Prediction of Health Risk Potential Using Fuzzy Rule Base System for Indoor Work Environmental Condition in Dyeing and Printing House

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Research

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Abstract

The physical work environment in any industry is dynamic and unpredictable. It highly influencing to the health, comfort and well being of the occupants. Work environmental condition can be evaluated by measuring four basic comfort parameters, which include thermal comfort, acoustic comfort, visual comfort and air change inside the working area. These parameters are the major contributing factors to the health of workers. Usage of heat and water in the different processes of textile dyeing and printing industry make the work environment hot and humid. Due to high thermal stress a wide range of disease and complications has been observed from mild disorder to heatstroke. Also, the high level of noise and the poor lighting condition has been impacting on the stress, absenteeism, turnover, production and output quality in the industry. Improper ventilation in the working area will affect the dispersion and dilution of the pollutants generated due to the processes. The parameters considered for evaluating comfort levels include wet bulb globe temperature index, illumination, noise and air changes in this study. Fuzzy rule base system approach had been used to predict worker's health risk associated due to the impact of the work environment condition. The modeling process has been carried out with the help of MATLAB (R2014a) fuzzy tool box. Triangular membership function had been used for the input parameters. Linguistic variables were finalized by the expert opinion. Total 144 fuzzy rules had been developed based on the linguistic variable. Output obtain is in the terms of crisp value [0,1] is divided into four linguistic term low, moderate, high and very high. The study reveals that work environment condition in the textile dyeing and printing mills at various sections of the industry fall in the category of a high and very high risk condition because of prevailing poor work environmental condition at various locations. Thus, the workers working in these sections having very high potential to get the diseases related to a hot and humid environment.

1. Introduction

Work environmental condition refers to the comfort and air quality at the place where an occupant is working. It reflects the condition of air quality and comfort in working within the close space whether it is a residential building or industrial premises. Good work environment refers to the environmental condition, which contains the lowest possible level of the air pollutants and satisfies the health, comfort and wellbeing of the workers working in that area. It is observe that most of the government authorities and people are more worried about outdoor air quality than indoor air quality because outdoor air quality can be easily visualized and predicted whereas indoor air pollution is difficult to predict. Due to this now-a-days ergonomic control of indoor environments in workplaces has drawn the attention of many scientists and researchers because it has the worst impact on health, comfort and wellbeing of the occupant beside productivity [1]. The study carried out worldwide shown that most of the people spent about 80% of the time in the indoor space depending upon job activities, season, age, sex, geographical area etc. [2, 3]. So, it is essential to assess the comfort level at working place to safeguard worker. Comfort parameters which are associated with the work environment include thermal comfort, acoustic comfort, visual comfort and air change. The complex human health system is vulnerable to work

environmental condition at a workplace, where workers spent maximum hours which contribute to the individual occupational risk to the workers. The model of the vulnerability of risk potential among workers assumes more complex due to the involvement of many measurable and non-measurable factors. Thus, determining health risk potential and its consequences for human health is a challenging task. Though the decision process is complex and highly uncertain, analytical tools like Fuzzy Rule Base System (FRBS) can model this behaviour.

Many researchers had used the fuzzy logic system to deal with uncertainty and prediction related to air pollution. Some of the researches done where fuzzy logic approach had been used to deal with uncertainty and prediction are highlighted here. Christian et al. [4] used fuzzy MCDM approach in their study to find a composite index of water and air pollution potential of industries. Lad et al. [5] also evaluate environmental pollution potential of industries in terms of air pollution through fuzzy MCDM. Chitnis et al. [6] had developed an air quality index for Vapi region using fuzzy MCDM. Erosan et al. [7] developed a fuzzy logic model to evaluate indoor air quality in offices and classroom. Rehman et al. [8] had used fuzzy logic system to improved ventilation system in the pharmaceutical industry. Javed et al. [9] developed an indoor air quality index using a fuzzy logic approach to assess the indoor air quality concerning human health. Kolokotsa et al. [10] developed a fuzzy logic controller for the assessment of an indoor visual and thermal comfort as well as indoor air quality. Atacak et al. [11] had been used as a fuzzy logic algorithm to model air quality and air pollution. Jablonski and Grychowski [12] designed a fuzzy system for assessment of indoor environmental conditions in the room. Jariwala and Christian [13] had been used FRBS approach to predict the abnormality in the solid waste worker.

2. Comfort Parameters At Workplace

The organization will try to keep an internal work environment as comfortable as possible to boost the efficiency of its employees. In large scale organization focus, it keeps on the good environmental practices. Failure to prevent a good working environment raises the problems related to health, productivity, absenteeism, turnover and owner-employee relationship. Comfort areas consider at the workplace are thermal comfort, acoustic comfort, visual comfort and air change per hour.

2.1 Thermal comfort

Every time the human body tries to maintain its body temperature to 37°C through evaporation, conduction, convection and radiation. Sometimes the body becomes so hot that its heat-regulating mechanisms can't eliminate enough heat, resulting in rising of the body temperature, which leads to various heat related illness from mild fever to heatstroke called as heat stress. Heat stress is measure by Wet Bulb Globe Temperature (WBGT), which is an important parameter to evaluate thermal comfort level at indoor locations. WBGT at indoor is calculated by taking wet bulb temperature and globe temperature into consideration as per Eq. 1.

$$WBGT = 0.7 t_{wb} + 0.2 t_g + 0.1 t_{air} \quad (1)$$

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Where t_{nw} is the natural wet bulb temperature and t_g is the globe thermometer temperature.

According to the American Council of Government Industrial Hygiene (ACGIH) [14], the threshold value of heat stress for different workload condition presented in Table 1.

Table 1
Threshold Values for Heat Stress

Permissible Heat Exposure Threshold Limit Values(TLV) [Values are given in degrees Centigrade WBGT (Fahrenheit)]			
	Work Load		
Work- Rest Regimen	Light	Moderate	Heavy
Continuous work	30.0 (86.0)	26.7 (80.1)	25.0 (77.0)
75% Work, 25% Rest/Hour	30.6(87.1)	28.0(82.4)	25.9 (78.6)
50% Work, 50% Rest/Hour	31.4 (88.5)	29.4 (85.0)	27.9 (82.2)
25% Work, 75% Rest/Hour	32.2 (90.0)	31.1 (88.0)	30.0 (86.0)

In this study threshold limit value of heat stress is taken 28°C for 75% work & 25% rest regime for the moderate workload.

2.2 Acoustic comfort

Noise is an undesirable sound, which produce because of various industrial and non-industrial activities. Noise beyond the certain limits cause occupational health problem. The hearing mechanism of the ear senses the sound waves and converts them into information which it relays to the brain [15]. Noise can be classified base on the types of activities carried out. It is classified into continuous, variable intermittent or impulsive. Most manufacturing noise is variable or intermittent. Normal conversation produces a noise of 60 to 65 dB(A), heavy street traffic produces 60 to 80 dB(A), factory processes creating noise 80 to 110 dB(A). Occupational noise exposure in addition to permanently damage the hearing capabilities, it is also associated with a range of indicators of physical health, including cardiac problems, sickness-related absenteeism and self-reported fatigue. Person suffering from hearing impairment shows interference with oral communication. It is observed that hearing-impaired disease can largely depend upon the duration, intensity and frequency of noise in which he works. It is also seen that a person who continuously working under noisy environment leads to an increase in job dissatisfactions and absenteeism [15]. Maximum permissible occupational noise exposure limit in the different developed nations were in the range of 85–90 dB for 8 h/d has been allowed [16]. National institute of occupational health and safety recommended 8 hours exposure limit of 85 dB for occupational noise [17]. Also, as per the central pollution control board (CPCB) maximum limit of the noise level in various areas has been described in Noise pollution (regulation and control) rules 2000 [18]. Same has been presented in Table 2.

Table 2
Noise standard as per Noise pollution rule, 2000

Area code	Category of area/zone	Limits in dB(A) Leq	
		Day time	Night time
A	Industrial	75	70
B	Commercial	65	55
C	Residential	55	45
D	Silence	50	40

2.3 Visual Comfort

Visual comfort refers to the illumination condition inside the workplace. The illumination is an extremely important factor in the safety of industrial workers as the poor lighting results in eye strain and increases the risk of accidents and faults in the work procedure. For good illumination, the factors responsible are proper distribution & spread of light, orientation of the building, absence of glare & sharp shadows. Surrounding condition like growth of tall trees can also be affects on the penetration of the light inside the area. Insufficient illumination in the working area affects employee's productivity, working speed and quality of product. It also increase rate of absenteeism and accident [19] Completion of a task is highly dependent on the good lighting environment with less stress and fatigue [20]. Depending upon types and nature of works lighting requirements are very. Working condition such as rough work, medium work, fine work and very fine work requires 200, 400, 900 and 2000 lux respectively [21]. Under this study illumination level of 500 lux is found sufficient for the proper working condition.

2.4 Air change per hour

The air exchange rate means replacing the entire volume of air in the workspace in one minute or one hour. This indirectly reflects the ventilation system of the building. Efficient ventilation system provides enough air circulation from outdoor to the building. Sufficient movement of fresh air can effectively help in the reduction of indoor temperature and provide thermally acceptable environment to the occupants. Proper ventilation system can also remove contaminants and toxic gases generated due to different activities. For ACH actual measurement of the working space will be taken to find out the cubic capacity of the room and numbers of opening with its dimension are used to find out for the total opening area. As per the Gujarat factories rule 1963 [22], in every factory the amount of ventilating openings in a workroom provided be of an aggregate area of not less than 15% of the floor area and so located as to afford a continued supply of air. IS-3103 [23] suggests that ventilation rates of 30 to 60 air change in one hour give good results in plants. Air changes per hour (ACH) can find out with the Eq. 2

$$\text{Number of air changes per hour} = \frac{\text{Total hourly air supply to room}}{\text{Cubic capacity of room}} \dots (2)$$

3.1 Study area

This study was conducted in one dyeing and printing house located in the industrial estate in the Surat city. For determination of work environmental condition parameters which were considered in this study includes ambient temperature, wet bulb temperature, dry bulb temperature, globe temperature, relative humidity, noise level, indoor illumination and air velocity. Total six locations were selected inside plant based on the manufacturing process out of which five locations were selected in the area of jet dyeing machine, printing machine, stenter machine, looping machine and washing where heat is used in the process and office area is selected as a non-heat area to compare the work environment conditions in the process heat used area and non-process heat generated area. The methodology adopted in the study is shown in Fig. 1

3.2 Dyeing and printing process

Work had been carried out in the textile dyeing and printing processing industry to access the indoor work environmental conditions. Dyeing and printing is the batch process carried out, which depends upon the quality of raw fabrics, customer requirement and design to be printed on fabrics. In the textile processing house from the raw fabric known as “grey cloth” turn into the final product known as “sarees” through wet processing technology, comprises various stages such as sizing, desizing, scouring, bleaching, mercerizing, dyeing, printing and finishing. All of the said operations are carried out at the temperature ranges from 100°C-180°C, so large variations in the humidity and temperature can be observed throughout the plant.

3.3 Data collection and observation

To obtain data on wet bulb temperature, dry bulb temperature, globe temperature and humidity, QuesTemp36 area heat stress monitor (figure: 2a) had been used. To avail data on noise, illumination and air velocity instrument used were a sound level meter (figure: 2b), lux meter (figure: 2c) and anemometer (figure: 2d) respectively.

To obtain data instruments had been set up at a height of 1.2–1.5 meter, which is the general height above abdomen level in human being. Observations had been recorded at each location for two seasons, one during the winter season (Dec-Jan) and another during summer season (Apr-May). Observations were recorded for both day shift (8.00 AM to 8.00 PM) and night shift (8.00 PM to 8.00 AM) at an interval of an hour. Data had been collected for 6 days and 4 nights in both seasons. Mean $\pm$ SD of various work environmental parameters is presented in Table 3.

Table 3
Mean $\pm$ SD of various environmental input parameters

Env. Parameter	Season	Shift	Office area	Printing machine area	Jet dyeing area	Stenter machine area	Looping machine area	Washing area
NWB (°C)	Winter	Day	20.6 ± 1.67	25.2 ± 2.23	25.3 ± 2.56	24.5 ± 2.36	22 ± 2.16	23.1 ± 2.14
		Night	18.1 ± 1.20	24.3 ± 1.45	23.2 ± 1.46	23.9 ± 1.73	23.1 ± 1.33	20.2 ± 2.09
	Summer	Day	26 ± 3.19	29.1 ± 2.57	29.2 ± 2.73	29.4 ± 2.65	28.8 ± 3.45	28.8 ± 2.40
		Night	25.1 ± 2.13	27.9 ± 1.84	26.9 ± 2.83	27.6 ± 2.11	27.5 ± 3.27	26.1 ± 2.35
GT (°C)	Winter	Day	31.6 ± 3.12	41 ± 3.38	36 ± 3.51	38.3 ± 3.32	32.7 ± 2.26	32.4 ± 2.29
		Night	24.9 ± 3.89	31.8 ± 2.87	32.3 ± 3.08	32.4 ± 2.34	28.8 ± 2.45	27.5 ± 3.37
	Summer	Day	32.9 ± 3.04	40.5 ± 2.73	42.6 ± 4.27	42.4 ± 2.60	39.9 ± 2.01	37.2 ± 2.01
		Night	29.7 ± 2.62	35.9 ± 2.57	37 ± 2.38	37 ± 2.43	33.1 ± 2.01	31.4 ± 3.41
WBGT index (°C)	Winter	Day	23.9 ± 1.96	30 ± 2.51	28.5 ± 2.72	28.7 ± 2.50	25.2 ± 2.07	25.9 ± 2.06
		Night	23.1 ± 1.68	29.5 ± 1.83	26.3 ± 1.79	25.8 ± 1.87	23.7 ± 1.52	22 ± 2.39
	Summer	Day	27.8 ± 2.18	32.8 ± 2.09	31.4 ± 2.40	32.2 ± 2.04	31.2 ± 2.38	30.3 ± 1.90
		Night	26.2 ± 1.68	31.5 ± 1.58	30.2 ± 2.47	29.3 ± 1.76	29.2 ± 2.25	29.2 ± 2.46
Noise (dB)	Winter	Day		89.2 ± 1.58	88.1 ± 3.08	89.4 ± 1.24	81.8 ± 2.92	82.7 ± 2.78
		Night		89.2 ±	85 ± 3.72	87.5 ± 3.13	82.3 ± 3.11	82.8 ± 3.38
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Env. Parameter	Season	Shift	Office area	Printing machine area	Jet dyeing area	Stenter machine area	Looping machine area	Washing area
	Summer	Day		89.6 ± 1.54	83.3 ± 1.85	85.1 ± 3.09	84.5 ± 2.13	83.5 ± 2.46
		Night		90 ± 1.39	82.8 ± 2.39	83.8 ± 3.15	83.8 ± 1.65	81.7 ± 2.25
Illumination (lux)		Day		106	31	156	122	241
ACH (No)				14	3	2	45	52

4. Development Of Frbs Model

From the expert's opinion and perceptions, identified factors responsible for health risk potential were quantified on fuzzy scales and used as an input parameter of the system. The output of the system is considered as the risk value which indicates the chance of getting risk potential. In this work, the quantitative solution of the fuzzy system is made convenient by using MATLAB (R2014a). The input and output parameters of the system are defined using the fuzzy tool box and the implication, aggregation and defuzzification operation also performed using the same programme. A schematic fuzzy decision system for finding the health risk potential among as shown in Fig. 3

4.1 Development of a fuzzy set

Subjective judgment, field data and the linguistic variables are employed to develop fuzzy membership functions of all input parameters and output parameters. It is a normal tendency of human experts to evaluate a variable in linguistic terms. Fuzzy linguistic variables are extensions of numeric variables in the sense that they can represent the condition of an attribute at a given stage by considering fuzzy sets. The fuzzy sets are represented by linguistic variables assigned, to each input and output factor. All the fuzzy sets, in turn, are represented by a function known as membership function i.e. A function that is associated with a real number in the interval [0,1] at each point [24]. The choice of function type (triangle, trapezoidal, Gaussian etc) depends on the quantity and homogeneity of the available data and definitely, it influences the accuracy of results. In the present study for all input parameters, three or four linguistic terms have been selected to describe the level of risk potential for input parameter because it was convenient for an expert to distinguish subjectively between them. In this study, triangle fuzzy numbers were used to represent the experts' opinion.

4.2 Membership function for input variables

The input variable WBGT in °C has been selected in the range of (12, 40), it has been divided into 4 fuzzy sets Low (12,14,16), Moderate (16,21,26), High (26,30.5,35) and Very High (35,37.5,40). Figure 4(a) represents the membership function selected for input variable WBGT.

The input variable Illumination in lux has been selected in the range of (10,2500). It has been divided into 3 fuzzy sets Poor (10,255,500), Moderate (500,750,1000) and Good (1000,1750,2500). Figure 4(b) shows the membership function for illumination.

The input variable noise in dB has been selected in the range of (60,106) and it has been divided into 4 fuzzy sets Low (60,65,70), Medium (70,75,80), High (80,85,90) and Very High (90,98,106). Figure 4(c) represents the membership function selected for the input variable noise level.

The input variable ACH in nos. has been in the range of (1,500) and it has been divided into 3 fuzzy sets Poor (1,25.5,50), Moderate (50,150,250) and Good (250,375,500). Figure 4(d) shows the membership function for ACH.

4.3 Membership function for an output variable

After the completion of inferencing, the output is the linguistic value that represents the health risk to a worker working at a particular place. The output variable Risk is a numeric value selected within range of (0,1) and it has been divided into 4 fuzzy sets Low (0,0.125,0.25), Medium (0.25,0.375,0.5), High (0.5,0.625,0.75) and Very High (0.75,0.875,1). Figure 5 represents the membership function for output variable Risk.

4.4 Fuzzy Rule

A rule-based system utilizes a model that represents human knowledge in the form of “IF-THEN” rules. This conventional approach has been adopted to build fuzzy rule-based systems for the study. Relevant and available input variables are selected and their domain is partitioned into several fuzzy sets of linguistic variables. In a fuzzy logic system, an expert defines the rule to describe the characteristics of risk assessment for each factor. The input variables are processed by rules to generate an appropriate output. The fuzzy rules represent the logical correlation between the input and output variables. They are derived from past data or the experience of the analyst or with the experts’ judgments of perception.

After obtaining the fuzzy numbers with their corresponding degree of a match the rule base of the system is to be defined. A set of rules is required to be constructed for the risk prediction model. Here each rule has an antecedent proposition connected using **AND** operator, resulting in some consequence. The assertions related to its antecedent part be obtained from the experts are imprecise or fuzzy. Thus a fuzzy rule based system can be developed for the knowledge representation or reasoning process. Here the partial matching is allowed and the analyst can estimate the extent to which the assertion satisfies the antecedent part of the rule contrary to the rule based system which examines as to whether the antecedent part is satisfied or not. The rule editor of Risk in MATLAB fuzzy tool box is as shown in Fig. 6(a). Rule editor is a platform on which relationship between input and output can be made. The R base 1 is the system in which determination of Risk is made. Risk system having four input variables. It needs $4 \times 3 \times 4 \times 3 = 144$ inference rules to evaluate the system.

4.5 Defuzzification

The final step in the fuzzy controller is the defuzzification process. It is a process of converting all fuzzy outputs into equivalent crisp value. The fuzzy input values entering the inference engine are converted to fuzzy output values after the evaluation of rules in the rule base and considering membership function value. The output fuzzy values are defuzzified using the centroid method. This defuzzification method is most accepted, effective method and is used here. Figure 6(b) shows the defuzzification steps for determination of Risk. Here input data of WBGT 26°C, Illumination 1255 lux, noise level 83 dB and ACH 251 has been considered and output risk has been obtained as 0.5 after defuzzification process, accordingly define the fuzzy rule.

5. Result And Discussion

Risk obtained from FRBS model indicating health risk associated with the individual persons working in a particular area. The output value is considered in 0 to 1 scale as low risk (0-0.25), moderate risk (0.25–0.5), high risk (0.5–0.75) and very high risk (0.75-1.0). Table 4 represents the categorization of risk potential obtained (% of observed value) as an output at various locations in the industry.

Table 4
Obtained risk potential (% of observed value) at various locations

Location and Risk	% Risk		
	Moderate	High	Very High
Jet dyeing machine area	51.67	–	48.33
Washing area	9.58	32.5	57.92
Looping machine area	–	30.83	69.17
Stenter machine area	100	–	–
Printing machine area	–	–	100

Observed data on various input parameters of work environmental conditions are used as input parameters. After modelling, the output value of risk is obtained in scalar value in 0 to 1 range. The risk value for the present study varied from 0.375 to 0.875. From the model, it is seen that work environmental condition at the printing area having very high health risk potential. Almost at all time worker who is working in the printing area, associate with high risk environmental condition. Such that worker working in the looping area, 69.17% time he is working in the very high risk condition and 30.83% time work condition at a particular place is having high risk. Also at jet dyeing area and washing area, the risk associated with work environmental condition is very high by 48.33% and 57.92%.

From this study, it is observed that work environment condition in the particular type of industry having the worst effect on the health of the worker. Almost at all locations majority of the time work environment to workers fall in the high to a very high risk condition. This can be due to the high-temperature condition as all the processes are carried out at a very high temperature and having less airflow at the workplace. So, proper attention must be given to proper planning and ventilation of the particular area.

Declarations

Availability of data and materials

Real time monitoring had been done during the study and data is available with author.

Competing interests

The authors declare they have no competing interests.

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Authors' contributions

This is the work done by DVJ during his post graduate dissertation. He had conducted all the monitoring work, along with data interpretation and statistical analysis during the study.

RAC administrative and technical support was given by him along with the critical comments during the study. Study was conducted under his supervision.

NDJ had guided on application of fuzzy logic in my dissertation work. All authors read and approved the final manuscript.

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Figures

Figure 1

Methodology used in the study

Figure 2

Instruments used to measure various study parameters

Figure 3

FIS editor for determination of health risk potential

Figure 4

Membership function for input parameters

Figure 5

Membership function for Risk

Figure 6

Defuzzification process for Risk