) to > 40dB(A))and it is similar. The outcome revealed that the number of respondents who observe wind turbine noise rise sharply from 39% (n=27) at 30.0 -32.5 dB(A) to 85% (n=53) at 35.0 -37.5, 2.5 dB(A).

Berg *et al.* [13] analyzed the data sets at two locations in Germany ranging from 400 m to 1500 m. The outcome reveals that WT noise is more dominant during the nighttime than in day time and it is 25% more dominant in the environment. Pedersen *et al* [14] [15] resulted that the risk perception of noise and annoyance is different in rural places compared with urbanized areas. The New Zealand study compared health depended on the quality of life in different proximities to a wind turbine site between two communities around a radius of 2 km and 8 km with similar socio-economic, geographic, and demographic characteristics. The study revealed that noise increased with A-weighted sound pressure levels., was furthermore annoyed when the noise level exceeded 35-40 dB (A). Lee *et al* [16] analyzed the combined study it was found that the people reported feeling tense, stressed, and sleep interrupted and also reported outdoor annoyance. The sleep interruption due to the impact of noise did not show any effect in lower sound levels which are stable at low levels and it impacts at 45 dB (A) in the Dutch study and 40 dB (A) in the Swedish study. Raudan *et al* [17] studied the influence of wind turbine noise and collect a report on the noise effect from the people close to the wind turbine. The new regulation for wind turbine noise levels is 17-39dB L_{Aeq}. They reported from the 676 residents as wind turbine annoyance at the sound level of 40dB. Van kamp et al [18] found in their study that annoyance from the wind turbine at a certain level disturbs sleep. They concluded the annoyance response was getting stronger when increasing the sound level of the wind turbine. Raudan et al [19] prepared the questionnaire for 318 residents living closer to the wind turbine in Finland. The survey includes indoor and outdoor annoyance and sleeping disturbance from wind turbine noise. That survey reported that women are more annoyed at the indoor WTN and men are affected by sleep disturbance.

From these works, the health impacts reported by people are headaches, pressure sensations, and sleep deprivation. The survey was conducted for the different places the wind turbine noise health impact on cardiovascular effects, metabolic effects, sleep disturbance, and annoyance. The main objective of this work is to study the noise annoyance and perception in the populated areas near the wind farm in districts in Tamil Nadu. This work is to conduct a social and psychoacoustical survey in the regions adjoining the wind farms. The Noise assessment on health and well-being is classified in terms of sleep disturbance, annoyance, and well-being, including quality of life and health-based problems. Finally, evaluate the annoyance and noise perception due to the Noise from WTs located in three districts in Tamil Nadu. this paper is organized with the social and psychoacoustical survey in section 2. The result obtained from the survey is discussed in section 3 and finally, the conclusion and findings are explained in section 4.

II. SOCIAL AND PSYCHOACOUSTICAL SURVEY

One's health is easily affected by the high potential of noise exposure which acts directly or indirectly as a stress inducer. The unique sound characterizes audible low-frequency noise amplitude modulation, infrasound, impulse noise, night-time noise, and tonal noise [20]. Annoyance to WT noise starts at wind turbine low levels of 30dB(A) sound pressure levels and peaks above levels. The sound impact on health has a direct relation to its pressure level. The health impact study was performed in the villages within the Dindigul, Coimbatore, and Tirupur districts of Tamil Nadu covering around the area of 80 to 290 m and 700 m radius from the WT respectively. The study included villages, schools, and poultry farms located in the surrounding area of the studied wind farms.

The daytime noise exposure level at minimum wind speeds (3m/s to 4.5m/s) for the installed turbines is 56 dB(A) respectively, whereas the corresponding maximum wind speeds of 12 to 13m/s have a sound pressure level of 61 dB(A) respectively. At night time the noise exposure level of the installed turbine at a minimum wind speed of 3 to 4m/s is 45 dB(A) and at a maximum wind speed of 12 to 15m/s is 55dB (A) respectively.

Various interactional surveys, which are measures of irritability, feelings of stress, and/or health outcomes, tend to support partly the potential of noise-related health impact [21]. The present study provided further insight and explains the objective of wind turbine noise exposure and noise stress. Apart from the human populace, other bird species present in the vicinity of the WTs were also taken into consideration while conducting the survey.

Two poultry farms are situated at a distance of 80 m and 90 m, respectively, from the current operational WT. The questionnaire method determines the onset timing and keeps distancing between the turbine and home and surrounding for installation.

A. Methodology Espoused to Conduct the Survey

The study conducted by [22] was referred and accordingly, the present study was conducted for eight days. This is the first of its kind of study conducted in India and considering the geography of the country as well as the location of wind farms there are lots of limitations while conducting the study, thus the scope is kept limited, and accordingly, the set of questionnaires is framed. Since the WTs are installed in an area where the houses are freely located thus the majority of the residents in the region were visited. During the visit to the residents, verbal consent was taken from each household before recording their responses and conducting the interview. Apart from this, all the questions are read out to them, and the questionnaire is also shown to them. The interviewers wrote the answers, and no exclusion criteria were applied.

Among the 47 pools of people considered, the population share of men, women, and children was found to be 23 %, 34 %, and 43 % respectively. The population residing in the surveyed area represents the lower-middle-income group and consists of daily wage laborers, poultry farm workers, and people involved in petty jobs. During the survey, it was observed that residents were living closer to wind farms. The google earth map is used to calculate the distance between the participant's residence and the wind turbine and the locations are also recorded using Global Positioning System (GPS).

The survey was conducted by recording the responses of the subjects to the framed questions. The questionnaire comprised of questions considering the following aspects:

1) Demographic information (age, gender, and occupation).
2) Place of residence (location, distance from WT, time spent at home).
3) Health conditions of every individual in the family.
4) Changes in quality of life

The results of the questionnaire were entered into a database which was further utilized to determine the exposure of Noise from WT and to develop a relationship.

B. List of Questionnaire

Several research articles were referred to while framing the questions for the survey [21]. The questions were designed in such a manner that will ease the analysis of their living standards, including the frequency of annoyance due to noise from WTs, and self-assessment of their well-being and physical health were asked to all the subjects and respective responses were recorded in every questionnaire sheet, respectively. At least one copy of the questionnaire was delivered to each household. The questionnaire framed the requirement of noise-related questions with categorized responses. Each participant was questioned for annoyance from ambient noise outdoors, sensitivity to noise, sleep disturbance due to noise, health effects assessment, and other problems faced due to the noise. The Response to the questions was categorized as dot not notice, noticed but not annoyed, slightly annoyed rather annoyed, and very annoyed. The format includes the name, gender, age, and occupation of the responder. The format of the list of questionnaires is given in Table 1.

Table 1: Format of List of Questions in Questionnaire Framed for the Participants

Name:			
Gender:	Age:	Occupation:	
Questions:		Response:	
1	Is the wind turbine visible from your location?	Yes	No
2	To what extent do you get annoyed, by ambient noise when you are outdoors?	• Do not notice	
		• Notice but not annoyed	
		• Slightly annoyed	

		• Rather annoyed
		• Very annoyed
3	How would you describe your sensitivity to ambient noise?	♦ Not sensitive at all
		♦ Hardly sensitive
		♦ Slightly sensitive
		♦ Rather sensitive
		♦ Very sensitive
4	When at home, how often is your sleep disturbed by ambient noise?	▪ Almost never
		▪ At least once a year
		▪ At least once a month
		▪ At least once a week
		▪ Almost daily
5	In general, how would you assess your health?	❖ Excellent
		❖ Very good
		❖ Good
		❖ Fair
		❖ Poor

The occupation of each participant is collected during the survey. Among the participants, the majority of the survey is collected from the student category. The remaining are the teachers, laborers workers, farmers, etc. The percentage of participants during the survey based on their occupation is given in Table 2. The survey is conducted in the three districts of Tamil Nadu that cover 10 different locations. The survey was collected from four locations in of Dindigul district, five locations in the Tirupur district, and one location in the Coimbatore district. The site covered the places of school, residence, an adjoining region, and poultry farms. The details about the surveying site location are given in Table 3.

Table 2: Details regarding the occupation of the participants

Occupation	% Participants
Students	49
Teachers	6
Labour/Worker	9
Farmer	6
Supervisor	6
Unemployed	11
Poultry	6
Others	6

Table 3: Details about Location of the Surveyed Sites

Sl.No.	District	Taluka	Village	Home/School
1)	Dindigul	Oddanchatram	Virappakavundanvalasu	School
2)	Dindigul	Oddanchatram	Virappakavundanvalasu	Residence
3)	Dindigul	Oddanchatram	Virappakavundanvalasu	Residence
4)	Dindigul	Oddanchatram	Virappakavundanvalasu	Adjoining region
5)	Tirupur	Dharapuram	Molarapatti	Family
6)	Tirupur	Dharapuram	Molarapatti	Family
7)	Tirupur	Dharapuram	Sangothipalayam, maruthur	Family
8)	Tirupur	Dharapuram	Kallipalayam	Poultry
9)	Tirupur	Dharapuram	Erukkalampalayam	Family
10)	Coimbatore	Palladam	Vadugavalayam	Shop

III. RESULTS AND DISCUSSION

Initially, questions on demographical factors such as age, gender, and employment that are hypothesized to influence noise annoyance were asked. Apart from the questions related to the demographic survey, two decisive questions were asked to the participants majorly emphasizing the following aspects of the study were:

1) Does the sound from the wind turbine audible in the adjoining area?

2) What are the other problems faced?

The response drawn from the list of questionnaires are tabulated in Table 4 and the analyzed responses of participants to the list of these questionnaires are given in the below subsections.

Table 4: Responses drawn from the conducted Social and Psychoacoustical Survey

Questions:		Number of Participants Responded	Percentage of Participants
1	Is the wind turbine visible from your location?		
	Yes	47	100
	No	0	0
2	To what extent you get annoyed, by ambient noise when you are outdoors?		
	A. Do not notice	0	0
	B. Notice but not annoyed	31	65.96
	C. Slightly annoyed	0	0
	D. Rather annoyed	6	12.77
	E. Very annoyed	5	10.64
3	How would you describe your sensitivity to ambient noise?		
	A. Not sensitive at all	0	0
	B. Hardly sensitive	31	65.96
	C. Slightly sensitive	0	0
	D. Rather sensitive	6	12.77
	E. Very sensitive	5	10.64
4	When at home, how often is your sleep disturbed by ambient noise?		

	Almost never	0	0
	At least once a year	6	12.77
	At least once a month	6	12.77
	At least once a week	13	27.66
	Almost daily	22	46.81
5	In general, how would you assess your health?		
	Excellent	2	4.26
	Very good	2	4.26
	Good	5	10.64
	Fair	5	10.64
	Poor	33	70.21
6	What are the other problems faced? (Total no of people - 47)		
	A. No rainfall	47	100
	B. Reduced groundwater	9	19.15
	C. Transformer explosion and firing	16	34.04
	D. Birds get hit by spinning blades	20	42.55
	E. No proper maintenance of turbine	6	12.77
	F. Fear of blade broken	11	23.40

A. Annoyance

There is 47 number of peoples who participated in the survey. These people are located near the wind turbine machine. For Q1, the response sheet shows that 100% of people reported visible wind turbines from their dwellings. The Q2 represents the annoyance caused by ambient noise outdoors. Figure 1 represents the percentage of participants annoyed due to the wind turbine noise outdoors. The wind turbine noise is depending on the weather condition of the site location. All the participants give the response of noticing wind turbine noise among these participants, 66%(31 members) of participants reported as they noticed the noise but they were not annoyed. Of the participants, 11%(5 members) and 13%(6 members) of people reported annoyance is on outdoors. Mostly the noise generated from the rotor blades is clear to hear from a greater distance. In the description of sound characteristics, the most common source of annoyance is swishing, pulsating, whistling, and throbbing [23].

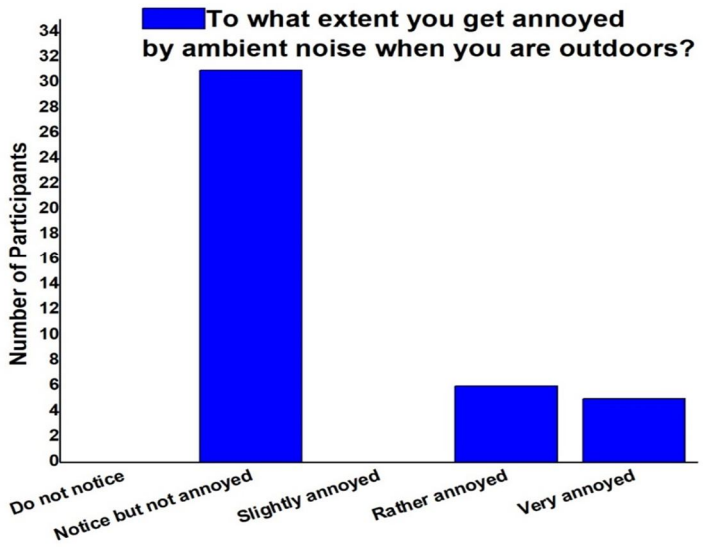

Figure 1: Response to the Q2: To what extent do you get annoyed, by ambient noise when you are outdoors?

B. Sensitivity

Noise sensitivity is the response to sound from a person's psychological state. This is measured by the question asked to people living near the location of the wind turbine. This sensitivity cause anxiety, serious illness, or trauma also the increase in sound sensitivity increase panic feeling [24]. The questionnaire Q2 describes the sensitivity to ambient noise and the analysis of sensitivity is given in figure 2. The response to the questionnaire was categorized into five characteristics. In the response, there is no one reported as "not sensitive at all". Of the participants, 66% responded as "hardly sensitive", 13% responded as less sensitive, and 11% as "very sensitive" to ambient noise. A study shows loud noise of annoyance from wind turbines near the poultry farm leads to stress and fatigue, high blood pressure, low egg production, and stunted growth in the chickens. A study has shown that ventilation fans and other operational machines create a loud noise that causes plasma corticosteroids and an increase in protein [25].

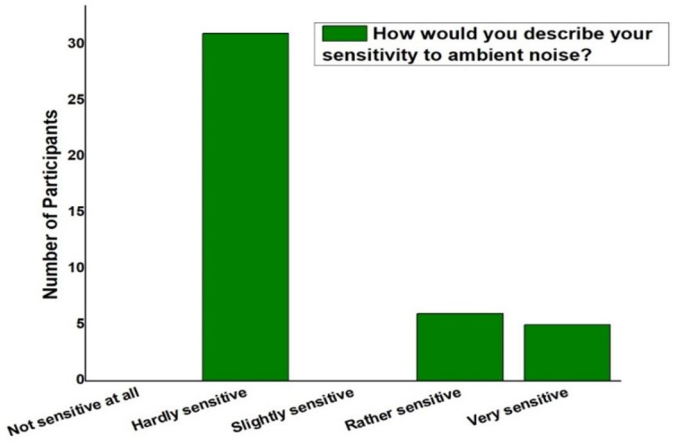

Figure 2: Response to the Q3: How would you describe your sensitivity to ambient noise?

C. Sleep Disturbance

The sleep disturbance is related to sound levels. It is regarded to be a higher disturbance in the daytime than in the nighttime. In the wind farms, the possible SPL at day time is range from 55dB(A) to 63dB(A) at the wind speed of 3m/s to 6m/s respectively. At night time the noise level is 45dB(A) at a wind speed of 3m/s and 55dB(A) at 12m/s wind speed. The noise characteristics and the noise duration result from the magnitude of the noise component and increase sleep disturbance [26]. In the questionnaire, Q3 is how often is their sleep disturbed by ambient noise. In the survey, 47% of participants reported sleep disturbance almost daily due to the ambient noise and 27% responded as once a week that sleep disturbance occurred. And 13% of responses in the category of at least once a month and 13% of responses for at least once a year. The responses from the participants are analyzed in figure 3.

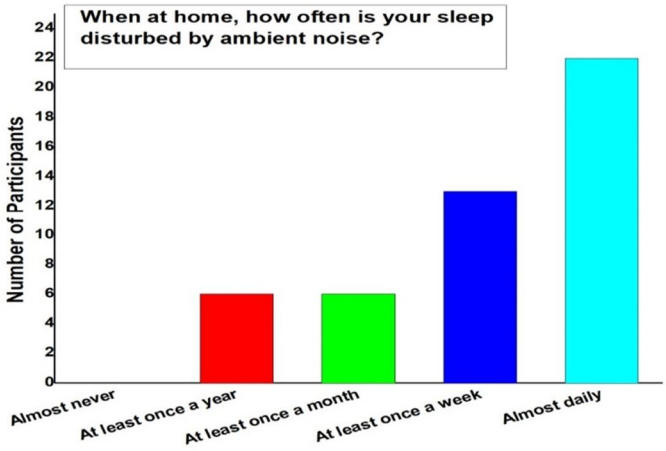

Figure 3: Response to the Q4: When at home, how often is your sleep disturbed by ambient noise?

D. Health Effects

Wind turbine noise exposure is widely suspected of health effects. The infrasound emitted from the turbine is not audible at all but is related to human health. This infrasound is possibly audible at high sound pressure levels and a frequency up to 20Hz. the non-audible sound makes adverse effects on the human body. It may affect the vestibular organ, auditory cortex in the brain, and ear in humans, and in animals, it affects hair cells [27,28,29]. In the survey questionnaire, Q5 represents the health assessment of participants. In the survey, most of the people reported "poor health". Among the 47 participants, 70%(33) responded to poor health, 11%(5) responded to fair and good health, and 4.27%(2) participants responded to "excellent and very good health". These responses are analyzed in the given figure 4.

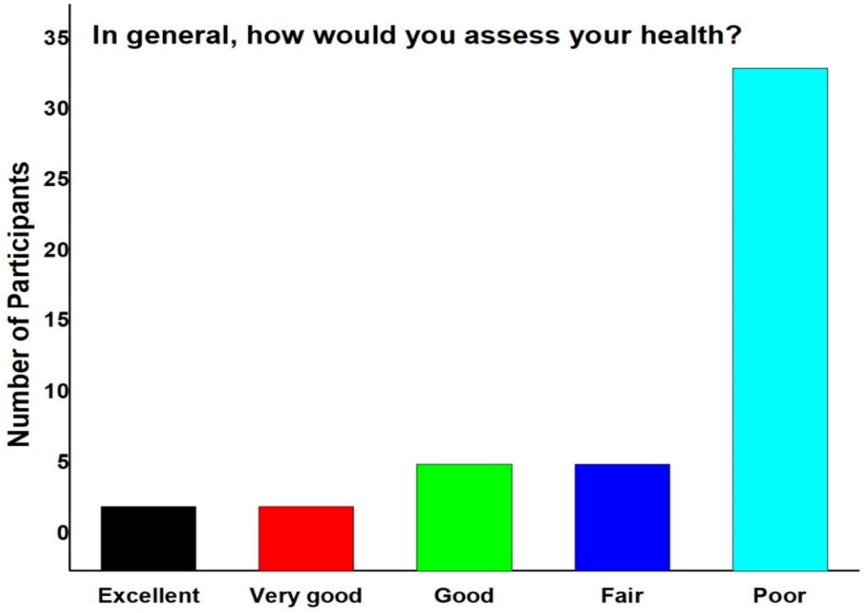

Figure 4: Response to the Q5: In general, how would you assess your health?

E. Other Problems

In the questionnaire, Q6 is the other problem faced due to the wind turbine. in the survey, 100% of people reported the problem of no rainfall. It is known that the rotating blades of windmills cause the mixing of air. During power generation, the wind passes through the blades. As the air leaves the rotor plane, it starts mixing with the flow in the mainstream and reaches nearly the original energy levels at a distance of about 10 times the rotor diameter. This is purely a local effect and some temperature changes are happening between the stream. This local effect of increasing temperature effect may cause the reduction of rainfall or particular monsoon rains near the wind farm, but it is still weaker than other global warming gases [30] [31][32]. Of the participants, 19% (9 members) reported the reduction of groundwater. In this 34% of participants' responses as fear of transformer explosion and firing. A study shows the possibility of transformer failure due to the increasing temperature which is connected to the wind farm [33]. In the survey, 12% of participants responded as no proper maintenance of wind turbines. Most of the participants responded as the birds had a risk of hitting the rotor blades. There are 42% of responses to this statement from the survey. Animal lovers are concerned about the risk to birds due to rotor blades but the study shows local birds learn about the obstacles and avoid the risks. Thus wind turbine is no danger to birds [34]. By concerning the migrating birds, their flight is always depending on the direction. The black kites learn the turbine mechanism and try to avoid the obstacles. The birds did not change their direction but they recognize the turbine behavior and avoid it [35]. A majority of the people reported this and stated that the poor maintenance of the WTs was the reason behind this. And there is a constant fear of falling off the broken pieces or derbies of the WTs on their properties during the time of failure. In the survey, 23% of participants responded as fear of broken blade and 12 % of responses fear of no proper maintenance. In India, blade failure is the most common difficulty in wind industries. This is caused by the change in climatic conditions in a different region of India. The turbine downtimes are controlled by the maintenance and repair of the wind turbine and it is a challenging task for the Indian wind industries [36]. The analysis of responses for the other problem faced by the wind turbine is given in figure 5.

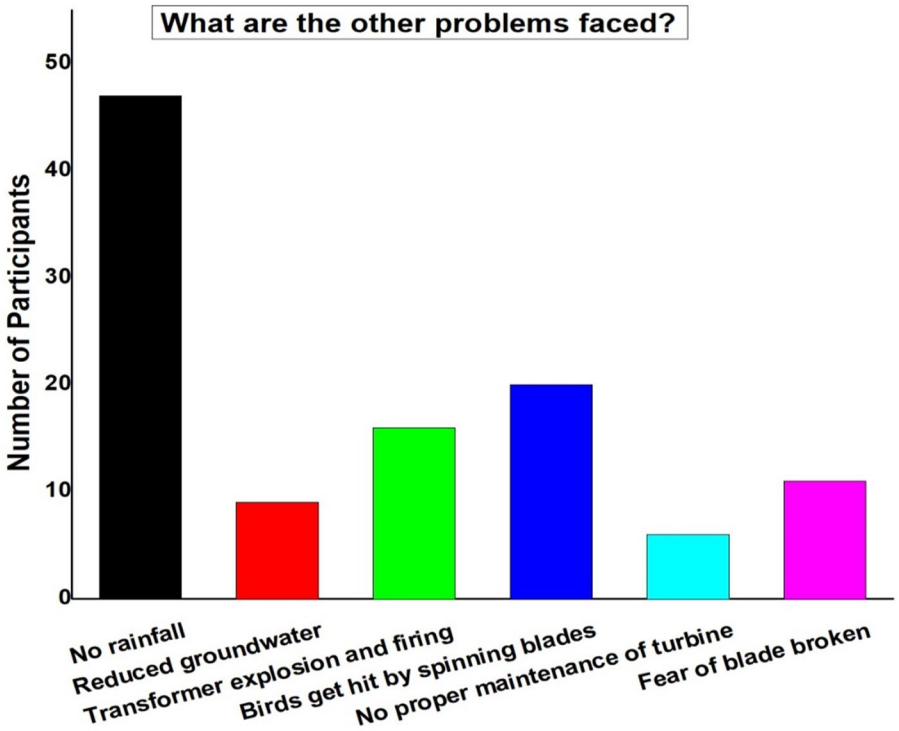

Figure 5: Response to the Q6: What is the other problems faced?

IV. CONCLUSION

The health impact due to wind turbine noise was surveyed in the three districts of Tamil Nadu, a state of India. The psychoacoustical survey was done by preparing a list of the questionnaire including health-related noise questions. By conducting this survey in the different locations of three districts it was obtained that the annoyance and the sleep disturbances were majorly affecting the dwellings near the turbine. The survey reflected that the WT noise was felt in each of the households, but its perception and level of annoyance varied from individual to individual. While a majority of them are not bothered by the swishing sound, a portion of them feel annoyed by the sound and another portion of them are putting up with it because they have no other option. By conducting the social and psychoacoustical survey, it was observed that the adult population who participated in the survey, attributed the loss of rainfall as the main problem faced due to the advent of the WTs and the Noise from the WTs. A further survey is conducted to study the health effects of people due to the low-frequency noise and other noises. To conduct the studies on the noise level of residences having roads and houses, more studies are conducted to concern the turbines in forest areas should also be included to get a better idea of how the terrain impacts noise generation.

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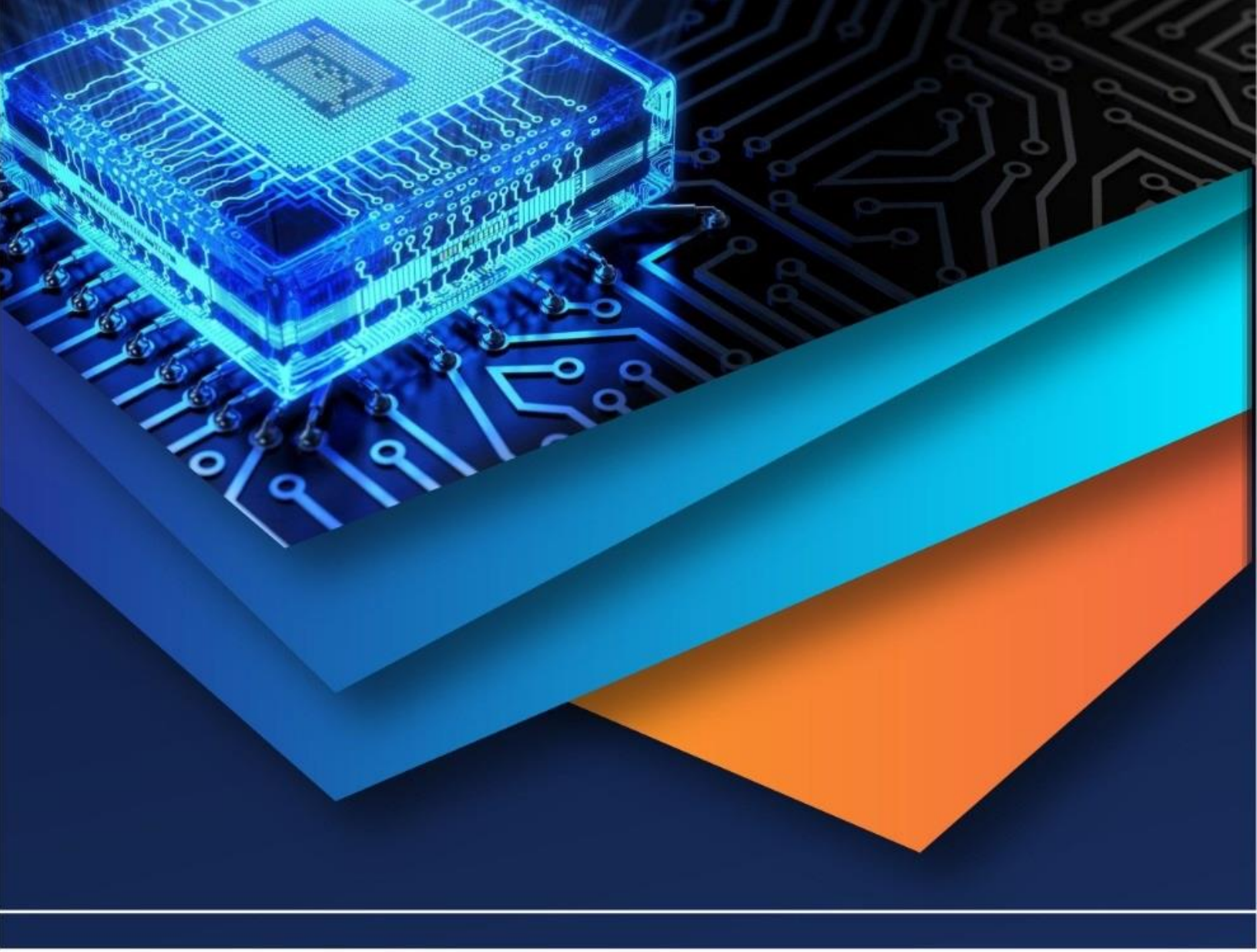

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