Journal of Geomatics Vol 9 No. 2 October 2015

Telecommunication utility analysis using GIS and GPS techniques

Prashant Persai and Sunil Kumar Katiyar
Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal – 462 003
Email: prashantpersai@gmail.com, skatiyar7@rediffmail.com

(Received on: Oct 30, 2014; in final form: Aug 06, 2015)

Abstract: In recent years, GIS (Geographic Information System) and GPS (Global Positioning System) technologies are being applied in various service industries like telecommunication. The GIS and GPS techniques in combination with high resolution images can be very helpful for better site selection in the city for telecommunication utility such as tower or mast. The aim was to analyze and perform various spatial and non spatial analyses techniques such as marking of radiation affected zone, coverage area calculation, slope of terrain, kernel density of tower and identification of alternate routes in case of fault at take place on digital intelligent map. The data were collected from Bhopal Municipal Corporation (BMC) for the preparation of digital intelligent map for telecomm utility.

It was ascertained from the results that GIS and GPS system is capable, competent and effective system for managing of assets, marking of radiation affected zones and its coverage area calculations for telecomm utility in the city. In this context conclusions and some useful recommendations have been suggested for planning and management of telecomm assets in the Bhopal city.

Keywords: Radiation affected zone, Coverage area calculation, Kernel density

1. Introduction

In today's era without telecommunication system we cannot even think of luxurious life. Many emergency services are fully dependent on this technology. In India most of the urban as well as rural population is using telecommunication mobile system and availing various services to get better response and intend to complete sustainable development cycle for the country. This service has taken prime place in nation's agenda. Telecommunication can be defined as signals over long distance such as by telegraph radio or television.

The tremendous growth of telecommunication industry has resulted in increase of the number of handset users. Mobile phone usage is changing our lifestyle as well as increasing the risks of many diseases which originate from the exposure of mobile phone radiations. Electromagnetic Fields radiation has raised concerns within several segments of the population in the past three decades. (Johnson et al., 2007). People are concerned about exposure from mobile handsets and base stations (Verma et al., 2012). To support the growing number of users, base stations or telecomm towers can be seen in almost everywhere. (Biebuma and Esekhaigbe, 2011). The simultaneous exposure to multiple frequency fields exceeds by several times than the prescribed guidelines (Sangeetha et al., 2014). Telecommunication masts or towers emit lot of radiation and that is confirmed by various scientific communities and experimenters. When a call is made, sound energy is converted into radio frequency (RF) waves i.e. electromagnetic energy. Billions of people are self exposed by base station antennas which are installed within residential and working areas. According to technical analysts, the base stations are the most energy intensive part of a typical cellular network. (Murthy and Kavitha, 2012). This is a serious environmental issue and government of India is planning to control the legal and illegal installation of towers at residential areas. In the recent years, microwave Base Stations (BTS) are deployed closer to houses and public buildings. The situation has become a reason for growing concerns to the general population. Scientists and researchers worldwide are indeed very concerned about the potential health risks associated with the increasing numbers of BTS installation. Small adverse effects on health could have major public health implications (Ismail et al., 2012). Counting of towers, marking of radiation affected zones; planning and managing of telecomm assets are very difficult. Indian penal court has given instruction for removal of telecomm towers from school, colleges and hospitals etc. to control the radiation effects on human bodies.

The Geographic Information System (GIS) with integration of Global Positioning System (GPS) has extensive potential to resolve various problems and calculate amount of radiation in affected areas. The GPS field surveys are versatile extension of traditional information and capable in providing accurate and efficient GIS data that is useful for planning and preservation of cumbersome data for future reference.

The GIS technologies have the capabilities to provide cost effective solutions in the maintenance, display, recording and analysis of the scenarios with association of different aspects. The GIS mapping for telecommunication tower helps to identify and locate the appropriate locations of sites geographically. GIS is an integrated system that performs manipulation and Analysis of spatial data. The GIS technology efficiently maintains databases of urban areas for use in the telecommunication industry (Franzet al., 1998).

Journal of Geomatics Vol 9 No. 2 October 2015

The various GIS based spatial and aspatial analysis techniques are beneficial and enhance the capabilities of planner and decision maker.

Research work is being carried out worldwide to address the issue of radiation form BTS using state of the art GIS technologies. Potential health effects of electromagnetic pollution are the subject of on-going researches and a significant amount of public debate. Telecommunication infrastructure has become the most extensive spatial structure in a region (Cai, 2002). Information management has become a very important topic in recent times and technological advancement depends more on the amount of information that is available in real time (Omogunloye et al., 2013). In recent years, GIS has developed rapidly, and it is applied in various industries. But the application of GIS in telecommunication information resources (such as BTS) management is far behind its application in other areas (Shu et al., 2011). This study was designed to ascertain awareness of consumers/users are against the reported health hazards from GSM technology (Biebuma and Esekhaigbe, 2011). A base station and its transmitting power are designed in such a way that mobile phone should be able to transmit and receive enough signal for proper communication up to a few kilometres. Majority of these towers are mounted near the residential and office buildings to provide good mobile phone coverage to the users. These cell towers transmit radiation 24x7, so people living within 10's of meters from the tower will receive 10,000 to 10,000,000 times stronger signal than required for mobile communication. In India, crores of people reside within these high radiation zones (Girish, 2010). Health hazard study therefore establishes that there are health implications of exposure to mast radiation and minimizing them will go a long way to improve healthy living (Akintonwa et al., 2008). There has been concern about possible health consequences from exposure to the RF fields produced by wireless technologies. The fact sheet reviews the scientific evidence on the health effects from continuous low-level human exposure to base stations and other local wireless networks (WHO, 2006).

A standard planner Kernel Density Estimation (KDE) aims to produce a smooth density surface of spatial point events over a 2-D geographic space (Xie and Yan, 2008). KDE is a useful way to consider exposure at any point within a spatial frame, irrespective of administrative boundaries. Utilization of an adaptive bandwidth may be particularly useful in comparing two similarly populated areas when studying health disparities or other issues comparing populations in public health (Heather et al., 2010). KDE techniques are widely used in various inference procedures such as signal processing, data mining and econometrics (Arsalane, 2014). Many human related point phenomena are distributed over a space that is usually not homogenous and that depend on a network-led configuration. KDE and K-functions are commonly used and allow analysis of first and second order properties of point phenomena (Giuseppe, 2005).

According to technical analysts, the BTS are the most energy intensive part of a typical cellular network. In this regard, present research proposes mapping of telecommunication assets mainly location of towers or mast, Unique Ids generation, attribute attachment in each tower segment, marking of radiation spot on map, density of towers in the city, marking of radiation affected zones etc..

2. Study area and data resources

The study area situated by the side of Malwa Plateau in the Northern –Eastern part of state, Bhopal is the capital city of Madhya Pradesh. The geographical location of AOI (Area of Interest) lying between 77.288 E to 77.552 E longitude and 23.122 N to 23.333 N Latitudes and is shown in Figure 1. There are total 592 towers installed by the telecomm operators at various locations in the city. The 250 prominent locations of multiple operators covering entire Bhopal city were considered to analyze the coverage of urban and sub urban areas. The statistics of telecommunication towers in Bhopal city are listed below in **Table 1**.

The GIS software utilized for this research is ArcGIS 10.1 that provides data visualization, Image Enhancement, Geometric Network Analysis, Spatial and non spatial query and analysis capabilities with powerful data creation and editing environment. The Magellan Promark3 GPS receiver was used for collection of latitude and longitude information for telecomm towers of entire study area. The Google Earth Images were utilized to extract various layers of area for creation of geometric network along with land base features for telecomm mapping. Location of tower, operator name, and owner name along with tower type and ward boundaries were also collected from Bhopal Municipal Corporation (BMC). Collected data from BMC were verified during field visit.

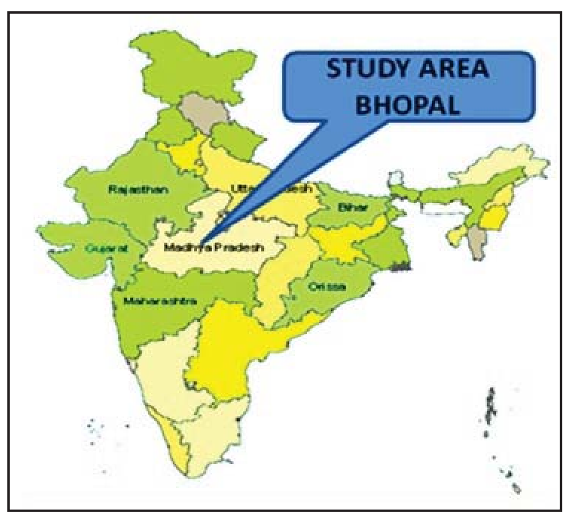

Figure 1: Study area

Table 1: Telecomm operator in Bhopal city

SINO	Name of Company	Total Number of Towers
1	Idea	62
2	Airtel	129
3	Reliance	82
4	Vodafone	66
5	YIOM (Tata /TT Info / Tata Dokomo/QUPO	138
6	B.S.N.L	77
7	I.T.I.L	3
8	Tower Vision	1
9	ETISALAT	1
10	G.T.L	2
11	A.T.C	3
12	ACME	9
13	Other's	19
Total Towers		592

3. Density of telecomm mast

Density of telecomm mast is also one of the prime concerns in an area. A simple density estimation method is to place a grid on a point distribution, tabulate points that fall within each cell, sum the point values, and estimate the cell's density by dividing the total point value by the cell size. Point density calculates magnitude per unit area from point features that fall within a neighborhood around each cell or grid.

Karnel estimation is a different density estimation method, which associates each point or observation with a kernel function (Silverman, 1986), that calculates a magnitude per unit area from point features using a kernel function to fit a smoothly tapered surface to each point. It is expressed as a bivariate probability density function, a kernel function looks like a "bump", centering at a point and tapering off to 0 over a defined bandwidth or window area. The kernel function and the bandwidth determine the shape of the bump, which in turn determines the amount of smoothing in estimation. The KE at point x is then the sum of bumps placed at the observations, xi, within the bandwidth:

$$\hat{f}(x) = \frac{1}{nh^d} \sum_{i=1}^{n} K\left\{\frac{1}{h}(x - x_i)\right\} \quad \text{-- (A)}$$

where K( ) is the kernel function, h is the bandwidth, n is the number of observations within the bandwidth and d is the data dimensionality. For two-dimensional data (d=2), the kernel function is usually given by

$$K(x) = 3\pi^{-1}(1 - X^T X)^2 \text{, if } X^T X < 1 \quad \text{-- (B)}$$

K(x) = 0, otherwise by substituting equation for K ( ), equation can be rewritten as

$$\hat{f}(x) = \frac{3}{nh^2\pi} \sum_{i=1}^{n} [1 - \frac{1}{h^2}\{(x - x_i)^2 + (y - y_i)^2\}]^2$$

where π is a constant, and (x –xi) and (y-yi) are the deviations in x-,y- coordinates between the point x and the observation xi within the bandwidth. Using the same input as for the simple estimation method the kernel estimation usually produces a smoother density surface than the simple estimation method (Chang, 2002).

4. Coverage area of telecomm mast

The initial establishment of a wireless system is very expensive and time consuming process. Due to this it is required to develop a mathematical model before establishment of such type of systems (Purnima and Singh, 2012). A cellular network is a radio network distributed over land areas called cells and served by fixed location as a cell site or base station. The cell and its coverage area depend mainly on natural factors such as geographical aspect and human factors such as urban, suburban and rural etc. As per RF theory the radio waves or signals directly depend on signal mechanisms such as reflection, diffraction and scattering.

There are various propagation models / path loss models available or planer can create their own propagation models for calculation of coverage area. The cell sizes or ranges determined by reflection, diffraction and scattering are as follows (Purnima and Singh, 2012):

- Large cells - cell radius is 1km and normally it exceeds 3 km
- Small cells -cell radius 1 - 3km
- Microcells of radius 200 – 300m

5. Methodology

In assessment phase, the requirements, solutions, goals, objectives and benefits for development of Mast Information System and Radiation Zoning were analyzed. It provides the baseline description and direction as shown in fig. 2. Base map and land use land cover map etc. were prepared using Google earth images, based on tone, texture, pattern and colours. Spatial Analyst tool was used to carry out coverage analysis, mast density analysis, radiation zoning area identification and calculation of radiation affected dwelling units etc. A Schematic representation of the methodology is shown in fig. 2.

5.1 GPS survey and ground truthing

The detailed GPS surveys were carried out to confirm ground realities and latitude - longitude information of towers. They were collected by using Magellan Promark3 GPS receiver. The subset of image has been extracted from Google Earth and stored separately. Print outs were taken along during field visit and verified the location and attributes on ground. The data were stored into GPS device and prepared delimited text files for further process into GIS software.

5.2 Geo-referencing of the satellite data

The spread out control points were used for geo-referencing of pieces of an Image and 69 points were considered to achieve high accuracy with small RMS errors. The UTM projection and WGS84 datum parameters were considered for geo-referencing of Google Earth images. The following steps were involved for georeferencing of the Google Earth images.

- Import control points
- Import Google images in ArcGIS environment
- Generation of single output image in Geotiff format

5.3 Thematic map generation, data acquisition and design of database

The Google Earth is an excellent source, to understand the complex scenarios easily for development of mast information system and zonation of radiation. It provides integrated information on several factors which directly or indirectly control the spatial relationship and are helpful in the mapping of telecomm tower utilities. The tower location, operator name, type of tower etc. were collected from BMC and finalized the layers for extraction of data from Google Earth. The various thematic maps like road networks, buildings and landmarks etc. were interpreted in separate layers from Google Earth based on texture, pattern and association. GIS database with corresponding feature types were also designed and mentioned below in Table 2, Table 3 and Table 4, respectively.

Table 2: Layers of GIS database, feature types and data type

SI .No.	Name of Layer	Feature Type
1	Tower Locations	Point
2	Ward Boundaries	Area
3	Roads	Line
4	Landmarks	Point
5	Buildings	Area
6	Georeferenced Google Images	Raster

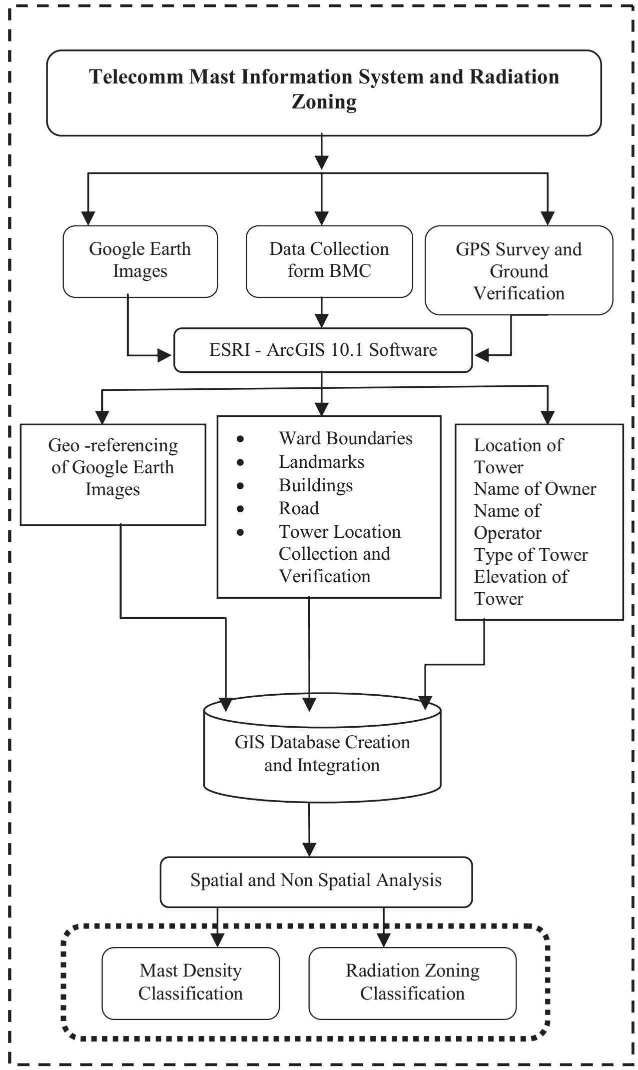

Figure 2: Schematic representation of the methodology

Table 3: Tower location attribute table

SI No.	Field	Data Type
1	Site Name	Text Data
2	Address	Text Data
3	Operator	Text Data
4	Type	Text Data
5	Elevation	Decimal Number
6	Ward Number	Whole Number
7	Height	Decimal Number
8	Easting (X)	Decimal Number
9	Northing (Y)	Decimal Number
10	Any other remarks	Text Data

Journal of Geomatics Vol 9 No. 2 October 2015

Table 4: Ward boundary attribute table

SI No.	Field	Data Type
1	Ward Name	Text Data
2	Ward Number	Text Data
3	Any other remarks	Text Data
4	Shape Length	Decimal Number

5.4 Creation of telecommunication tower location map

The extracted images covering of AOI with associated text files generated during field visit and shape files of roads and buildings etc. were imported into GIS environment for geo-referencing of images. Various layers like, important landmarks, tower location etc. were generated for creation of telecomm tower information system. Spatial data were generated using heads up digitization techniques. All necessary attribute data were attached with spatial data using unique ids fundamental concept. The developed data were found useful for analyzing the planning aspect of telecomm sector including various scenarios in the study area. Various tables were created for storing all the telecomm related information in database.

5.5 Telecomm tower density map

The grid networks were created using 300 meter interval and area features were created for generation of telecomm tower frequency map covering of AOI. Grid sections were converted into the area features and calculated the points fall in the grid area. All the attribute data attached in the respective grids and based on attribute data different colour coding has assigned and density map was created. The higher numeric count of towers in a particular grid indicating higher density and low count of tower in a grid that was indicated low density of an area.

Inbuilt kernel density function were utilized to calculate the density of point features around each output raster cell and calculate magnitude per unit area from point features using a kernel function to fit a smoothly tapered surface to each point.

5.6 Geometry validation and integration of GIS data

Cleaning and validation of geometry was involved the removal of dangles, undershoots, overshoots, duplicate objects etc. All linear, point and polygon features were confirmed to meet plannerity requirement, i.e., nodes created at intersection of linear features after validation of geometry. A seamless data covering an AOI was created and overlaid all the layers eventually.

5.7 Creation of geometric network

A geometric network is composed of edges that are connected and specify the edges as junction or intersection points. These edges can have weights that assigned to them and often used to generate the models for public utilities such as Telecomm etc. The topological errors such as dangle, overshoot and undershoot etc. were taken care and prepared error free data set for creation of geometric network and the feature tolerance limit has been fixed and processed data accordingly.

5.8 Telecomm tower information system

The telecomm tower locations were marked on the map and assigned unique ids while doing the survey. Attribution has done and stored into the database in separate table. Owner name, type name, operator name, height of the tower, locality etc. were attached in tower point layer.

5.9 Quality control and quality assurance schemes

Quality Control and Quality Assurance (QC / QA) were undertaken in every step of the workflow to maintain the quality standard and achieved the high accuracy of data. The measure of accuracy derived based on the permissible limits that fall under physical and logical accuracy.

The following steps were taken care while creation of final outputs, like:

- Verified features against symbology
- Verified edges of features in between adjacent maps
- Verified the valid attribute data entries
- Verified the updated feature were having the attribute data in correct division
- Verified attribute information against tables for attributes
- Verified uniqueness of ID numbers etc.

6 Results and discussions

The experiments described in this work, in particular, intended to overlay operation, spatial query, non spatial query, route identification, tower type and company identification, shortest route identification, radiation spot marking and density of mast, telecomm asset maintenance, coverage analysis and fault rectification or restoration within minimum response of time etc.

6.1 Overlay operation

The overlay operations were carried out to superimpose various layers like road, landmarks, towers location, buildings etc. Base map, telecomm utility map, coverage map, radiation hot spot zone, contour maps were prepared. The results of the overlay operation were displayed in ArcGIS software.

6.2 Spatial query

Spatial queries were generated to get information about the telecomm utilities like type of tower, name of owner, elevation height of the terrain, unique id of the tower, height of the tower etc. and queried for tower, where the height of the tower is greater than 40 meter and software selected 48 out of 250 towers highlighted in query window. The results were displayed in separate window. The residential address or location of tower was manually geocoded into the available digital map using GIS software and analyzed the point pattern of an area.

6.3 Coverage analysis

The discussions were held with telecomm companies' planner to understand the coverage of telecomm mast of an area. Companies suggested the things they considered important while planning of the telecomm mast of an area. They have to classify urban area into various sub classes like sub urban and urban etc. that is land use and land cover classification. For urban area they have to consider a tower can cover less than 300m and for sub urban distance would be greater than or between 500m in aerial circle.

Based on the classification, the buffer zones were created to understand the coverage pattern in the city. It was found that all the business hubs were well connected and having very good coverage. While collecting the latitude and longitude information of mast, a survey was also conducted wherein around 1000 people participated. Survey was carried out near slum areas and people complained of weak signals and call drops. The results were plotted in ArcGIS software shone in Figure 3.

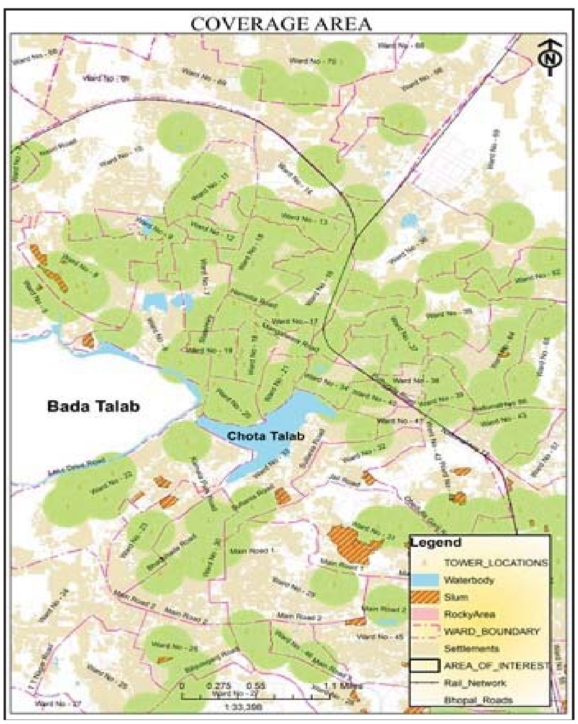

Figure 3: Coverage analysis

The highlighted circle in lemon color is good coverage area in the Bhopal city. The intersection of coverage area is called interference prone area which is shown in the Figure 4. As per telecomm theory interference prone area is somewhat good to poor coverage area. In interference prone area, strength of the signal depends on the RSL (received signal level) of the tower. It was confirmed from the field and people complained some time about poor signal and call drooping problems in interference prone area.

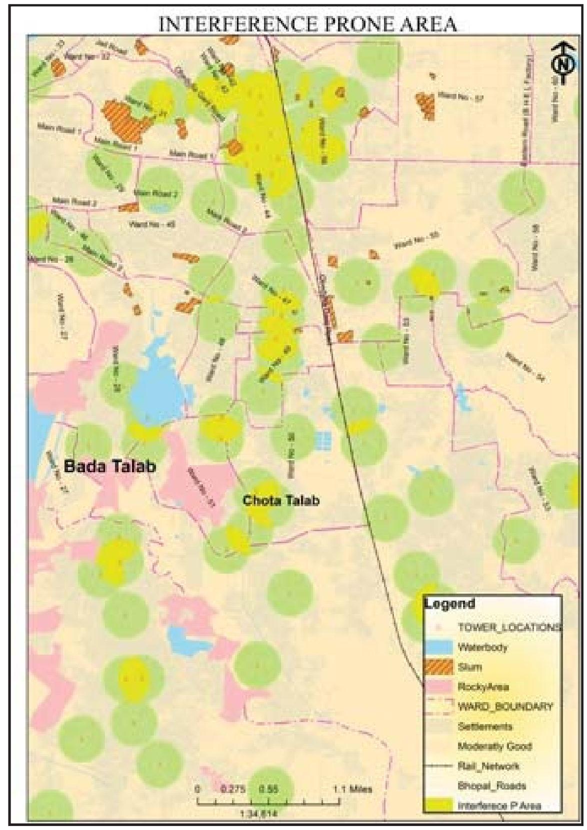

Figure 4: Interference prone area

6.4 Density analysis

It is a fact that, the density calculates a magnitude per unit area from point features that fall within a neighborhood around each cell. The cell defines unites of the selected neighborhood measurements in cell unites. The density map was generated using assigned cell size 8 meter and outcome was 6.39 cell sizes. The output was divided into five different ranges that are shown in the Figure 5. According to output we assigned the classes like; poor, moderate, average, good and very good density of towers in the Bhopal city.

Inbuilt kernel function was used to generate the raster output and displayed in the ArcGIS software that is shown in the Figure 6. As a result, Chowk Bazar, MP Nagar, Lal Ghati, Biraghar, New Market are the dense area having good coverage of signals.

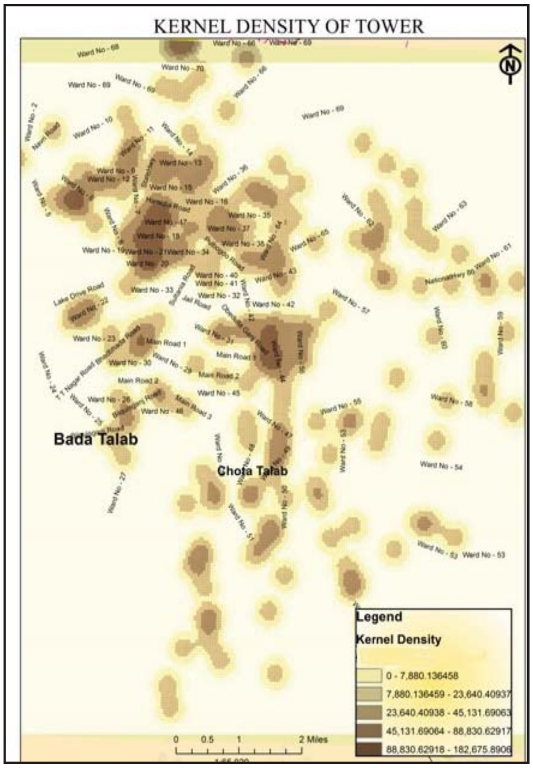

Figure 5: Kernel density

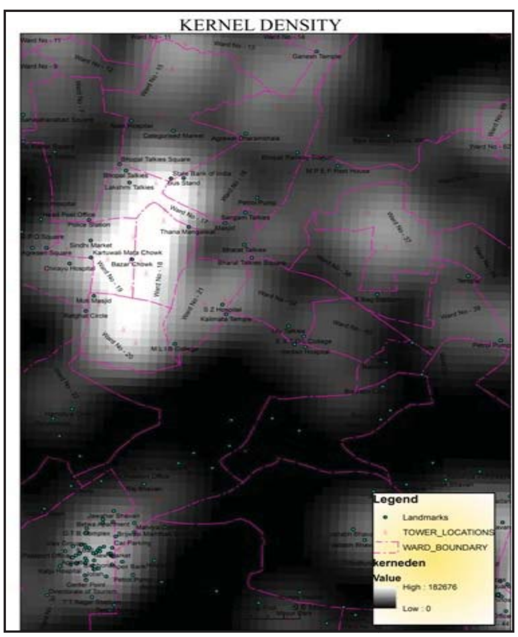

Figure 6: Kernel density

6.5 Radiation affected area calculation

Around 94518 buildings polygons were extracted from Google images using supervised classification technique for urban area. The same procedures were adopted for sub urban area and extracted 7678 polygons for comparison of urban and sub urban area for coverage's analysis. Training sample manger were used and categorized to generate polygons features for buildings and imported into GIS environment. Building layers were generated. Hundred meter buffer in surrounding of telecomm mast were created. The ArcGIS spatial analyst tools were utilized to calculate the affected building counts and results were displayed in GIS software. There were 30265 radiation affected buildings were found in surroundings of towers for urban area and 3025 for sub urban area. Multiple operators within proximity of 100 to 200 meter were found and extracted intersection areas on the map.

Intersected areas are highly affected and building counts were 17817 and 1201 respectively. Urban area and sub urban area settlements were analyzed and compared. The statistics of radiation affected areas are shown in Table 5, Figure 7, Figure 8, Figure 9, Figure 10 and Figure 11.

Table 5: Statistics of urban and sub-urban buildings

Total building	Radiation affected buildings	Radiation affected buildings (highly)	Gap
94518	30265	17817	46436
7678	3025	1201	3452

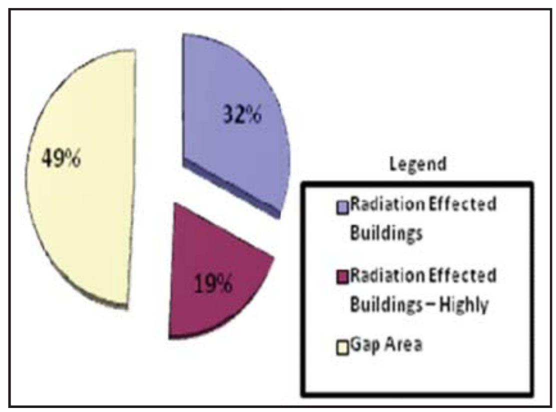

Figure 7: Statistics of radiation affected in urban area

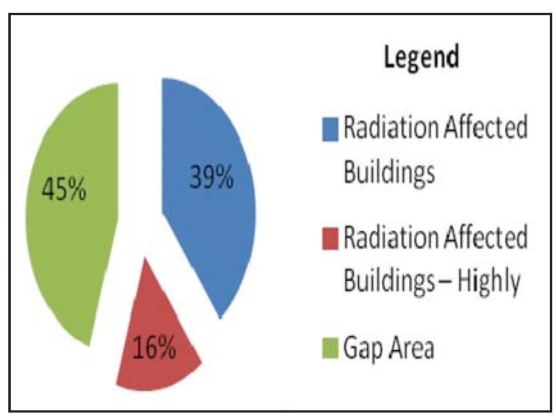

Figure 8: Statistics of radiation affected in sub urban area

Figure 9: Radiation affected zone

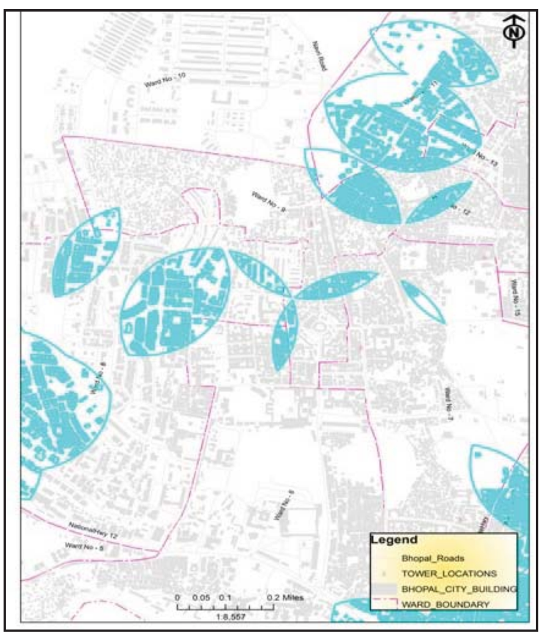

Figure 10: Intersection of radiation affected zone

6.6 Slope analysis

The SRTM data was used for generation of contour map covering of an AOI. The shape files of 10 meter interval for contour map were generated. The slope in percentages were categorized and maps were prepared to understand and identify the heighted sites in Bhopal city. The city is having undulated topography and contour values lie between 440 - 620 meter, as shown in figure 12.

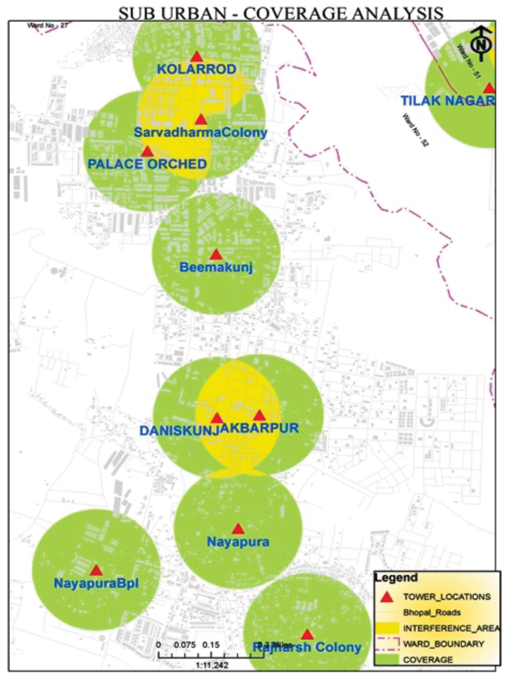

Figure 11: Sub urban coverage analysis

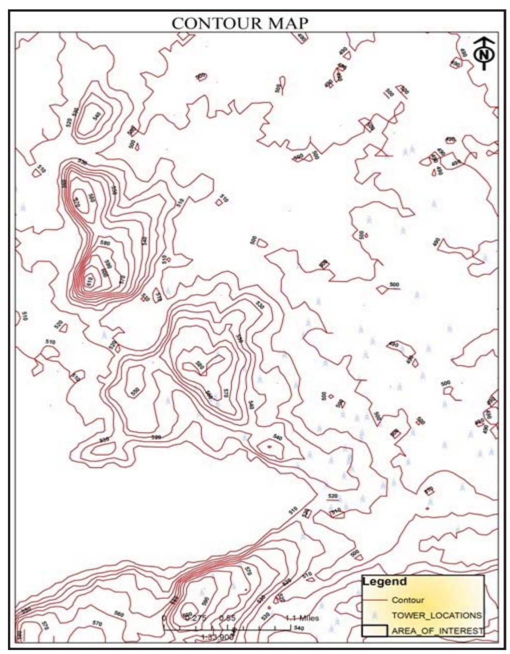

Figure 12: Contour map

6.7 Route identification and optimal path findings

The route identification and optimal path finding services are capable to overcome or restore the telecomm failure situations rapidly and effective reduction of the risk resulted from telecomm utility. The roads we categorized as one way and two way and used the network analyst tool from software to identify the best optimum routes in case faults take place. This is shown in figure 13. The speed field was added in database and on an average speed limit “40” kilometer per hour was assigned to all the roads. Any fault occurs at any place and repairmen or technician can identify optimal route based on different situations from its current position for restoration of failure sites within minimum response time easily. The various scenarios we created in the presence of technician and his supervisor in advance. They realized if fault takes place, one can easily verify the details of tower and connectivity from nearest base station for restoration of telecomm failure sites. Three stops on digital intelligent map, as point 1 (Vindiya Nagar), 2 (Jail Road) and 3 (Arera Hill) were marked respectively and calculated route distance, which was 0.8 mi, shown in the Figure 14.

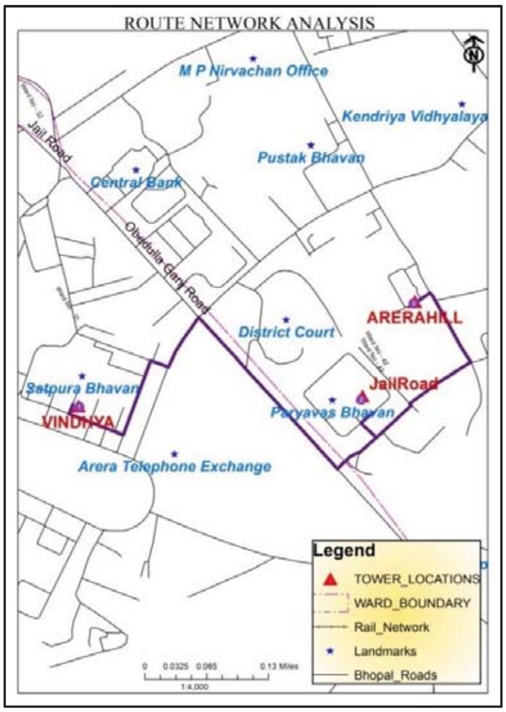

Figure 13: Route network analysis

Directions (Route 2)

[-]	Route: Graphic Pick 1 - Graphic Pick 3	0.8 mi	Map
1:	Start at Graphic Pick 1		Map
2:	Go south	< 0.1 mi	Map
3:	Turn left	< 0.1 mi	Map
4:	Turn left	< 0.1 mi	Map
5:	Turn right	< 0.1 mi	Map
6:	Turn left	< 0.1 mi	Map
7:	Turn right on Obedulla Ganj Road	0.2 mi	Map
8:	Turn left	< 0.1 mi	Map
9:	Turn left and immediately turn right	< 0.1 mi	Map
10:	Arrive at Graphic Pick 2, on the left		Map
11:	Depart Graphic Pick 2		
12:	Go back southwest	< 0.1 mi	Map
13:	Turn left and immediately turn left	< 0.1 mi	Map
14:	Turn left and immediately turn right	< 0.1 mi	Map
15:	Turn left	< 0.1 mi	Map
16:	Turn left	< 0.1 mi	Map
17:	Finish at Graphic Pick 3, on the right		Map
	Driving distance: 0.8 mi		

Figure 14: Route direction statistics

Output of values of slope data we further divided into three categories and found that only 17 % sites are located on the hilly reason.

7. Conclusion and recommendations

This paper has presented analysis on the use of available GIS technology for telecomm utility. Various data were incorporated to facilitate planning and management of telecomm assets in Bhopal city. The GIS technology has capability to calculate and project the radiation affected zones on the map geographically. In this paper calculation and intersections of coverage areas were discussed that is useful to identify radiation patterns and affected dwelling units in the city. In brief, all the coverage and radiation affected zones were marked on the digital intelligent map for telecomm utility management and planning of the sites for city.

It is recommended that, there is need for greater awareness of GIS technology for establishment of GIS system in the city spatially for telecommunication utilities. Various other modules for specific purpose can be developed to improve the quality of life of the common citizens. The modules should have capability to solve user's queries on selected areas and it should also have capability to generate reports, charts and graphs for various statistical analysis purposes. These all applications should be linked and published in cloud for decision makers.

References

Akintonwa, A., A.A. Busari., O. Awodele and O.S. Olayemi (2008). The hazards of non-ionizing radiation of telecommunication mast in an urban area of Lagos, Nigeria. African Journal of Biomedical Research 12, pp. 31-35.

Arsalane, C.G. (2014). Kernel estimator and bandwidth selection for density and its derivatives. The kedd package Version 1.0.1, pp. 1-22.

Biebuma, J.J. and E. Esekhaigbe (2011). Assessment of radiation hazards from mobile phones and GSM base stations. Journal of Innovative Research in Engineering and Science, Global research publishing 2(1), pp. 1-9.

Cai, G. (2002). A GIS approach to the spatial assessment of telecommunication infrastructure. Kluwer academic publishers, Networks and spatial economics (2), pp. 35–63

Chang, K.T. (2002). Introduction to Geographic Information Systems. 2nd ed. New Delhi: India, Tata McGrew-Hill, 2.

Franz, W.L., R. Ledner and W. Walcher (1998). Advances in built-up area 3D GIS data for telecommunication. Am. Soc. for Photogrammetry and Remote Sensing, pp. 1-12.

Girish, K. (2010). Report on cell tower radiation. Electrical Engineering Department, IIT Bombay, pp. 1-50.

Giuseppe, B. (2005). Network density estimation: analysis of point patterns over a network, Springer-Verlag Berlin Heidelberg, pp. 126 – 132.

Heather, A.C., X. Shi,. J. Sargent, S. Tanski and E.M. Berke (2010). Density estimation and adaptive bandwidths: A primer for public health practitioners, International Journal of Health Geographics 9(39), pp. 1-8.

Ismail, A.F., H.A. Mohd Ramli, N.I. Sidek and W. Hashim (2012). Development of radio frequency radiation (RFR) prediction tool. In Proc. 18th Asia Pacific Conference on Communication, pp. 204-207.

Johnson, A., Z. Chaczko and K. Aboura (2007). Radio frequency pollution mapping, computing and communications. University of Technology Sydney, pp. 1-6.

Murthy, C.R. and C. Kavitha (2012). A survey of green base stations in cellular networks. International Journal of Computer Networks and Wireless Communications, 2(2), pp. 232- 236.

Omogunloye O.G., A.J Qaadri, H.B. Omogunloye and O.E. Oladiboye (2013). Analysis of mast management distribution and telecommunication service using geospatial technique. Journal of Environmental Science, Toxicology and food Technology, 3(3), pp. 58-75.

Purnima, K.S and R.K. Singh (2012). Cell coverage area and link budget calculations in GSM system. International Journal of Modern Engineering Research 2(2), pp. 170-176.

Reyes, C. and B. Ramos (2010). Mitigation of radiation levels for base transceiver stations based on ITU-T recommendation K.70. World academy of science, engineering and technology 45, pp. 743-749.

Sangeetha, M., B.M. Purushothaman and S.S. Babu (2014). Estimating cellphone signal intensity and identifying radiation hotspot area for Tirunelveli taluk using RS and GIS. International Journal of Research in Engineering and Technology 3(2), pp. 412-418.

Shu, Z., L. Hong and L.Q.X. Guodong (2011). Application of GIS in telecommunication information resources management system. International Conference on Information Management, Innovation Management and Industrial Engineering, IEEE computer society, 401-404, 2011.

Silverman, B.W. (1986). Density estimation for statistics and data analysis. Published in Monographs on Statistics and Applied Probability, London: Chapman and Hall (online), file:///e|/moe/HTML/March02/Silverman/Silver.html

Verma, P., T. Singh and A. Kumar (2012). Electromagnetic radiation exposure: A survey report. International Journal of Applied Engineering Research, Research India publications 7(11), pp. 1-3.

Wilson, O., K. Robert., M. Joseph and O. Chrispine (2011). Monitoring of radiofrequency radiation from selected mobile telephones in Kenya. Baraton Interdisciplinary Research Journal 1(1), pp. 5-13.

World Health Organization (2006). Electromagnetic fields and public health (online). http://www.who.int/mediacentre/factsheets/fs304/en/print.html, (Available March 2007)

Xie, Z. and J. Yan (2008). Kernel density estimation of traffic accidents in a network space, computers, environment and urban systems. Elsevier Ltd 32, pp. 396–406.