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Full Length Research Paper

Simulation of rainfall runoff process for Khartoum State (Sudan) using remote sensing and geographic information systems (GIS)

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Using geographic information systems (GIS) and remote sensing integration to determine runoff caused due to rainfall from watershed has performed increasingly attention in recent years. This study was conducted in the Khartoum State. Curve Number (CN) method was applied for estimating the runoff depth in the watershed. Hydrologic soil group and land use maps were generated in GIS Environment. Hydrologic soil groups and land use maps were used to generate the CN map. Soil Conservation Services-Curve number (SCS-CN) method was followed to estimate runoff for the watershed. It was found that the model can predict runoff reasonably well. It could be concluded that the SCS-CN method can be applied to predict runoff volumes for planning of various conservation measures and for other water resources applications.

Key words: Soil Conservation Services-Curve number (SCS-CN), geographic information systems (GIS), remote sensing, runoff estimation

INTRODUCTION

Surface runoff is the water flow that occurs when soil is saturated to full capacity and excess water from rain over the land. This is a major component of the water cycle. Rainfall generates runoff, and its occurrence and quantity are dependent on the characteristics of the rainfall event, that is, the intensity, duration and distribution. Apart from these rainfall characteristics, there are numbers of catchment specific factors, which have a direct effect on the occurrence and volume of runoff.

Measured rainfall is one of the most significant input data in applying the hydrological models for runoff estimations. Unfortunately, the distribution of rainfall usually varies significantly in both space and time. Therefore, the limited number of rainfall stations in the catchment can have a major impact on the accuracy of runoff estimations. The accurate estimation of the spatial distribution of rainfall therefore requires a very dense rainfall network, which involves high installation and operational costs.

Remote sensing can provide measurements of many of the hydrologic variables used in hydrologic applications, either as direct measurements comparable to traditional forms, or as entirely new data set. The pixel format of digital remote sensing data makes it suitable to merge it with geographic information system (GIS).

Most of the previous work on adapting remote sensing to hydrologic modeling has involved the Natural Resources Conservation Service runoff Curve Number

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(CN) model. This involvement used remote sensing data as a substitute for land cover maps which had been obtained by conventional means.

The GIS technology provides suitable alternatives for efficient management of large and complex databases; it is used in hydrologic modeling to facilitate processing, management and interpretation of hydrologic data.

Several studies have been done to incorporate GIS in to hydrologic modeling of watersheds. The traditional method for establishing CN on small watersheds includes field surveys and interpretations of aerial photographs. For large drainage basins, field surveys are prohibitively expensive and an excessive number of aerial photographs may be required for complete coverage. A further disadvantage of conventional techniques may be the infrequency of the surveys and the consequent failure to account for changes in vegetative cover and land use.

Land use is an important characteristic of the runoff process that affects infiltration, erosion, and evapotranspiration. Hydrologic models, distributed models in particular, need specific data on land use and its location within the basin. Remote sensing can provide measurements of many of the hydrologic variables used in hydrologic and environmental model.

Rainfall-runoff modeling is a very important topic of research that can be utilized for management and control of water resources. Where there is lack of important elements such as digital land use map, digital curve number map, hydrological soil groups map and digital runoff map, these types of maps are very useful in hydrological investigations. In addition, future predictions with different scenarios can be undertaken by rainfall-runoff modeling.

The integration of remote sensing and GIS has been widely applied and has been recognized as a powerful and effective tool in estimating and evaluating rainfall; therefore the main aim of the present study is to apply a rainfall-runoff model using GIS and remote sensing techniques to simulate the rainfall-runoff process and create digital runoff map for the study area using SCS-CN method.

Nowadays, modeling has become a common practice in every field of endeavor, and runoff modeling is no exception (Donigian, 1995). The main reason behind the using of modeling in general is the limitations of the techniques used in measuring and observing the various components of hydrological systems (Beven, 2001). Also using hydrologic models will increase our understanding and explanation of the natural phenomena and its dynamic interactions with the surrounding systems (that is, climatic terrestrial, pedologic, lithologic and hydrologic systems) (Chiew, 1994). However, under some conditions, predictions can be made in deterministic or probabilistic sense.

Another use of modeling is to predict how the system will respond to the future alternative conditions and actions (Donigian et al., 1995; Linsley, 1982) summarized the principal purposes for which hydrological model have or can be employed. In general they can be used for hydrologic research purposes, for forecasting and prediction of stream flow, and for engineering and statistical applications (record extension, operational simulation, data fill-in, and data revision).

Detailed analysis of flood hydrograph has special importance in flood mitigation, flood forecasting and/or establishing flows for many structures which must convey floodwaters (Linsley, 1982). Rainfall-Runoff modeling covers a wide range of applications and practices. This can be divided into two main groups, viz: flood studies (planning and designing new hydraulic structure, operating and/or evaluatingexisting hydraulic structures, preparing for and responding to flood, flood damage reduction, and regulating flood plain activities), and storage studies (catchment and reservoir yield analysis, and water resource potential) (Blandford and Meadows, 1990; Chiew, 1994; Connolly, 1995).

The Soil Conservation Service - curve number (SCS-CN) method has its origins in the unit hydrograph approach to rainfall-runoff modeling. The unit hydrograph approach always requires a method for predicting how much of the rainfall contributes to the storm runoff. The SCS-CN method arose out of the empirical analysis of runoff from small catchments and hill slope plots monitored by the USDA. The Curve Number method (SCS, 1972),also known as the Hydrologic Soil Cover Complex Method, is a versatile and widely used procedure for runoff estimation. In this method, runoff producing capability is expressed by a numerical value varying between 0 to 100.

METHODOLOGY

This study is conducted in Khartoum State, the study area located in the middle of Sudan, lies between latitudes 15.8° N to 16.45° N and longitudes 31.5° E to 34.45° E, surrounded by five states, divided to seven localities. It has an area of 22,122 km^2 (Figure 1).

The topography of the area is undulating. Khartoum featured as hot arid climate, with only months of July and August seeing significant precipitation. Khartoum averages a little over 155 mm (6.1 in) of precipitation per year. Temperatures may exceed 45°C in summer time.

Rainfall data is collected from National Meteorological Corporation. Data from five gauges were used here, namely: Al Sahafa, Jabalawlia, Shambat, Soba and Omdurman; the rainfall data were obtained for 20 years.

Soil data are obtained from the Ministry of Agriculture of Khartoum State. Land use map was obtained from remote sensing authority. Arc GIS version 9.3 produced by ESRI, 2008 was used for creating, managing and generating of different layers and maps.

Soils were classified into A, B, and D groups according to their minimum infiltration rate, which obtained for a bare soil after prolonged wetting as shown in Table 1.

To prepare the land use layers in the study area, eight major land use classes were identified. Classified land use map was integrated with the hydrological soil groups map to produce the CN. To estimate curve numbers for the entire basin, vector coverage of soil showing the HSG, and use map were overlaid. The soil layer and classified land use layer were used to calculate curve numbers

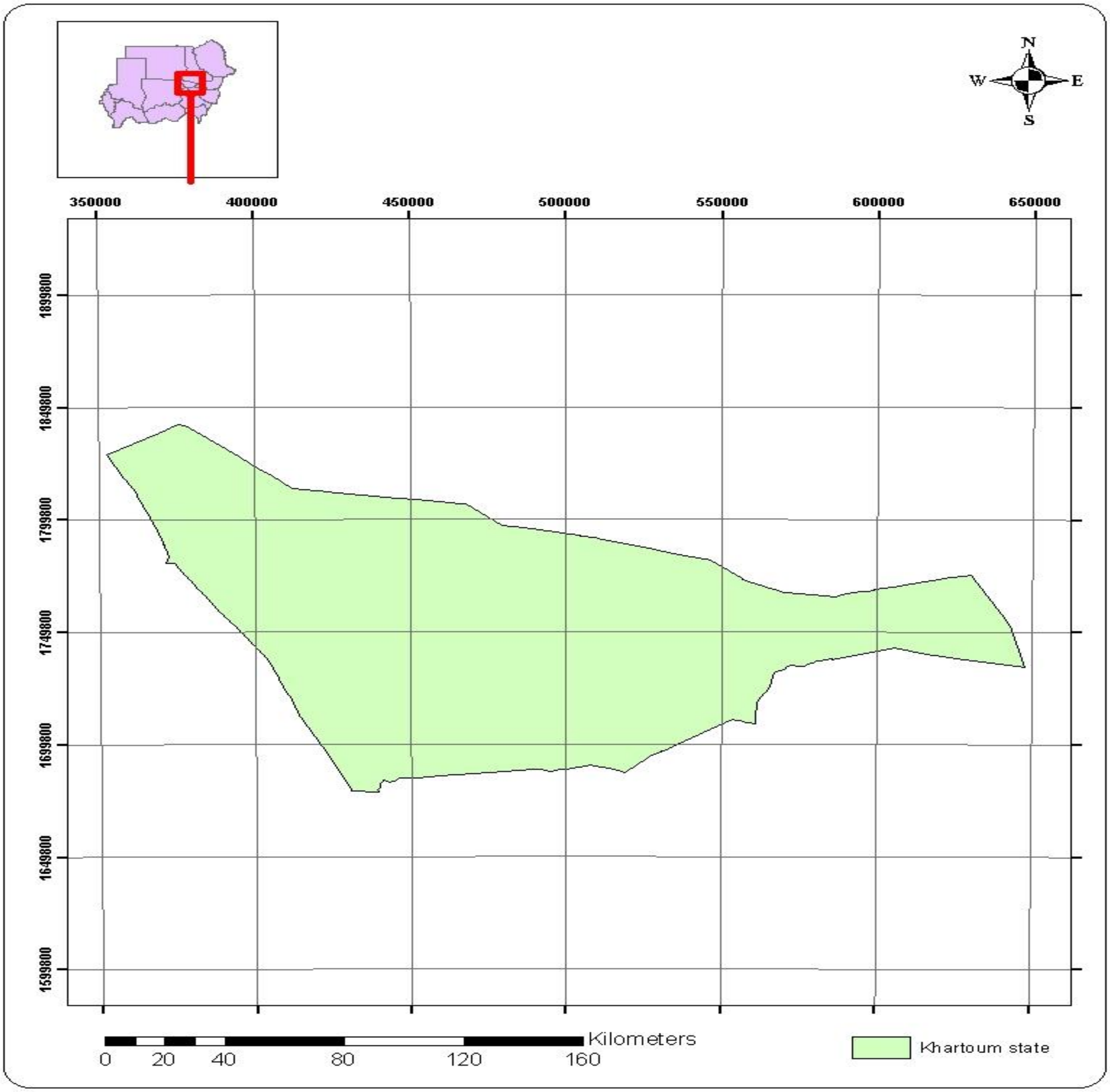

Figure 1. Study area.

value.

The rainfall-runoff equation used for estimating depth of direct runoff from storm rainfall (USDA, 1972):

$$Q=(P-0.2S)^2/(P+0.8S)$$

The CN is a dimensionless runoff index determined based on hydrologic soilgroup (HSG) and land use. The CN method is able to reflect the effect of land use on runoff. The NRCS runoff equation is widely used in estimating directRunoff because of its simplicity, flexibility and versatility.

RESULTS AND DISCUSSION

Remote sensing and GIS technologies are suitable tools for rainfall-runoff estimation which were used to determine CN distribution in the study area. It could be used to calculate runoff depth of the basin area. The results of this study may be very useful for flood forecasting and the development of hydrologic and hydraulic structure. These results are useful to understand

Table 1. Hydrological soil groups.

Soil Group	Characteristics
A	Low overland flow potential, high minimum infiltration capacity even when thoroughly wetted (>0.76 cm/h), deep, well to excessively drained sands and gravel.
B	Moderate minimum infiltration capacity when thoroughly wetted (0.13 to 0.76 cm/h), moderately deep to deep, moderately to well drained, moderately fine to moderately coarse grained (e.g. sandy loam).
D	High overland flow potential: Very low minimum infiltration capacity when thoroughly wetted (<0.13 cm/h) clay soils with high swelling potential, soils with permanent high water table. Soils with a clay layer near the surface, shallow soils over impervious bedrock.

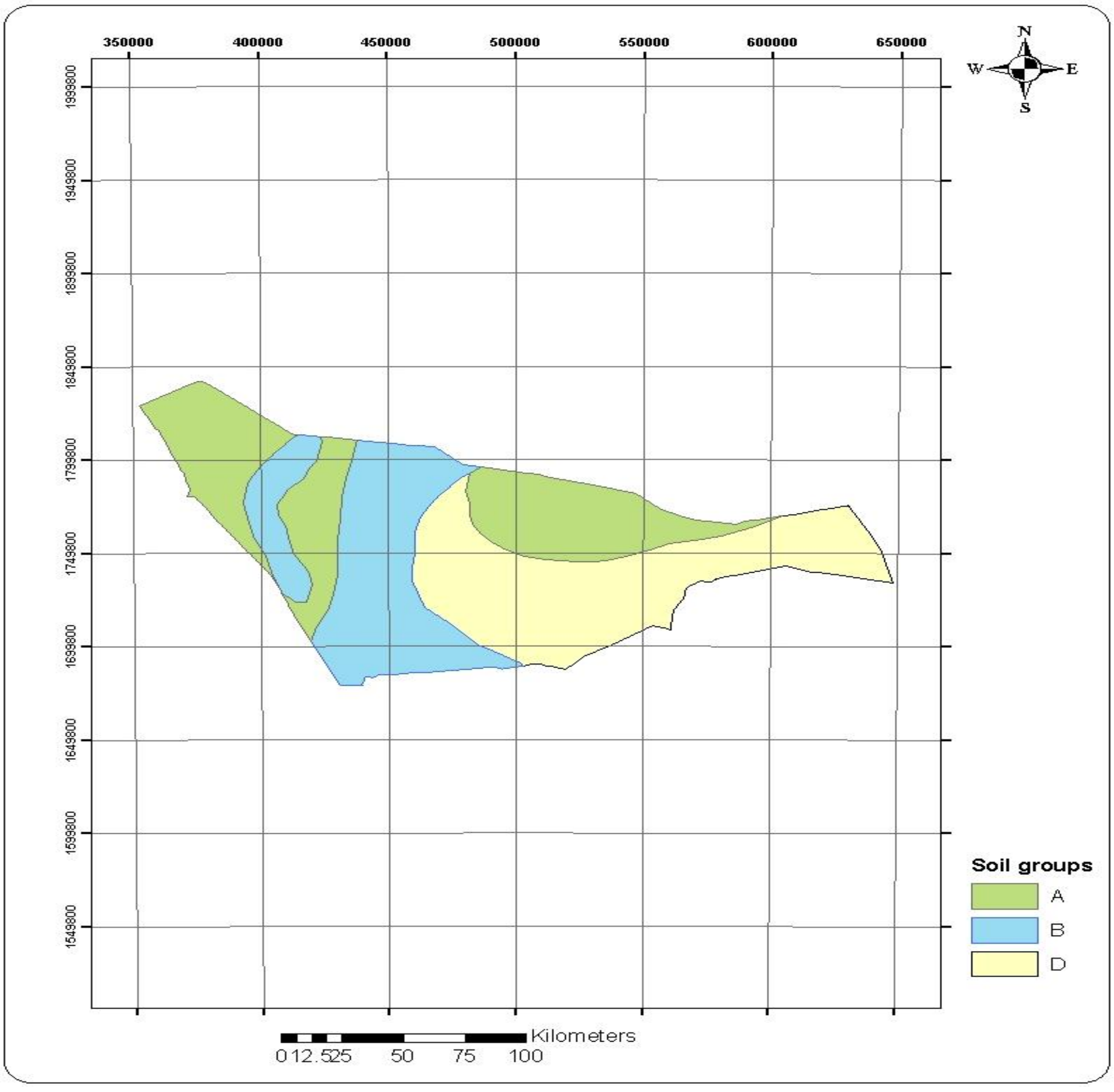

Figure 2. Hydrological soil groups (HSG).

hydrological characteristics of basin area.

From classified soil map three hydrological soil groups (HSG), it has been found that three HSG covered the study area, namely A, B, and D. Figure 2 represents the distribution of these groups.

From Figure 2 it can be observed that 30% of the study

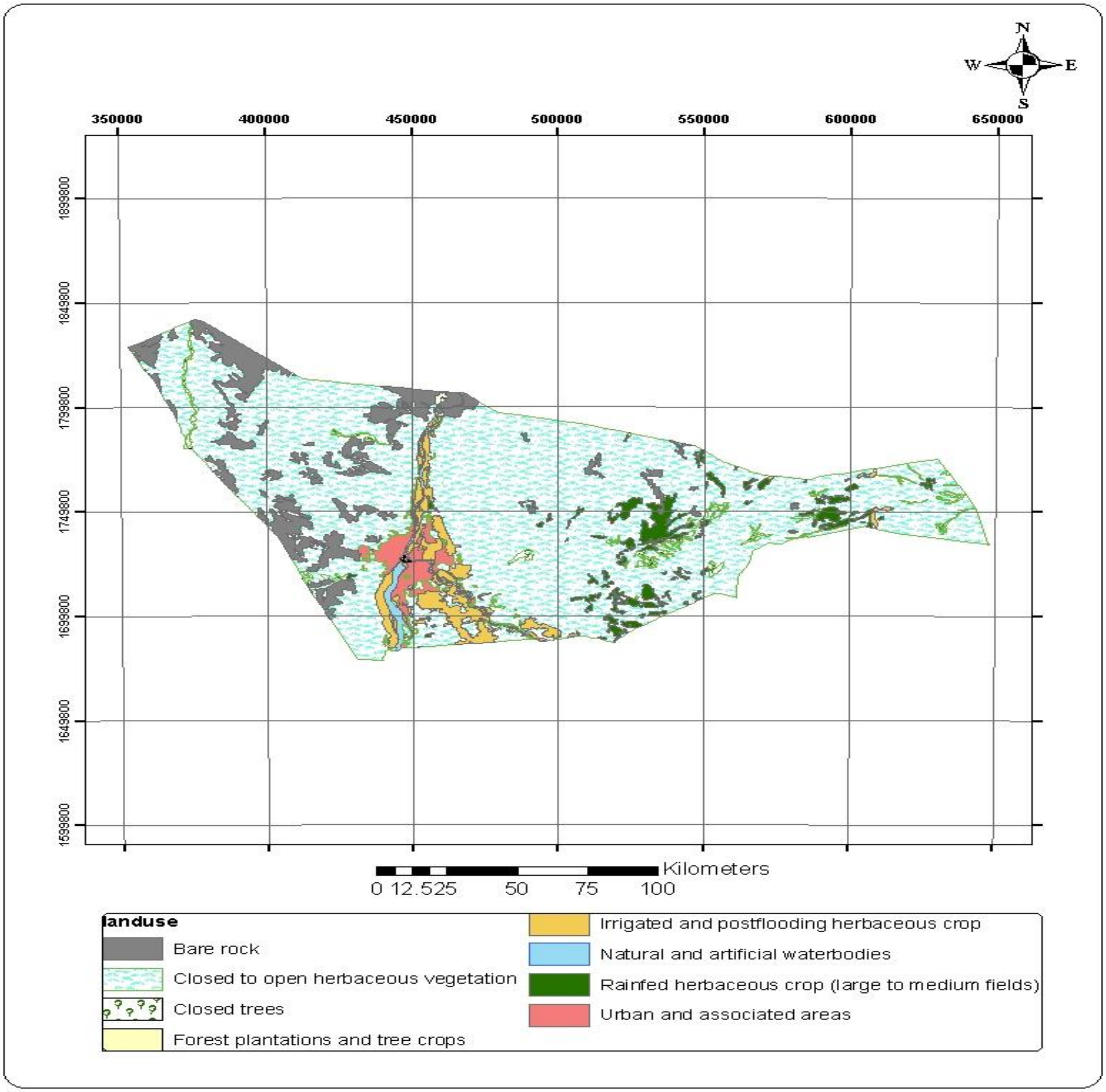

Figure 3. Land use classed distribution in the study area.

area is covered by group B and 34% is covered by group A while the rest of the area covered by group D (36%). The classified land use map is shown in Figure 3. The study area has been classified into eight major land use classes. Table 2 represents the percentage of each class.

From Table 2 it can be observed that most of the study area was covered by closed to open herbaceous vegetation while the forest plantation and tree crops have least coverage.

The CN value for each soil hydrologic group and corresponding land use class were calculated. Hydrologic soil groups A and B leads to low CN value while the hydrologic group D leads to high CN value in the study area. The lowest CN value was found to be 30 in closed trees while the highest CN value was found to be 100 in water bodies; watershed generates more runoff for a given rainfall in areas having greater CN values. The CN

Table 2. Percentage of land use classes.

Land use	% Area
Bare rock	9.09
Urban and associated area	2.67
Rainfed herbaceous crops	3.53
Irrigated and post flooding herbaceous crops	4.29
Natural and artificial water body	0.99
Forest plantation and tree crops	0.014
Closed trees	1.73
Closed to open herbaceous vegetation	77.66

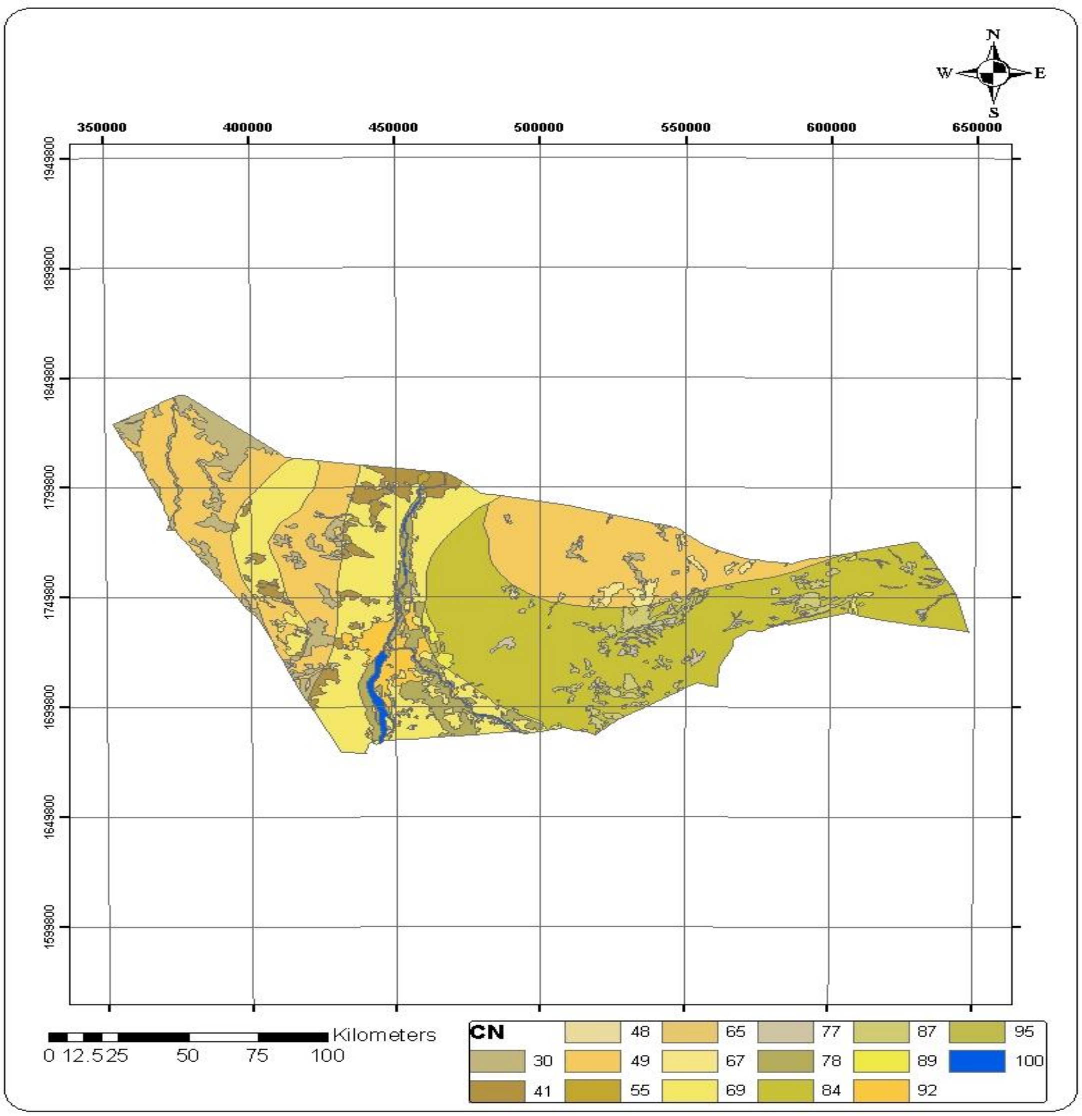

Figure 4. Distribution of CN values in the study area.

values were mapped and displayed in Figure 4.

Runoff depths of the basin were estimated using CN values in the SCS-CN equation as shown in Figure 5.

Conclusion

Remote sensing and GIS technologies can be used to

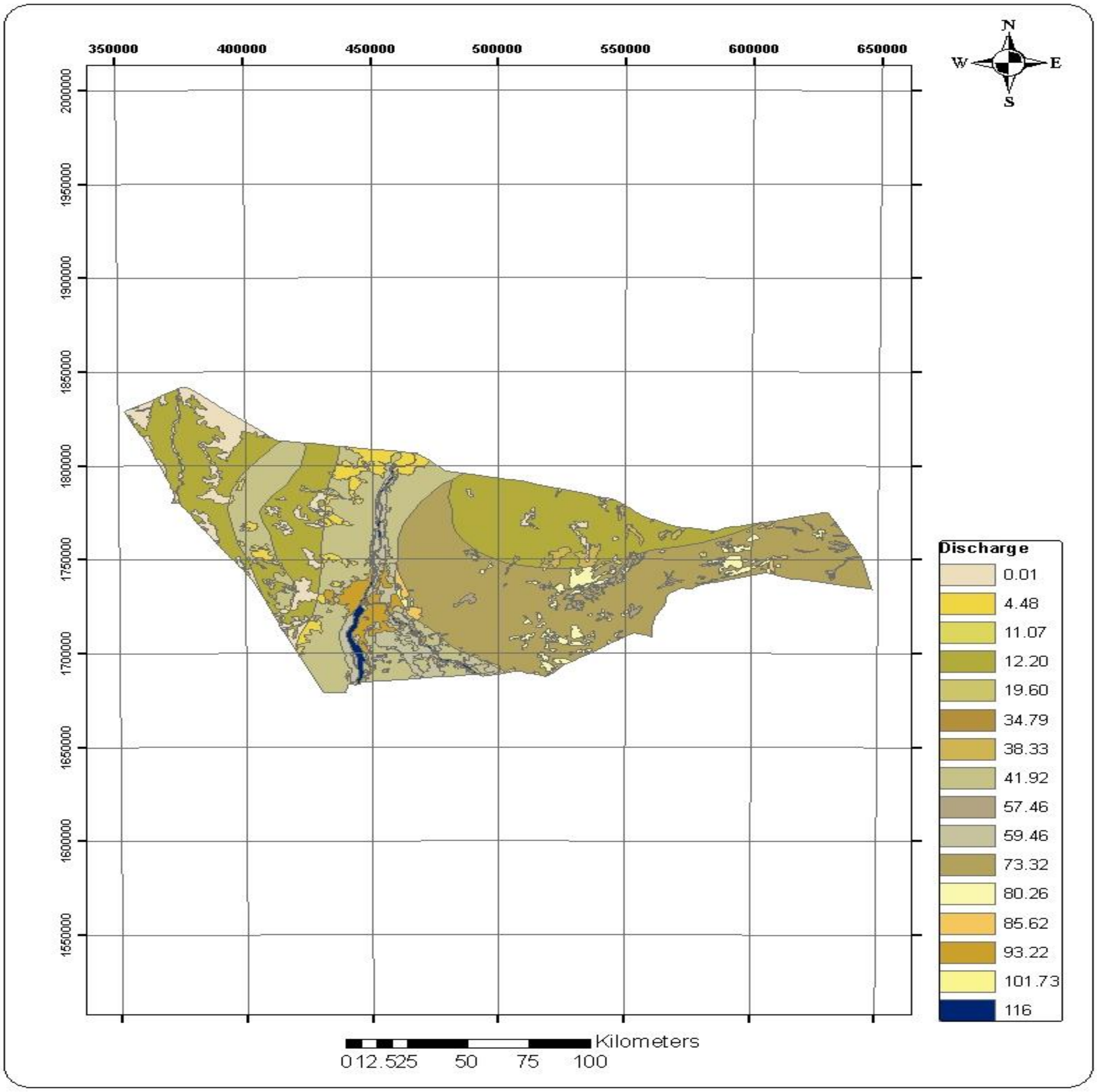

Figure 5. Runoff estimation based on CN values.

determine curve number values which could be used to calculate runoff depth. In this study, SCS-CN method was applied to simulate the rainfall-runoff process and create digital runoff map using GIS and remote sensing techniques. Three HSG covered the study area. The study area has been classified into eight major land use classes. Curve numbers values were estimated and thereafter the runoff amounts were determined for different areas. The results of the study would be very useful for flood forecasts and future land use changes scenarios.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Full Length Research Paper

Classification of transmissivity magnitude and variation in calcarious soft rocks of Bhaskar Rao Kunta Watershed, Nalgonda District, India

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Pumping test was used for the appraisal and evaluation of groundwater potential and design of well. Pumping tests of the calcarious sedimentary rocks of Bhaskar Rao kunta watershed area were carried out for twenty five selected bore wells for quantitative understanding of the groundwater for crop water requirement and groundwater use efficiency. The tests were carried out independently for short duration under constant rate conditions. The acquisition of the drawdown data was interpreted by Jacob straight line method. The results of transmissivity vary from 2.67 to 236.9 m^2/day with mean of 37 m^2/day, whereas the specific capacity varies from 5.47 to 451.63 m^3/d/m with a mean of 76 m^3/d/m. Spatial variation of transmissivity values was further analyzed using statistical testing and Krasny's classification systems; from the results of the statistical testing, 72% of the wells were under covered background transmissivity anomalies; 12% under positive anomalies; 8%, negative anomalies and remaining 8%, positive extreme anomalies. From the results of Krasny's classification system, 12% of the wells was under high magnitude (withdrawals of lesser regional importance), 40% of wells was under intermediate magnitude (withdrawals for local water supply), 48% was under low magnitude (smaller withdrawals for local water supply) and 100% of the wells was under covered moderate variations (fairly heterogeneous hydrogeological environment). Spatial variation of transmissivity magnitude and variation was identified as best useful in management practices.

Key words: Transmissivity, magnitude, variation, statistical testing, Krasny's classification.

INTRODUCTION

Quantitative understanding of most problems in hydrogeology (Ramakrishna, 1998), determination and evaluation of aquifer parameters of transmissivity and storage coefficient from aquifer test data is a continual field research (Birpinar, 2003); it is field–scale prediction (Illman and Tartakovsky, 2006) and integral part of assessment and management of groundwater study (Sarwade et al., 2007; Mayooran et al., 2011; Sudher Kumar et al., 2012). Generally, there are two types of pumping tests evaluation methods for determining aquifer parameters: (i) drawdown and (ii) recovery. In the present study, only drawdown test was conducted.

The present study was done in a semi-arid region of Bhaskar Rao kunta watershed area (40 km^2), which is a

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Figure 1. Location map of the study area.

purely remote and tribal area in the Nalgonda District. The Government Organization of Andhrapradesh State Irrigation Development Corporation (APSIDC) was incited to help each selected group of economically backward farmers by giving them a single bore well with a nominal subsidy to share the groundwater for irrigation use only. After the completion of bore wells drilling in the area, randomly pumping tests were conducted to check the availability of quantitative understanding of the groundwater used for a few number of bore wells. It is valuable and useful for crop water requirement and enhances agriculture productivity and sustainable development of the farmers.

Study area

Semi-arid region of Bhaskar Rao kunta watershed geographically lies between Northern latitudes from 16° 42' 25" to 16° 37' 58" and Eastern longitudes from 79° 28' 15" to 79° 32' 30" of the Krishna Lower Basin. The watershed elevation ranges between 80 and 140 m above the mean sea level, with slightly undulating terrain to moderate slopes (2 to 3%); its annual normal rain fall is 737 mm. The average maximum and minimum temperature is 40 and 28°C, respectively. The drainage system has dendritic to sub-dendritic pattern, governed by regional slope; its homogenous lithology and relief are exhibited by 146 streams (1st, 2nd and 3rd order streams), which curve and contribute to the flow of mostly dry stream except for seasonal run-off. Soils are covered with red sandy and black clay.

Geology

The study area, part of the Kurnool group of Palnadu sub basin (Upper Proterozoic period of Vindyan rocks), is partially covered by Srisailam succession of Kadapa Super Group (Pre-Cambrian period of Archaean rocks) (Figure 1). Srisailam sub basin rocks are exposed with Quartzites; the Quartzites are inter bedded with thin siltstone units and are usually thick bedded, with dense and fine to medium grain. Palnadu sub-basin rocks are exposed with Calcareous sedimentary rocks of quartzites, shales and flaggy-massive limestones (Geology and Mineral Resources, 2006). General sequence of sub-surface strata is encountered in the top soil, weathered/semi weathered layered shale inter bedded with quartzite.

Hydrogeology

In the study area, groundwater occurs mainly along the bedding planes, cleavages, solution channels, cavernous formations and joints. Aquifers often have different hydraulic heads, caused by various surface topographic undulations or cap rock structures. Aquifers are under confined to semi-confined conditions with shallow to deep zones. The shallow aquifer depth and thickness range between 30 to 40 m and 5 to 25 m (Kotturu, Kalvakatta Villages), respectively. Deep aquifer depth and thickness range between 40 to 60 m and up to 60 m (Banjaranagar Thanda, Gonina Thanda, Champla Thanda, Ham Thanda and JK Thanda) respectively. It has been found that, most of the aquifer zones are encountered within 40 to 60 m depth. The depth of open wells ranges from 5 to 20 m, whereas the bore wells are about 60 m deep. An average yield is 448 m^3/day (Table 1). Due to fluctuations of the groundwater in the monsoon pattern, static water levels were changed in depth from 1 to 7 m below ground level.

MATERIALS AND METHODS

Acquisition of data

In the study area, twenty five pumping tests data were collected and carried out in selected bore wells (Figure 2). The average depth of bore wells is 60 m below ground level. Submersible pump of 7.5 HP is lowered to a depth of 40 m. Static water level and drawdown were recorded with automatic water level indicator. During duration pumping test for 300 min, to ensure uninterrupted

Table 1. Results of aquifer parameters of twenty five bore wells.

Well No.	Pumping duration (min)	Static water levels (m)	Drawdown (m)		Discharge (m^3/day)	Specific capacity (m^3/d/m)	Transmissivity (m^2/day)
			Min.	Max.			
1	300	5	16	29.8	130	4.36	3.65
2	300	1	2.9	4.9	726	148.16	69.98
3	300	5.8	13.3	26.95	473	17.55	16.98
4	300	6	4.25	11.4	453	39.81	16.59
5	300	1	2.5	29.6	162	5.47	2.67
6	300	1	2	13.9	466	33.53	12.91
7	300	0.2	2.6	14.55	602	41.37	16.22
8	300	6	1.15	2.85	971	451.63	236.9
9	300	7.15	1.35	6.75	773	114.52	54.17
10	300	1.5	7.65	15.76	456	29	9.73
11	300	1.3	1.4	2.3	869	377.83	186.15
12	300	6.8	9.45	22.58	359	15.9	7.07
13	300	0.2	18.6	35	272	7.77	5.41
14	300	6.2	12.3	28.3	188	6.76	6.53
15	300	2.1	1.6	4.55	727	199.18	102.39
16	300	4	16.2	31	250	8.06	4.82
17	300	6	0.15	13.5	227	16.81	5.21
18	300	1.2	2.3	5.4	512	94.81	52.13
19	300	0.2	2.5	6.6	455	68.94	26.01
20	300	3.5	0.2	12.7	557	43.86	8.43
21	300	7	8.2	25.2	235	9.36	10.26
22	300	7	0.8	12	173	14.42	6.14
23	300	6	14.1	24	225	9.38	5.87
24	300	6	0.6	7.6	413	54.34	20.43
25	300	6.2	1.7	13.3	216	17	5.31
Minimum		0.20	0.15	2.30	130.00	5.47	2.67
Maximum		7.15	18.60	29.6	971.00	451.63	236.90
Mean		3.89	5.33	15.45	448.33	76.06	37.01
Standard Deviation		2.67	5.66	9.93	233.54	115.76	59.55

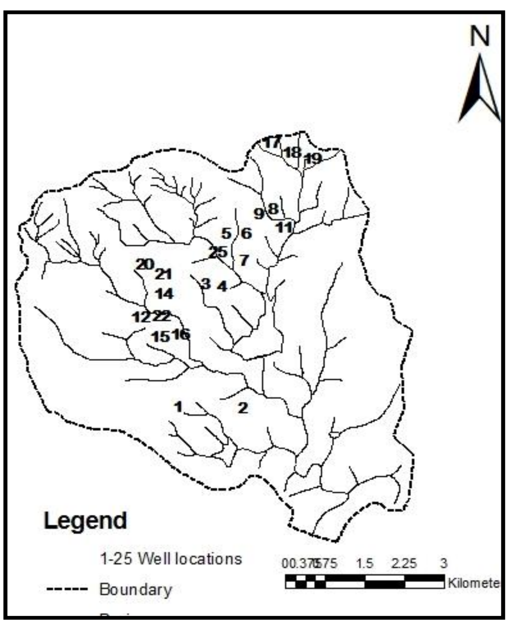

Figure 2. Pump testing locations in the study area.

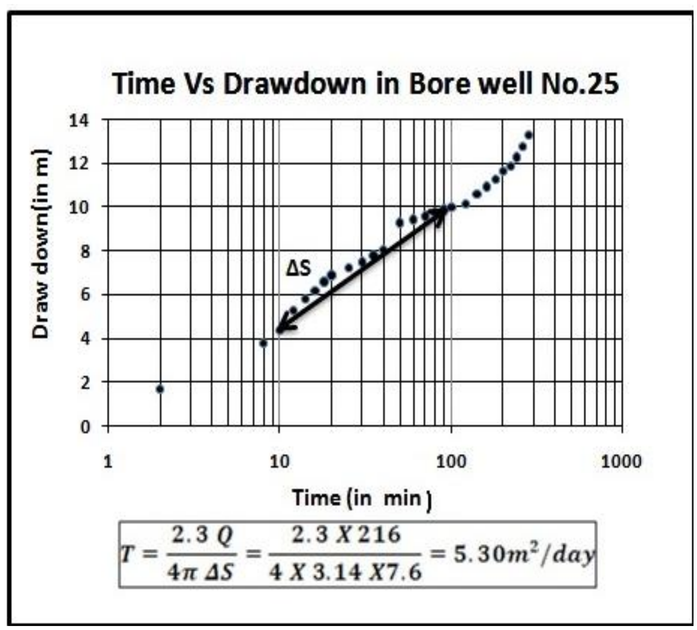

Figure 3. Data Interpretation on log-log graph in Jacob method.

Table 2. Transmissivity analysis based on transmissivity index 'Y' classification.

Classification	Description	Range of T index 'Y'
Negative extreme anomalies	Less than [mean – (2 * standard deviation)]	Less than 4.13
Negative anomalies	Between (mean – standard deviation) and [mean – (2 * standard deviation)]	4.13-4.66
Background transmissivity	Between (mean – standard deviation) and (mean + standard deviation)	4.66-5.74
Positive anomalies	Between (mean + standard deviation) and [mean + (2 * standard deviation)]	5.74-6.28
Positive extreme anomalies	Greater than [mean + (2 * standard deviation)]	Above 6.28

power supply a stand by 15 KV diesel generator was used. 200 L drum was used for measuring discharge. In the present study, a single well drawdown test was adopted, as an aquifer pre-test to determine an optimal pumping rate of the wells and neighboring wells could not be used as observation wells due to field limitations. In single well test drawdown well is influenced by well losses as well as well-bore storage. Pumping test data were statistically analyzed by MS Excel-2007 version.

Data interpretation

The pumping test data were interpreted by Jacob straight line method (Jacob, 1950). To determine transmissivity, on the semi-log paper the values of 'drawdown' were plotted against the corresponding values of 'time' and a straight line was drawn through the plotted points; and to determine the slope of the straight line '∆S' the drawdown difference was plotted over one log cycle of time (Figure 3). The transmissivity is determined from the following equation:

$$\boldsymbol{T}(\textbf{Transmissivity}) = \frac{\mathbf{2.3}\boldsymbol{Q}}{\mathbf{4}\boldsymbol{\pi}\boldsymbol{\Delta}\mathbf{s}}$$

Where, T=Transmissivity in m^2/day, Q=Pumping well discharge in m^3, ∆s = Slope of time vs drawdown plot.

RESULTS AND DISCUSSION

Spatial analysis of transmissivity

The transmissivity analysis is carried out using two methods. One method is based on descriptive statistical testing by identifying transmissivity and anomalies and the other method is based on a classification scheme introduced by Krasny in 1993.

Statistical testing

In this approach, all the transmissivity values collected are pooled in a particular region using Transmissivity index 'Y'. The relationship between transmissivity (T) and logarithmic transmissivity index (Y) is;

$$T(m^2/day) = 10^{Y-8.96} X\ 86400 \quad (1)$$

Found by Jetal and Krasny in 1968, it is used to calculate the logarithmic transmissivity index (Y) from transmissivity (T) values. The above stated equation can be modified as, Logarithmic Transmissivity Index,

$$Y = log\left[\frac{T}{86400}\right] + 8.96 \quad (2)$$

Where T – Transmissivity in m^2 / day

The logarithmic transmissivity index (Y) values are calculated using the modified equation and the calculations are tabulated in Table 2. The mean value of transmissivity index is obtained as 5.2 and the standard deviation of transmissivity index is 0.54. By using these two values, the classification is found as given in Table 4. From the results of the statistical testing, 72% of the wells are under covered background transmissivity anomalies; 12%, under positive anomalies; 8%, negative anomalies and remaining 8%, positive extreme anomalies. The values outside this interval are considered as positive or negative anomalies. The positive anomalies represent prospective zones for groundwater exploration relatively compared to the areas of background transmissivity and the negative anomalies represent less favorable zones. The areas with extreme positive anomalies are highly suitable for local water.

Krasny's classification

Jiri Krasny (1993) proposed a transmissivity classification system based on transmissivity and standard deviation of transmissivity index magnitude and variation of the transmissivity and transmissivity index values. The methods of classifications for transmissivity magnitude and variation are tabulated in Table 3. By using the classification given in Table 3, the groundwater supply potential was identified as given in Table 4, and the standard deviation value of 0.54 observed in transmissivity index 'Y' represents a moderate transmissivity variation and fairly heterogeneous hydro geological environment. From the results of classification of magnitude, 12% of the wells are under high magnitude (Withdrawals of lesser regional importance),

Table 3. Krasny's classification of transmissivity of magnitude and variation.

Classification of T Magnitude				Classification of T Variation			
Coefficient of T (m^2/d)	Class of T magnitude	Designation of T magnitude	Groundwater supply potential	Standard deviation of T Index (Y)	Class of T Variation	Designation of T Variation	Hydro geological environment
> 1000	I	Very high	Withdrawals of great regional importance	< 0.2	a	Insignificant	Homogeneous
1000 - 100	II	High	Withdrawals of lesser regional importance	0.2 – 0.4	b	Small	Slightly heterogeneous
100 - 10	III	Intermediate	Withdrawals for local water supply (small communities and plants)	0.4 – 0.6	c	Moderate	Fairly heterogeneous
10 - 1	IV	Low	Smaller withdrawals for local water supply (private consumption)	0.6 – 0.8	d	Large	Considerably heterogeneous
1 - 0.1	V	Very low	Withdrawals for local water supply with limited consumption	0.8 – 1.0	e	Very large	Very heterogeneous
< 0.1	VI	Imperceptible	Sources for local water supply are difficult	> 1.0	f	Extremely large	Extremely heterogeneous

Table 4. Results of summary statistics of transmissivity index (Y), Krasny's magnitude and variation.

Well No.	T (m^2/day)	T Index 'Y'	Results of T index 'Y'	Results of 'T' magnitude	Results of 'T' variation
1	3.65	4.59	Negative anomalies	Smaller withdrawals for local water supply	Extremely heterogeneous
2	69.98	5.87	Positive anomalies	Withdrawals for local water supply	Extremely heterogeneous
3	16.98	5.25	Background transmissivity	Withdrawals for local water supply	Extremely heterogeneous
4	16.59	5.24	Background transmissivity	Withdrawals for local water supply	Extremely heterogeneous
5	2.67	4.45	Negative anomalies	Smaller withdrawals for local water supply	Extremely heterogeneous
6	12.91	5.13	Background transmissivity	Withdrawals for local water supply	Extremely heterogeneous
7	16.22	5.23	Background transmissivity	Withdrawals for local water supply	Extremely heterogeneous
8	236.9	6.40	Positive extreme anomalies	Withdrawals of lesser regional importance	Extremely heterogeneous
9	54.17	5.76	Positive anomalies	Withdrawals for local water supply	Extremely heterogeneous
10	9.73	5.01	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
11	186.15	6.29	Positive extreme anomalies	Withdrawals of lesser regional importance	Extremely heterogeneous
12	7.07	4.87	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
13	5.41	4.76	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
14	6.53	4.84	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
15	102.39	6.03	Positive anomalies	Withdrawals of lesser regional importance	Extremely heterogeneous
16	4.82	4.71	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
17	5.21	4.74	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
18	52.13	5.74	Background transmissivity	Withdrawals for local water supply	Extremely heterogeneous
19	26.01	5.44	Background transmissivity	Withdrawals for local water supply	Extremely heterogeneous
20	8.43	4.95	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
21	10.26	5.03	Background transmissivity	Withdrawals for local water supply	Extremely heterogeneous
22	6.14	4.81	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
23	5.87	4.79	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous
24	20.43	5.33	Background transmissivity	Withdrawals for local water supply	Extremely heterogeneous
25	5.31	4.75	Background transmissivity	Smaller withdrawals for local water supply	Extremely heterogeneous

40% of wells are under intermediate magnitude (withdrawals for local water supply), 48% are under low magnitude (smaller withdrawals for local water supply) and 100% of the wells are under covered moderate variations (fairly heterogeneous hydrogeological environment).

CONCLUSION AND RECOMMANDATIONS

The study has shown that the transmissivity varies from 2.67 to 236.9 m^2/day (with a mean of 37 m^2/day), whereas the specific capacity varies from 5.47 to 451.63 m^3/dd/m (with a mean of 76 m^3/d/m). Spatial variation of transmissivity values was further analyzed using statistical testing and Krasny's classification systems. From the results of the statistical testing, 72% of the wells are under covered background transmissivity anomalies; the remaining 12, 8 and 8%, under positive, negative and positive extreme anomalies, respectively. From the results of Krasny's classification system, 48, 40 and 12% of the wells aree under covered low magnitude (smaller withdrawals for local water supply), intermediate magnitude (withdrawals for local water supply) and high magnitude (withdrawals of lesser regional important) respectively. 100% of the wells are under covered moderate variations (fairly heterogeneous hydrogeological environment). Spatial variation of transmissivity magnitude and variation were identified as best useful in management practices and sustainable development of groundwater.

A much more appropriate quantitative understanding of the groundwater for a long time pumping test and observation is well required.

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Conflict of Interests

The author(s) have not declared any conflict of interests.

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Full Length Research Paper

Assessment of noise pollution of two vulnerable sites of Sylhet city, Bangladesh

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The study reports the analysis and measurement of the noise levels of CNG refueling Stations and Power Generators of Power Development Board (PDB) induced noise pollution in Sylhet City. For this purpose noise levels have been measured at ten major locations of the city for CNG refueling Stations and in PDB, Kumargaon. Sound levels are measured at different location at different time interval for the respective study locations with the help of a standard Sound meter. It was found that the noise levels for both study locations are much higher that exceed the allowable permissible noise limits. The study suggests that noise path must be controlled by using appropriate sound barriers that can reflect and diffuse noise appropriately and particularly use of sound enclosure can reduce noise level.

Key words: Noise pollution, sound level, permissible exposure level.

INTRODUCTION

Sylhet city is one of the largest cities of Bangladesh in the northeast portion of the country. Sylhet is the 4th largest city of Bangladesh by the population. It covers an area of 26.5 km^2. Day by day the unplanned Urbanization is going on in this city in a threaten way. Infrastructure is not developing in the right places. As a result of unplanned urbanization, hospitals, schools, colleges and universities like sensitive institutions are building in the noisy area (Shilpy, 2007).

The noise pollution is one of the major problems for developing countries like Bangladesh. Sylhet city is one of the largest cities of Bangladesh in the northeast portion of the country (Shilpy, 2007). The noise originates from human activities, especially the urbanization and the development of transport and industry. Measuring noise levels and workers' noise exposures is the most important part of a workplace hearing conservation and noise control program. It helps identify work locations where there are noise problems, employees who may be affected, and where additional noise measurements need to be made (Asthana and Asthana, 2013). Noise is any sound-independent of loudness- that can produce an undesired physiological or psychological effect in an individual, and that may interfere with the social ends of an individual group (Mackenzie and David, 2006).

Noise level was measured at two points which were considered as silent zones and at every point the noise level exceeded the permissible value. In this study the highest noise level found at Biroti CNG refueling Station, Mira Bazaar. Also we analyze the noise level & exposure level of Power Generator of Power Development Board (PDB). The selected Power Development Board and some CNG refueling stations were located near the residence rather than a safe distance away from the

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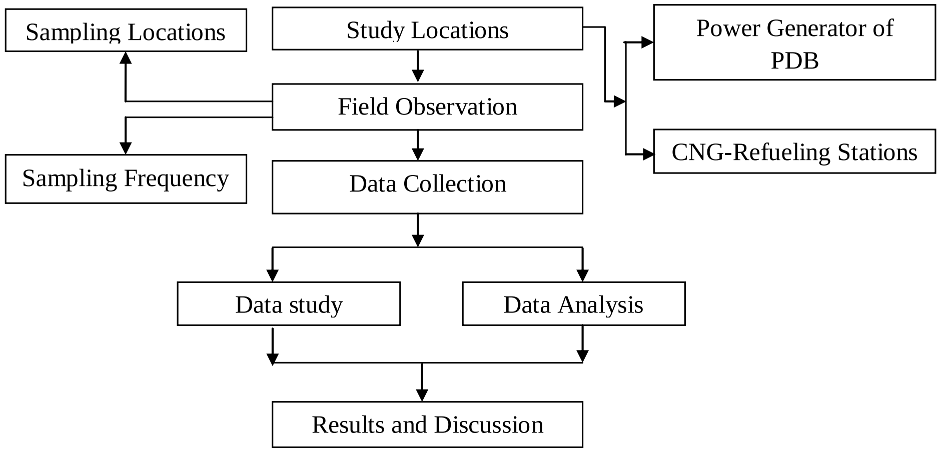

Figure 1. Flow chart of methodology which illustrates the methodology to assess the noise pollution of two major point of Sylhet City.

roadside.

METHODOLOGY

Noise measurement is an important diagnostic tool in noise control technology. The objective of noise measurement is to make accurate measurements which give us a purposeful act of comparing noises under different conditions for assessment of adverse impacts of noise and adopting suitable control techniques for noise reduction (Shilpy, 2007).

Noise measurements are usually conducted for one of three purposes:

1. To understand the mechanisms of noise generation so that engineering methods can be applied to control the noise.
2. To rate the sound field at various locations on a scale related to the physiological or psychological effects of noise on human beings.
3. To rate the sound power output of a source, usually for future engineering calculations, that can the sound pressure it produces at a given location.

The flow diagram that depicts the methodology of the method is shown in Figure 1.

Sampling method

All the measurements were made on “A – weighting “scale and the sound level meter were switched to fast response position. During each hourly interval, sound levels have been measured for 10 s,1 min,5 min and 10 min for a couple of times .The average values of these measurements have been recorded as the sound level for the corresponding location and time interval. Data collected was analyzed statistically to determine L_{10}, L_{50}, L_{90}, L_{max}, L_{ae} and L_{aeq}. The average values of these measurements have been recorded as the sound level for the corresponding location and time interval (Shilpy, 2007).

Sampling frequency

Noise levels measured at 2 different locations in the Sylhet city. These are power generators of PDB, CNG refueling stations. For collecting data of noise level of Power generators of PDB, CNG refueling stations are always running for all day long and there is no change sound level. Sound levels were measured for 10 s, 1 min, 5 min and 10 min for each point.

Field survey

The field survey can be classified chronologically (Shilpy, 2007) as:

1. Field super vision
2. Data collection
3. Sampling and
4. Tabulation.

The survey can be classified into two types; first one is quantitative survey, and another is qualitative survey. The planning of survey is the combination of technical and organizational decisions. The following field investigations and surveys were undertaken:

1. Investigation in the CNG stations and power generators of PDB located on the major locations of Sylhet city.
2. There overall conditions such as sound proofing facilities, sound barrier, and other types of protection measures and categorized the effect of noise on the city dwellers.
3. Noise level measured on those specific locations according to the different time interval.
4. To find out the relationship of noise level among those specified locations.
5. Noise level measured for an ideal case.
6. In our analysis, we took noise level (dBA) just for one minute for each location.
7. In the analysis, we neglected L_{95}, L_{pA}, and L_5 noise parameter.

Sampling location

Power generators PDB is situated in Kumargaon, Sylhet and some CNG refueling stations are situated in commercial and residential area in the Sylhet city. The following CNG refueling stations was observed (Table 1).

DATA ANALYSIS AND DISCUSSION

Noise level parameter such as L_{eq}, L_E, L_{max}, L_5, L_{10}, L_{50},

Table 1. Observed stations.

Obs. point	Name of CNG-refueling stations
P1	Jess Intraco CNG Refueling station, Kumargaon
P2	Ahmad CNG Refueling station Subidbazar
P3	Northeast CNG Refueling station Modina Market
P4	Uttara CNG Refueling station, Shibgonj.
P5	DibaRatri CNG Refueling station, Moulovibazar Road
P6	Surma Auto Care, East Shibgonj
P7	Monwar CNG Refueling station East Shibgonj
P8	Biroti CNG Refueling station, Mirabazar
P9	Navana CNG Refueling station, Chowkidekhi
P10	Karimullah CNG Refueling station, Naiorpul

Table 2. Permissible noise levels in different types of location [Environment (Protection) Rules, 1986].

Area code	Permissible noise levels limits (dB)	
	Day (6 am to 9 pm)	Night (9 pm to 6 am)
Industrial area	75	65
Commercial area	65	55
Residential area	55	45
Silence zones	45	35
Educational institutions	40	30

L_{90}, L_{95}, and L_{pA} are important parameter for the noise pollution survey. That parameter has been measured at different locations in Sylhet City (Table 2), which has never been previously surveyed (Shilpy, 2007).

Analysis of noise level of CNG refueling station

Table 3 shows the noise level in various CNG refueling stations at Sylhet. It shows that noise levels differs from each observation point. Some of the CNG refueling stations are located near the residential areas. From Table 1, we know in residential areas the noise level is 55 dB in day time and 45 dB at night time. Each of these CNG refueling station produce greater amount of noise. The measurement shows that the noise levels exceed the Permissible noise levels. Noise Levels (dBA) of L_{eq}, L_{AE}, L_{max}, L_{10}, L_{50} and L_{90} at Various Locations are shown in Table 3.

L_{eq}

To show the overall picture of noise level at CNG refueling station the following graphs is plotted. This represents that in ten different CNG refueling station noise level is between 84.8 to 90.0 dBA. The curve shows that peak value is 90.0 dBA which is obtained in P8 point (Figure 2).

L_{AE}

The following graph shows the noise level between 101.9 to 107.8 dBA. The curve shows that peak value is 107.8 dBA which is obtained in P8 point (Figure 3).

L_{max}

The following curve shows that peak value is 93.1 dB which is obtained in P4 observation point. We found another highest value which is observed at P8 point and the observed value is 92.0 dB (Figure 4).

L_{10}

The following figure shows that peak value is 90.7 dB which is obtained in P8 point (Figure 5). Here the sound level exceeded 10% of the time (Peak level).

L_{50}

The following curve shows that peak value is 90.0 dB (Figure 6). Here the Sound level exceeded 50% of the time (average or mean value).

L_{90}

The following curve shows that peak value is 89.3 dB

Table 3. Noise level in various CNG refueling station at Sylhet.

Obs. point	L_{eq}	L_{AE}	L_{max}	L_{10}	L_{50}	L_{90}
P1	84.8	102.6	87.6	86.0	85.4	81.6
P2	86.2	104.0	91.6	87.3	86.5	84.0
P3	87.6	104.5	89.8	86.4	85.2	83.6
P4	87.2	103.9	93.1	90.5	89.2	86.3
P5	85.3	101.9	86.3	82.9	80.5	78.5
P6	87.4	105.2	88.7	87.8	87.4	87.0
P7	86.2	103.9	88.1	86.9	85.4	84.5
P8	90.0	107.8	92.0	90.7	90.0	89.3
P9	85.1	102.9	91.8	85.5	85.0	84.5
P10	88.5	105.3	89.3	85.4	84.7	83.2

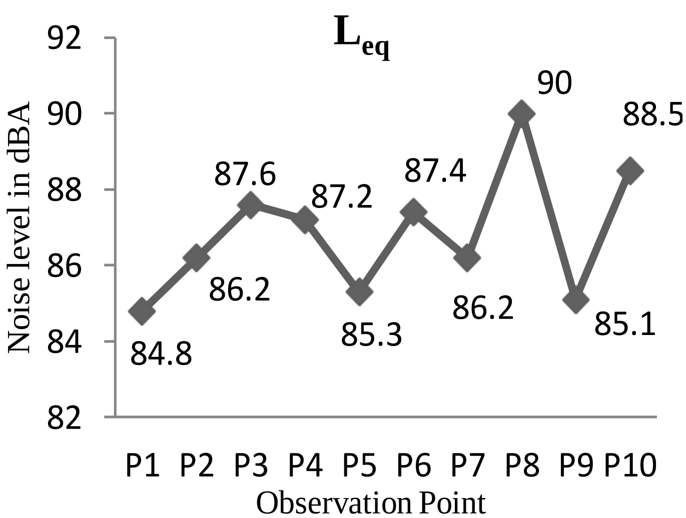

Figure 2. Noise levels at different CNG refueling station.

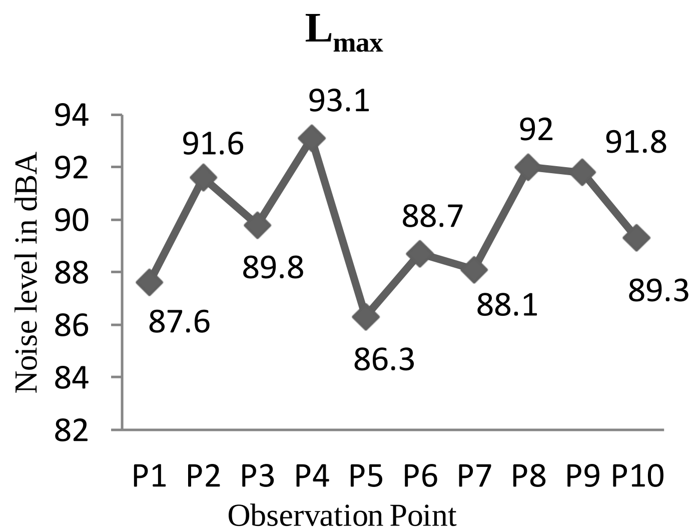

Figure 4. Noise levels at different CNG refueling station.

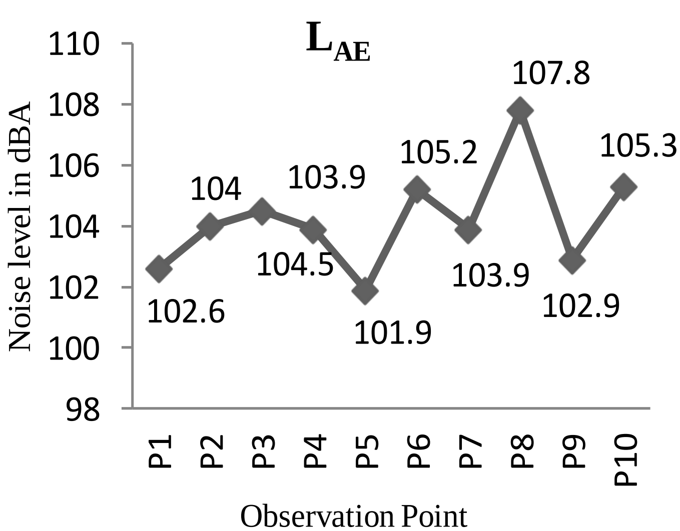

Figure 3. Noise levels at different CNG refueling station.

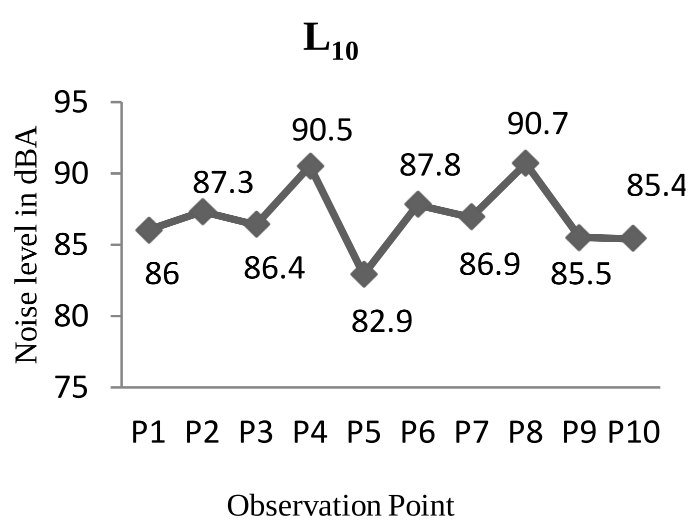

Figure 5. Noise levels at different CNG refueling station.

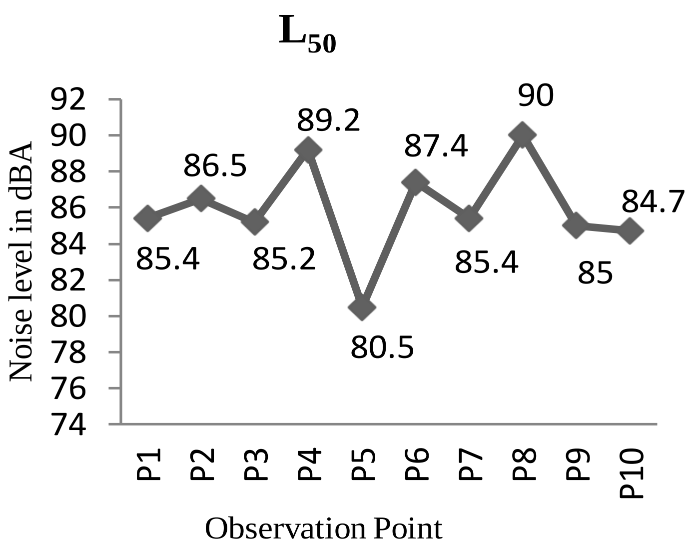

Figure 6. Noise levels at different CNG refueling station.

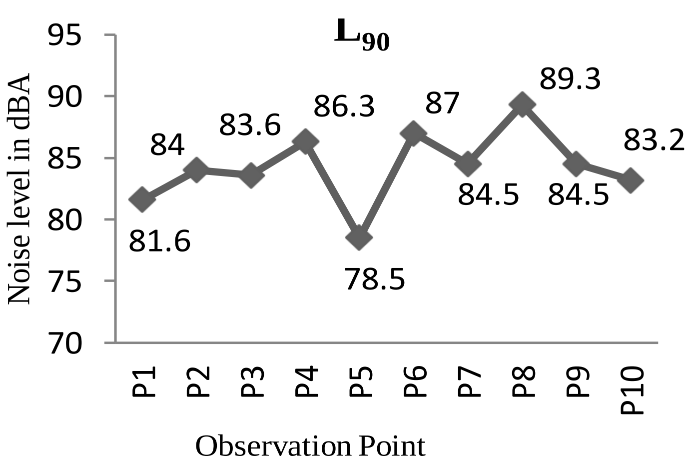

Figure 7. Noise levels at different CNG refueling station.

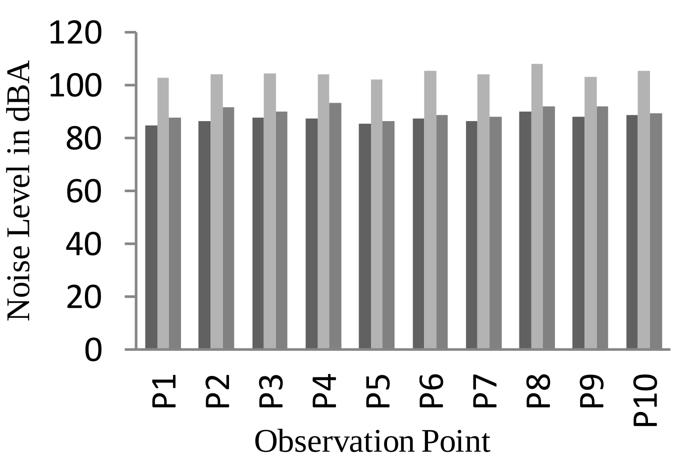

Figure 8. L_{eq}, L_{AE}, L_{max} of CNG-stations.

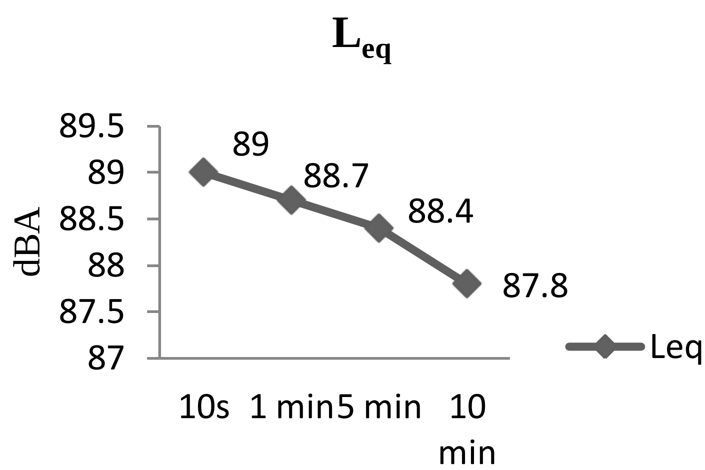

Figure 9. Noise levels at different time interval.

(Figure 7). Here the sound level exceeded 90% of the time (ambient level).

The variation and fluctuation of noise level at ten different CNG filling stations at Sylhet city is presented in the Figure 8. Figure shows the graphical presentation of L_{eq}, L_{AE}, L_{max} of filling stations noise level. Finally, from CNG refueling station Analysis, highest noise level found at Biroti CNG refueling Station, Mira bazaar is 90.0 dBA.

Analysis of noise level of PDB (Power generators), Kumargaon, Sylhet

Tables 4 and 5 shows the noise level in Kumargaon Power development board at Sylhet. It shows that noise levels are relatively same in four different time intervals. But in combination of three power generator the noise level is higher than others. From Table 1, we know in residential areas the noise level is 55 dB in day time and 45 dB at night time. But the measurement shows it exceed the permissible noise levels. Noise Levels (dBA) L_{eq}, L_{AE}, L_{max}, L_{PA}, L_{A5}, L_{10}, L_{50}, L_{90} and L_{95} at two generators are shown in both Tables 4 and 5.

L_{eq}

To show the overall picture of noise level covering whole day measurement the following graphs is plotted. This represents that in 150 MW generators noise level is between 87.8 to 89.0 dBA. The curve shows that peak value is 89.0 dBA obtained in 10 s time interval (Figure 9).

L_{50}

The following graph shows the noise level in 150 MW generators which vary between 86.5 to 88.9 dBA.

Table 4. Data of Noise Level Parameters in Kumargaon PDB (150 MW).

Time interval	L_{eq}	L_{AE}	L_{max}	L_{10}	L_{50}	L_{90}	L_{95}
10 s	89.0	99.0	89.6	89.3	88.9	88.7	88.5
1 min	88.7	106.5	90.4	89.2	88.7	88.3	88.2
5 min	88.4	113.1	90.4	88.7	88.3	88.0	88.0
10 min	87.8	116.3	89.5	87.8	86.5	86.1	86.0

Table 5. Noise level parameters in Kumargaon PDB combined power generator (150+20+10 MW).

Time interval	L_{eq}	L_{AE}	L_{max}	L_{10}	L_{50}	L_{90}	L_{95}
10 s	93.2	104.3	95.4	89.8	90.3	91.3	89.8
1 min	90.8	108.6	92.5	92.3	90.8	92.5	90.7
5 min	89.7	112.8	91.5	86.2	87.3	90.5	89.8
10 min	88.6	116.7	90.6	87.3	86.5	85.4	85.0

The curve shows that peak value is 88.9 dBA (Figure 10) which is obtained in 10 s interval.

L_{90}

The following curve shows that peak value is 88.7 dB (Figure 11) which is obtained in 10 s time interval.

Noise level analysis for combined (150+10+20 MW) generator

From Table 5, graphical presentation of L_{eq}, L_{50} and L_{90} are shown in the following graph.

L_{eq}

The following graph shows the noise level for combined generators which vary between 88.6 to 93.2 dBA. The curve shows that peak value is 93.2 dBA (Figure 12) which is obtained in 10 s interval.

L_{50}

The following graph shows the noise level for combined generators which vary between 86.5 to 90.8 dBA. The curve shows that peak value is 90.8 dBA (Figure 13) which is obtained in 10 s interval.

L_{90}

The following curve shows that peak value is 92.5 dB (Figure 14) which is obtained in 10 s time interval.

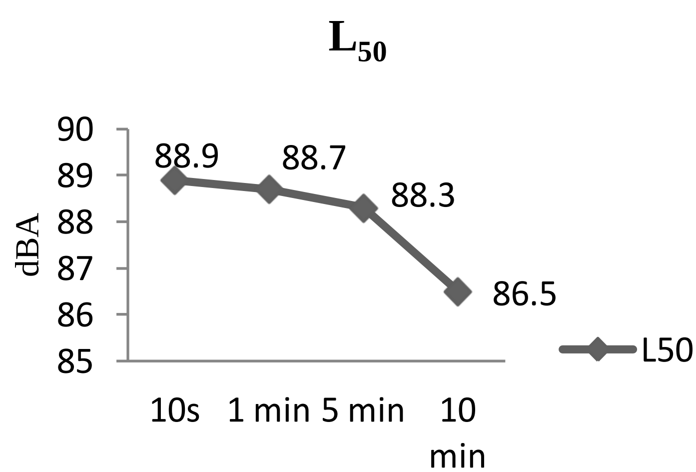

Figure 10. Noise levels at different time interval.

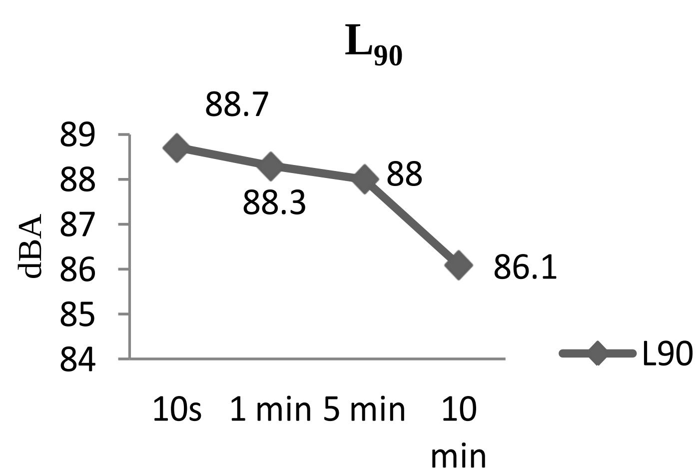

Figure 11. Noise levels at different time interval.

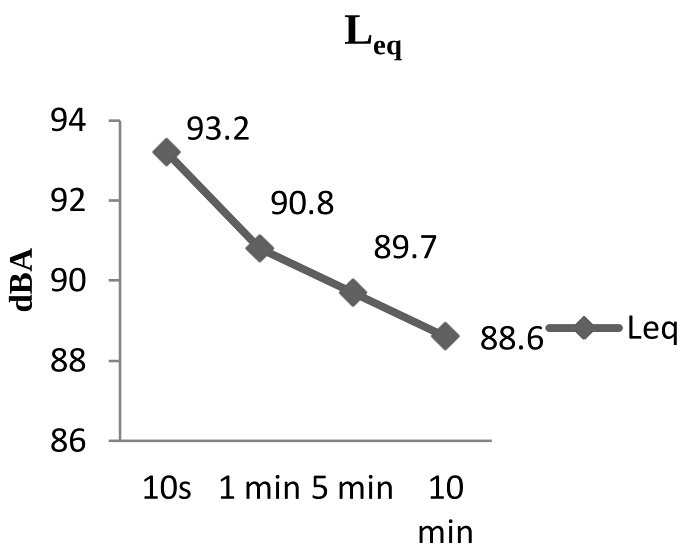

Figure 12. Noise levels at different time interval.

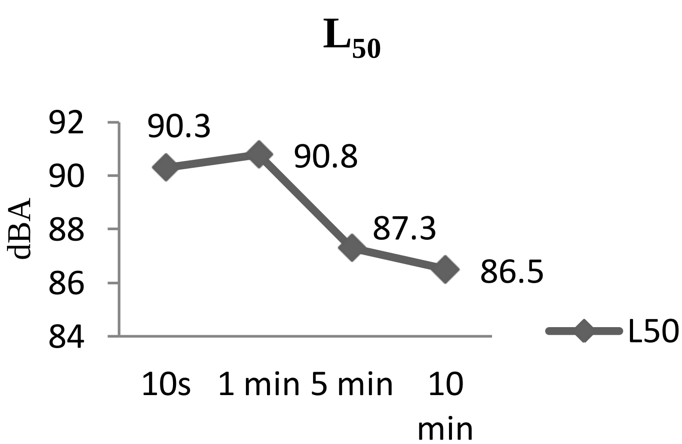

Figure 13. Noise levels at different time interval.

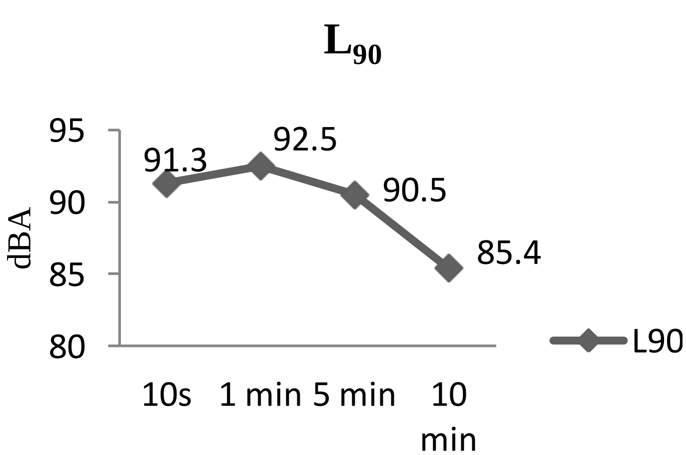

Figure 14. Noise levels at different time interval.

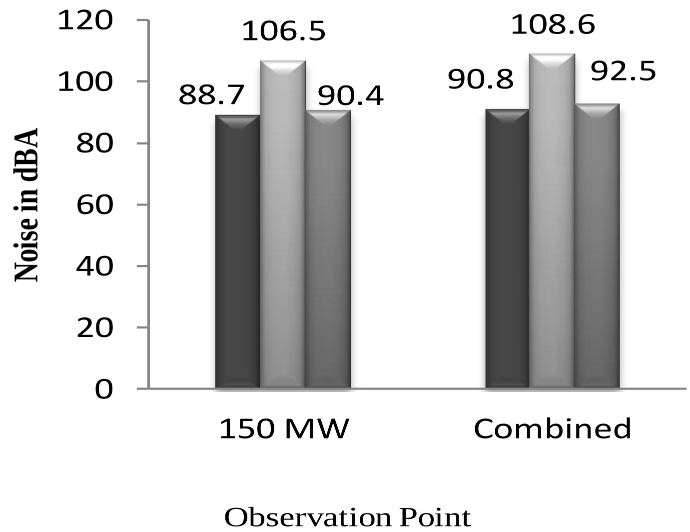

Figure 15. Comparision of L_{eq}, L_{AE}, L_{max} of PDB power generators.

As we plot the dBA versus observation point graph it shows the comparison between two observed areas noise level. Noise level increases for combined power generator. For rapid urbanization process noise increase at the same rate as it is the one of the major need of people. So it can be said that in future noise level will be increased at some rate. The variation and fluctuation of noise level at Kumargaon Power Development Board, Sylhet is presented in the Figure 15. The figure shows the graphical presentation of L_{eq}, L_{AE}, L_{max} of PDB noise level. Finally, from PDB (power generator) analysis, highest noise level found at Combined power generator is 93.2 dBA and noise level lies between 87.8 and 93.2 dBA.

Exposure level analysis

The amount of exposure time is reduced as the noise level increase. These time limits are shown in Table 6 for noise levels ranging from 90 to 115 dBA. As shown in the table, the allowable exposure time is cut in half each time the noise level increase by 5 dBA. For example, at 90 dBA, the allowable exposure is 8 h, but at 95 dBA, the allowable exposure is 4 h, and at 100 dBA it is reduced to 2 h. When a person is exposed to different noise levels throughout an 8 h period, the combined effect must be considered. This is done by calculating a combined exposure fraction, using the following equation (Gayle and Dianna, 1997)

$$\sum_{i=1}^{n} \frac{Ci}{Ti}$$

Where, n is the number of different noise levels, C_i is the

Table 6. Permissible noise exposures.

Noise duration per day, Ti (h)	Sound level dBA slow response (dB)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or Less	115

Source: Gayle and Dianna (1997).

Table 7. Noise levels.

Noise levels (dBA)	Actual exposure time (Ci)
99.0	4 h
106.5	2 h
113.1	1 h
116.3	45 min

amount of time a person is exposed to noise level i, and T_i is the total amount of time permitted at that noise level. Any amount of time the person is exposed to noise levels of less than 90 dBA is not include in the sum. If the sum of the individual C/T fraction is grater then 1.0, the allowable exposure is exceeded. If the allowable exposure is exceeded, the employer must be use administrative and engineering controls to reduce the exposure to allowable levels. The limits in Table 6 are based on continuous noise, not intermittent or impact-type noise (Gayle and Dianna, 1997).

Exposure level analysis of PDB (power generators)

Exposure level analysis for 150 MW generators

From Table 4, value of exposure (L_{AE}) level 99.0 dBA was measured for 10 s time duration. Similarly, 106.5 dBA was measured for 1 min, 113.1 dBA was measured for 5 min and 116.3 dBA was measured for 10 min time duration. From above literature, exposure level calculations require 4 h, 2 h, 1 h and 45 min noise level observations. But in this study it was not possible to take measurement for longer time duration such as for 4 h, 2 h, 1 h and 45 min. So for analysis we assume, at 99 dBA, the allowable exposure (Ci) is 4 h, 106.5 dBA the allowable exposure (Ci) is 2 h, 113.1 dBA the allowable exposure (Ci) is 1 h, 116.3 dBA the allowable exposure (Ci) is 45 min. Then noise level can be expressed as shown in Table 7.

Table 8. Exposure level analysis for PDB combined (150+20+10 MW) power generators.

Noise levels (dBA)	Actual exposure time (Ci)
104.3	4 h
108.6	2 h
112.8	1 h
116.7	45 min

Now exposure fraction calculation for 99 dBA can be written as (Table 7):

Actual exposure fraction (Ci) ÷ Duration per day (Ti) = 4 ÷ 2 = 2

Similarly we can write,

Exposure fraction for 106.5 dBA = 2 ÷ 1 = 2
Exposure fraction for 113.1 dBA = 1 ÷ 0.5 = 2
Exposure fraction for 116.3 dBA = 0.75 ÷ 0.25 = 3

Then sum of the exposure fraction is,

2 + 2 + 2 + 3 = 9

Because the total exposure fraction is 9.0 is more greater than 1.0, the allowable exposure level is exceeded.

Exposure level analysis for PDB combined (150+20+10 MW) power generators

From Table 5, exposure level can be analyzed for combined generator.

Now exposure fraction calculation for 104.3 dBA (Table 8) can be written as,

Actual exposure fraction (Ci) ÷ Duration per day (Ti) = 4 ÷ 1 = 4

Similarly we can write,

Exposure fraction for 108.6 dBA = 2 ÷ 0.5 = 4
Exposure fraction for 112.8 dBA = 1 ÷ 0.5 = 2
Exposure fraction for 116.7 dBA = 0.75 ÷ 0.25 = 3

The sum of the exposure fraction is,

4 + 4 + 2 + 3 = 13

Because the total exposure fraction is 13.0 is more greater than 1.0, the allowable exposure level is exceeded. Figure 16 shows the exposure level of both generators.

Noise measuring device

In this study we use integrating sound level meter NL-07 which allows not only conventional sound pressure level

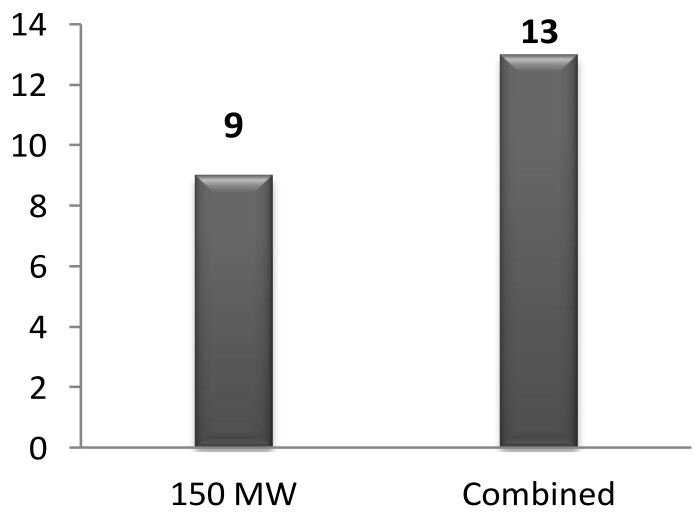

Figure 16. Exposure level of PDB Kumargaon, Sylhet.

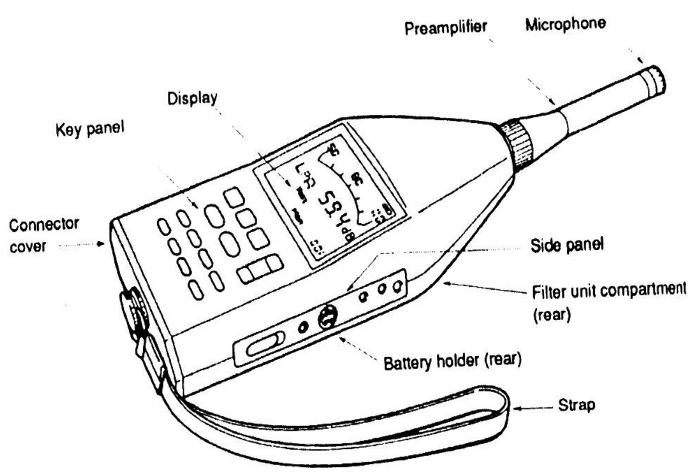

Figure 17. Noise level meter.

measurements, but also incorporate processing functions, which make it possible to determine equivalent continuous sound pressure level L_{eq} sound exposure level L_e, percentile sound pressure level L_x (L_5, L_{10}, L_{50}), maximum sound pressure level L_{max} (Shilpy, 2007).

The large, backlit display shows measurement results in numerical form and on a graphical scale, and gives information on measurement parameters and settings. The wide display range of 70 dB for numerical indication and 60 dB for graphical indication make range switching virtually unnecessary during normal measurements. A typical Noise Level Meter (NL07) has been shown in Figure 17 (Shilpy, 2007).

Conclusion

The result of the study reported in this paper is that noise level in Sylhet City near the vulnerable industry, CNG refueling stations and Kumargaon PDB, noise level are much higher than the acceptable limit; consequently careful measures should be taken to design and construct sides of the buildings which are situated in noisy area, people awareness should be increased by undertaking programs, respective authority should take effective measures to reduce noise level as soon as possible because it is high time to take initiatives against noise pollution; otherwise the environment of Sylhet City will be unfavorable to live in.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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