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USING GEOGRAPHICAL INFORMATION SYSTEMS IN EPIDEMIOLOGY: MAPPING & ANALYZING OCCURRENCE OF DIARRHEA IN URBAN – RESIDENTIAL AREA OF ISLAMABAD, PAKISTAN

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Using Geographical Information Systems in Epidemiology: Mapping & Analyzing Occurrence of Diarrhea in Urban – Residential Area of Islamabad, Pakistan

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Master Degree Project (2017), 30 credits in Geographic Information Sciences

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Glory is to Almighty Allah, the creator for uncountable favors and for this success. I am grateful not just to Allah ﷲ (the merciful God) but to those who matter most in my life, starting from Prophet Muhammad صلى الله عليه وسلم, the greatest role model for the humanity.

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The Muslim holy book the Quran says in Surah[5] Verse[32] "if anyone saves a life, it shall be as though he had saved the lives of all mankind". Research using Geographic Information System would reap best of its utilization in epidemic study which is a motivation behind.

Abstract

Islamabad, the capital of Pakistan is attracting families due to safety, lush green scenery and good infrastructure. Almost 2 million people are living in this city, and significant number of workforce commute from neighboring areas and other parts of the country. The city is facing restraint on natural resources due to increased urban migration coupled with rapid population growth. As a result, the infrastructure facilities and living conditions are deteriorating. Approximately 43 % shortage in water supply was reported by Capital Development Authority (CDA) in year 2015, the problems associated with drinking water availability and quality is rising along with other challenges including poor hygiene conditions and low income areas. A significant portion of population living in Islamabad is vulnerable to diarrhea epidemic, which has become a major public health problem.

This research is limited to several residential sectors of Islamabad (city) to understand diarrhea epidemiology through the mapping of residents with diarrhea incidence, then global and focused test were conducted for cluster detection based on covariate factors illustrated using Geographic Information System (GIS).

Diarrhea patient' s data from a main public sector hospital was available for a complete year (2013). Other relevant data on district boundary, residential sectors, Streets and Highways, Water Filtration Plants (WFP), Water Drainage Streams (WDS), Slums and Non-slum was received and prepared according to research requirements. During data preparation, all the data were digitized using point shapefiles, polyline shapefiles and polygon shapefiles.

Hypothesis testing was conducted using global test (Average Nearest Neighbor) on diarrhea patients, the results indicated the spread of diarrhea had strong evidence of pattern. The study further explored, whether the disease spread is random or has some covariate factors influencing the spread. Henceforth, focused test was conducted using the location of WFP, WDS, Slums and Non-Slum to understand the role of those factors for the spatial dispersion of the disease using Average Nearest Neighbor. Diarrhea Incidence Rate (DIR) for each factor was found for summer and winter season to understand the effect of season/ temperature. In addition to that, KD maps were used for the detection of diarrhea hotspots visually. Finally, hotspot maps were produced for summer and winter using Getis-Ord GI* statistics method using DIR to show vulnerable areas in Islamabad with diarrhea Hotspots & Coldspots.

GIS methods and tools were used in this study to explore spatial patterns of diarrhea based on factors identified. The results clearly demonstrated that the increase in distance of a household from WDS decreases diarrhea risk in summer and winter; the increase in distance of a household from WFP increases diarrhea risk in summer but the same is not observed for winter; increased diarrhea risk is observed in Slum during summer and winter, and increased diarrhea risk is observed during summer but the same is not observed for winter in Non-Slum.

The derived information can be used for the containment of diarrhea epidemic in Islamabad using proper planning based on observed phenomenon. Similarly, GIS methodology adopted in this research can be further used in researches for other diseases spread through water contamination.

Table of Contents

List of Figures

List of Tables

List of Appendices

List of Abbreviations

ANN	-	Average Nearest Neighbor
CDA	–	Capital Development Authority
DIR	–	Diarrhea Incidence Rate
ESRI	-	Environmental System Research Institute, Redlands, CA, USA
GIS	-	Geographical Information System
JNB	-	Jenks Natural Breaks
KD	-	Kernel Density
MDG	-	Millennium Development Goals
MGD	-	Million Gallons per Day
MRB	-	Multiple Ring Buffer
NNR	-	Nearest Neighbor Ratio
PCRWR	-	Pakistan Council of Research in Water Resources
PIMS	-	Pakistan Institute of Medical Sciences
PTCL	-	Pakistan Telecommunication Corporation Limited, G-8/4, Islamabad
UN	-	United Nations
WDS	-	Water Drainage Streams
WFP	-	Water Filtration Plants

Keywords

Cluster, Diarrhea, Disease, Geographic Information System, GIS, Hotspots, Islamabad, Mapping, Pakistan.

1. Introduction

This research is an assessment on the occurrence of diarrhea using Geographic Information System (GIS) and covers Islamabad’ s developed residential sectors. The goal of this research is to use GIS for devising a supporting mechanism for the understanding and prevention of diarrhea spread, through identification of potential covariate factors responsible for spatial dispersion of disease so that all the stakeholders could be provided awareness about the severity and vulnerability of diarrhea in Islamabad.

On a macro level, this research will support to achieve Millennium Development Goals (MDG) for Pakistan by identifying the improvements required for public health, water facilities and for reducing Diarrhea Incidence Rate (DIR) through preventive measures. The methodology used in this research can be adopted for similar studies in other cities of developing countries and for other diseases spread through contaminated water.

The importance of an improved understanding of factors associated with enteric diseases such as diarrhea has been widely recognized and has particular relevance in spatial epidemiology (Török et al. 1997; Kelly-Hope et al. 2008). Epidemiology is the study of health and disease in human populations, because populations are inextricably bound to place, it is reasonable to expect GIS to advance epidemiology as science (Jacquez 2000). Research in this direction for less developed regions is strongly supported where the burden from enteric diseases is still very high (Fewtrell et al. 2005).

1.1 Background

Property of spatial dependence was employed to formulate vulnerability of diarrhea in Islamabad for investigating the spread of diarrhea disease and causation of spatial patterns of disease by analyzing the relationship of diarrhea with natural and social environment. "Everything is related to everything else but near things are more related than distant things" (Miller 2004, p.284), gives the generalization that diarrhea cases emerging from a place due to causative factors are more likely to be similar in nearby places.

Many published reports of studies found excess urban diarrhea cases to occur in areas having lack of access to potable water, low income areas and poor hygiene conditions (Masendu et al. 2000; Baragatti et al. 2009; Ajjampur et al. 2007; Biritwum et al. 2004; Lawoyin et al. 1999).

1.1.1 Diarrhea

Diarrhea is defined as at least three or more liquid stools in past 24 hours (Wu et al. 2011). Vibrio cholera, Escherichia coli, Giardia lamblia, and Salmonella typhi are typical infectious microorganisms causing diarrhea (Njemanze et al. 1999), it includes viruses, bacteria, protozoa and helminths that are transmitted from fecal-oral transmission (Keusch et al. 2006).

Diarrhea remains among top five leading causes of preventable deaths in developing countries (Baltazar et al. 2002). Four percent of the global disease burden is carried by diarrhea, and around 88% of all diarrhea incidents are due to poor hygiene (sanitation) and unsafe water (Prüss-Üstün and Corvalán 2006;

Corcoran et al. 2010). Other leading diseases in low income group are stroke, low respiratory infections, HIV/aids, ischaemic heart disease, etc (WHO 2016).

Nearly half of the population in developing countries have infections or diseases associated with inadequate water supply and sanitation (Bartram et al. 2005). Diarrhea is usually caused by drinking water that had been contaminated with human and animal feces (Boadi and Kuitunen 2005). Ninety to ninety five percent of all the domestic sewage and 75 percent of industrial waste on average is discharge into surface waters without proper treatment in developing countries (Carty 1991; Hinrichsen and Tacio 2011). The hygienic disposal of human excreta plays important role in controlling diarrhea (Esrey et al. 1985; Dev et al. 2014).

Due to poor sanitary facilities in unplanned societies (slums), most of the household dumps their sewage underground or on the surface which mostly comes into contact with underground clean water streams through leaching and erosion (Olugbemiro and Odita 1998), and people get infected with water related disease (Diarrhea). Slums lack the basic municipal facilities such as safe water supply, sanitation and waste collection (Rehman et al. 2014), and often discharge sewage with storm water and open drains that flows untreated into local waterways (Corcoran et al. 2010), this lack of access to facilities create health hazards in poor neighborhoods (Boadi 2004). Each family lives in a very small quarter comprised on mostly a single room made of brick-mud-plaster and sharing common lavatory, disposing urine and feces in some nearby surface with many other families in slum (Corcoran et al. 2010); without the provision of piped water and hand washing facilities lacking sanitation and safe disposal of feces. Fecal contamination is more prevalent in poor urban areas having insufficient water availability and sanitation due to overcrowded conditions. It was found that children belonging to poor socioeconomic status had high diarrhea incidence then children living in better socioeconomic group (Gupta et al. 1998). Attention and improvement in slums and informal settlements on the issue of sanitation and water availability is suggested (Kumar et al. 2011).

In Pakistan, 82% of the population (approximately 16% of global population) is without safe drinking water access, 30-40% of the hospitalized patients are due to water borne diseases and 80% of infant deaths are due to un-safe water that cause diarrhea (Ali et al. 2012). The cost associated with diarrhea alone is estimated in rage of USD 0.5 million to USD 0.75 million per year according to Pakistan Economic Survey 2010-11 (MOF 2011).

Access to safe drinking water has become a major health challenge for Pakistan (Ahmed et al. 2014), due to constant decrease in water availability, ill water management and increase in population. Pakistan ranks at 80 among 122 nations regarding drinking water quality (Azizullah et al. 2010).

Islamabad being the capital of Pakistan is expected to have better living standards, its sources of drinking water is ground water from tube-wells, and surface water is taken from Simly dam and Khanpur dam reservoirs fed by rivers (Hisam et al. 2014). In a study conducted in Islamabad, the consumption of tap water was associated with high incidence of water related diseases, even boiled and filtered water was not clean from those diseases (Riaz et al. 2010), little attention is being paid to drinking water quality, monitoring and surveillance in Pakistan (Aziz 2005).

Urbanization, population growth and migration all affect availability and quality of water resources (Hinrichsen and Tacio 2011). In last few decades, urban population of developing countries increased from 27% to 40%. Pakistan is a developing country in northwest part of South Asia Subcontinent, it' s the sixth most populous country in the world with number of inhabitants (PRB 2016). It was estimated that in year 2015 in Pakistan, 39% of the population would be living in urban area, this figure will rise to 46.6% in year 2030 and 57.5% in 2050 (UN 2015). According to a population estimate for 2015, Pakistan' s population would be 188,925,000 (UN 2015). Overcrowding creates sanitation problems and lack of access to clean drinking water and urbanization is linked with human health problems due to various health stressors (Vlahov et al. 2007). The rapid increase of population in slums also creating anthropogenic changes and more likely to affect human health (Aguirre et al. 2002).

Environment plays more important role in the spread of diarrhea (Fobil et al. 2012), current water management policies neglect to link water quality to human health, the environment and the quality of life (Hinrichsen and Tacio 2011). In the Dahlgren – Whitehead (1991) model (Figure 1), the reason for the spread of disease may include socioeconomic, cultural and environmental conditions, social networks, community networks and individual lifestyle factors. The model tries to establish relationship between individuals, their environment and disease. The model provides basic framework which can be useful for GIS to study factors responsible in world-wide emergence of diseases.

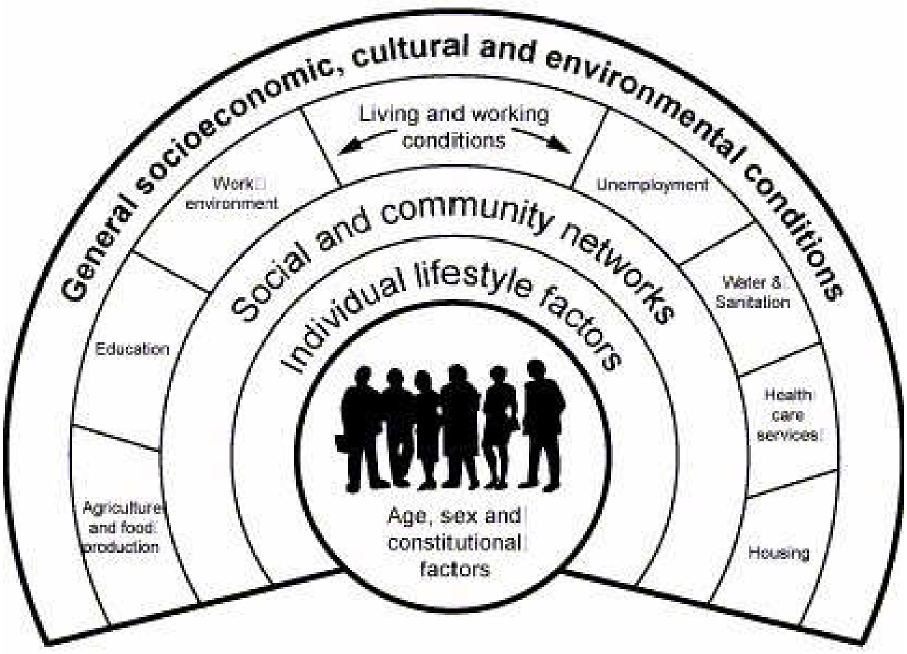

Figure 1: Dahlgren - Whitehead Model (1991)

Cholera is acute attack of diarrhea caused by vibrio cholera and both diarrhea and cholera belong to group of diseases know as 'infectious diseases' . Review of cholera outbreaks worldwide during 1995-2005 presented twelve most common risk factors identified from 306 reports including rainfall, water source contamination, sanitation, lack of potable water, refugee camp, conflict zone, travelers, dense population, seasonal, funeral/ feast, food and prison (Griffth et al. 2006). Most prevalent risk factors identified for South Asia (including Pakistan) are rainfall, water contamination, sanitation, lack of potable water, refugee and funeral/ feast. Other known risk factors for cholera epidemic were found as lack of development, poverty, high population density, low education, and lack of previous exposure (Borroto and Martinez-Piedra 1999).

Diarrhea no longer poses threat to countries having appropriate standards of hygiene, but it remains a challenge for Pakistan and other developing countries (India - being the neighboring country with similar conditions) where access to safe drinking water and adequate sanitation facilities are often limited (Dev et al. 2014).

In a study conducted by Pakistan Council of Research in Water Resources (PCRWR) during 2005-06 under National Water Quality Programme, 357 water samples from 364 selected water sources in 23 major cities of Pakistan revealed that 45 (13%) water sources were found safe and the remaining 312 (87%) were un-safe (chemical or microbiological contamination) for drinking purposes (PCRWR 2008). In the same research, twenty seven (27) locations were selected for sample collection within Islamabad city, seven (25%) water sources were found safe while twenty (75%) were un-safe.

Previously, research by PCRWR during 2004 had nine (35%) safe against seventeen (65%) un-safe water sources revealed from Islamabad. The researches demonstrate dire need to improve efforts for the provision of safe drinking water in Islamabad and its monitoring for sustainability of efforts.

Poor hygiene resulting from lack of adequate water is a key factor for the transmission of infectious diarrhea (PCRWR 2008). National Report of June 2012 by United Nations Children's Fund Islamabad reported that about 2 million tons of human excreta produced in urban sector, of which 50% go into water bodies and pollute them and cause human deaths, several epidemics of Pakistan in recent years are solely due to water contamination. The report further exhibit that 1.8% of GDP is lost due to death and illness resulting from waterborne diseases caused by poor water supply, poor sanitation and poor hygiene in Pakistan (UNICEF 2012).

The problem does not end here, drinking water lines and open sewage drains are often laid very near to each other. Most of the sewers sections are linked without proper safety seals, the leakage from sewer mixes with water table and contamination is carried to deeper level sand and causes contamination in groundwater, the problem further enhances due to lack of decontamination facilities in all cities (PCRWR 2008).

1.1.2 Geographic Information System (GIS) in Epidemiology

GIS is defined as a computerized system that facilitates the phases of data entry, data analysis and data presentation especially in cases we are dealing with georeferenced data (Rolf 2001). Since, health is a geographical phenomenon and many factors involved in health diagnostic and planning are based on geography, this has led to the greater use of GIS for the analysis of maps and variation in public health (Kandwal et al. 2009), it is an ideal tool for monitoring waterborne disease interventions over time and management of epidemics (WHO 2011).

Advancement in geographic and mapping technologies have created new opportunities for public health administrators in planning, analysis, monitoring and management of health systems (Johnson and Johnson 2001). GIS can link health statistics with the surrounding environment of patients using georeferenced epidemiological data and their existing infrastructure using overlay techniques, database and interactive queries. This combination makes GIS a powerful tool for monitoring and management of epidemics for public health purposes.

Mapping with GIS can make a substantial contribution to the assessment of environmental health risks (Briggs 1996); disease mapping is an important tool useful for disease detection, disease prevention, and other public health intervention strategies (Cliff and Haggett 1988).

Health is largely determined by spatial factors, it always has an important spatial dimension (Kandwal et al. 2009). Disease maps provide a rapid visual summary of complex geographic information and may identify subtle patterns in the data that are missed in tabular presentations (Elliott and Wartenberg 2004). Landscape structure, configuration, and composition is also important for the understanding on patterns, drivers, and causes of diseases in societies (Foster and Gilligan 2007). Maps of disease occurrences have been used for at least a century to identify potential spatial pattern in health outcomes and generate hypothesis about etiologic risk factors (Gilbert 1958). John Snow in 1854 investigated cholera epidemic (Figure 2) by plotting location of deaths using maps, it was found that near the intersection of Cambridge and Broad Street in Solo, London more than 500 deaths were reported within 10 days. John Snow had a theory that water contaminated by the sewage was the reason of cholera and eventually used maps to prove the theory, since then mapping has become important tool to resolve problems associated with the spread of disease within localities and regions (Colledge et al. 1996).

Figure 2: A Reproduction of Jhon Snow's Map of Solo, Mapping the Cholera Epidemic of 1854
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Subsequently, interest has increased over the last decade in study of potential association between human health and environmental quality (Boadi. 2004). Spatial analysis techniques using existing health data have been useful for the identification of problem areas based on the findings of spatial pattern of diseases in relation to covariate factors (Chaikaew et al. 2009). In recent years GIS is facilitating developed countries for identification of geographic areas that triggers epidemics, many studies paved the way to prevent and control such of events in future (Naves et al. 2013; Chaikaew et al. 2009; Venkateswaran et al. 2011). During the summer of 1997, diarrhea epidemic was reported with majority of children being affected at Fort Bragg, North Carolina. GIS was applied to investigate the problem using home addresses in addition to demographic data. A single housing area was identified to curve the outbreak (McKee et al. 2000).

Developing countries are facing problems due non-availability of information and resource constraints to deal with health surveillance (Kandwal et al. 2009). Continuing surveillance and longitudinal studies may allow tracking of current levels and trends in diarrhea incidence and provide the basis for future projections for evaluations of different control strategies (Keusch et al. 2006). A period of January to December 1996 was examined in another study for the prevention of diarrhea disease in Nigeria. GIS technology was used to evaluate health impact of water source using several covariate factors (Philip et al. 1999).

GIS can provide an opportunity to specify the health burden from diarrhea within infected areas and also facilitates to analyze correlated factors responsible for the increased disease risk using existing health data and spatial analysis (Chaikaew et al. 2009), it can facilitate to understand the spatial variation in incidence of disease and its co-variation with environmental factors with health care (Kandwal et al. 2009). Water related disease patterns always correlated with socio-demographic factors (age, education, income etc), environmental and sanitation factors (poor access to good water source and poor sanitation), climate factors (rainfall, temperature and humidity) (Pande et al. 2008). It would be helpful to investigate water related diseases using GIS to specify the health burden from a specific disease in a geographic area so that public health officials may take informed decisions for the prevention.

1.2 Study Objective

The overall aim of this study as mentioned earlier is to understand and analyze epidemiology of diarrhea geographically (medical geography) in urban areas comprised on completely developed sectors of Islamabad city using GIS to demonstrate the technique used in this research for validation.

Since diarrhea is an instrument of disease, mortality, poverty and hunger, the prevention and control on this disease using methods adopted in this research will facilitate in achieving the micro and macro objectives of Pakistan's 2012-13 MDG in broader prospective. Specific objectives of the study include:

- To explore whether diarrhea incidence are clustered, randomly distributed or dispersed, and its tendency to aggregate in space or in time?

  Null Hypothesis (H_0): Diarrhea reflect distribution of disease with equal risk in all study area without clustering.
- To explore DIR near Water Drainage Stream's (WDS) proximity, Water Filtration Plant's (WFP) proximity, and in Slum & Non-Slum?
- To study whether spatial dispersion of diarrhea is associated with the proximity to other covariate factors?

  Alternate Hypothesis (H_1)?
- To explore hotspot analysis for diarrhea incidence during summer and winter.

The purpose of this assessment is to provide an overview of spatial dispersion of diarrhea in Islamabad city during winter and summer season, and to create understanding about the distribution of disease in relation to covariate factors. This research will be a beacon for the residents, medical practitioners, researchers, scientists, planners and city administration for revealing geographic trends and understanding of diarrhea within urban settlement.

1.3 Study Area

Islamabad lies between 33°49′ N latitude and 72°48′ E longitude having total area of 906.50 Km^2, including urban area of 220.15 Km^2, rural area of 466.20 Km^2 and Islamabad Park having exactly the same as urban area of 220.15 Km^2. Its altitude ranging from 457 to 610 meter above the sea level (CDA 2016).

It′ s surrounded by Margala hills north of the city (Figure 3 & 4) and old imperial city of Rawalpindi at south. Murree and Kotli Sattian hill range starts from eastern side of the city. Hills (Margala) reaches 1600 meter on highest point and falls sharply due to steep slopes (Jabeen et al. 2009).

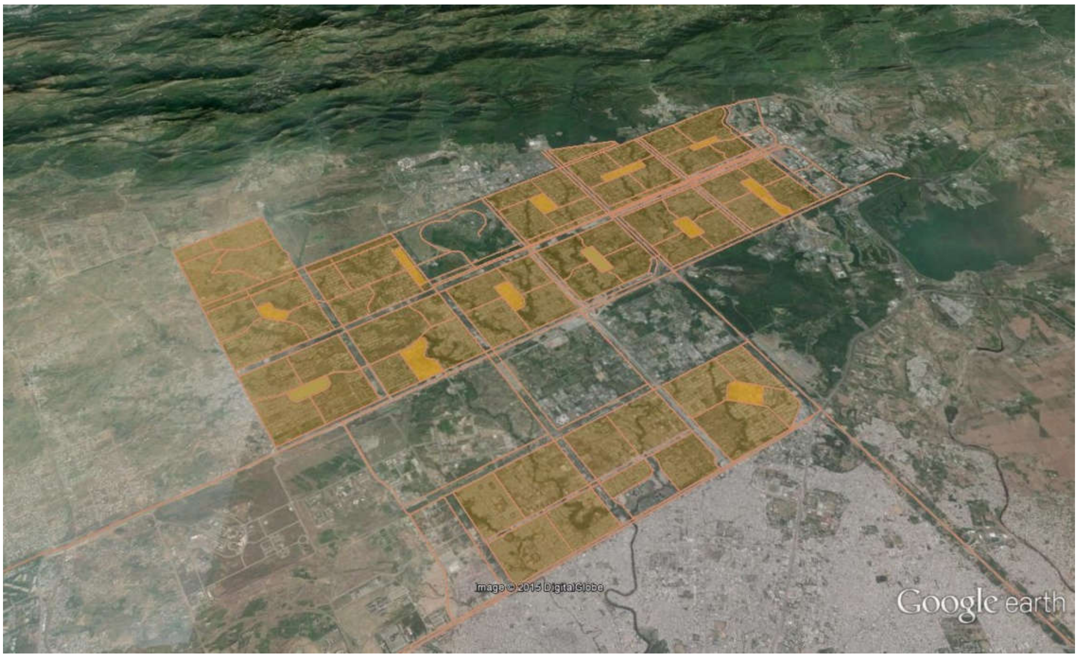


Figure 3: Islamabad's Topography

Most of the area in western and southern side of the city is undulating and on various places, land is dissected due to drainage streams (Figure 4). WDS "Lah

Nala" emerges from Margala hills and passes through many developed sectors of Islamabad city (open water ways) before entering into Rawalpindi city situated on southern side.

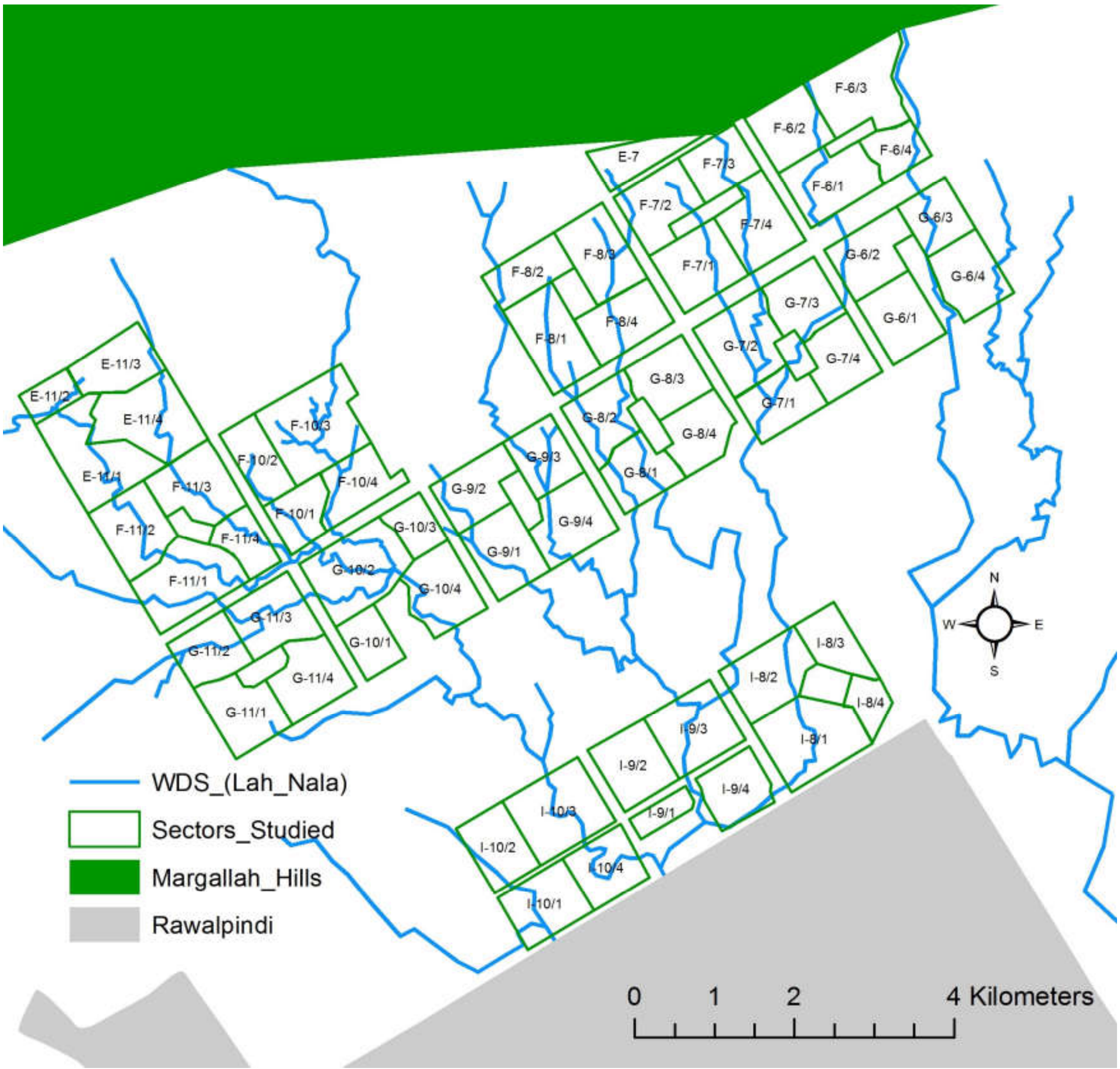


Figure 4: WDS

Islamabad has an overall extreme weather of hot summer with monsoon rain in July and August (Jabeen et al. 2009; Maqsood 1991). Hottest months are May and June having temperature reaching 42°C and the coldest months are December and January having temperatures fall below zero (Hussain 1990). The cold winter comes with occasional snowfall over the hills and sleet in and around the city (Butt et al. 2012).

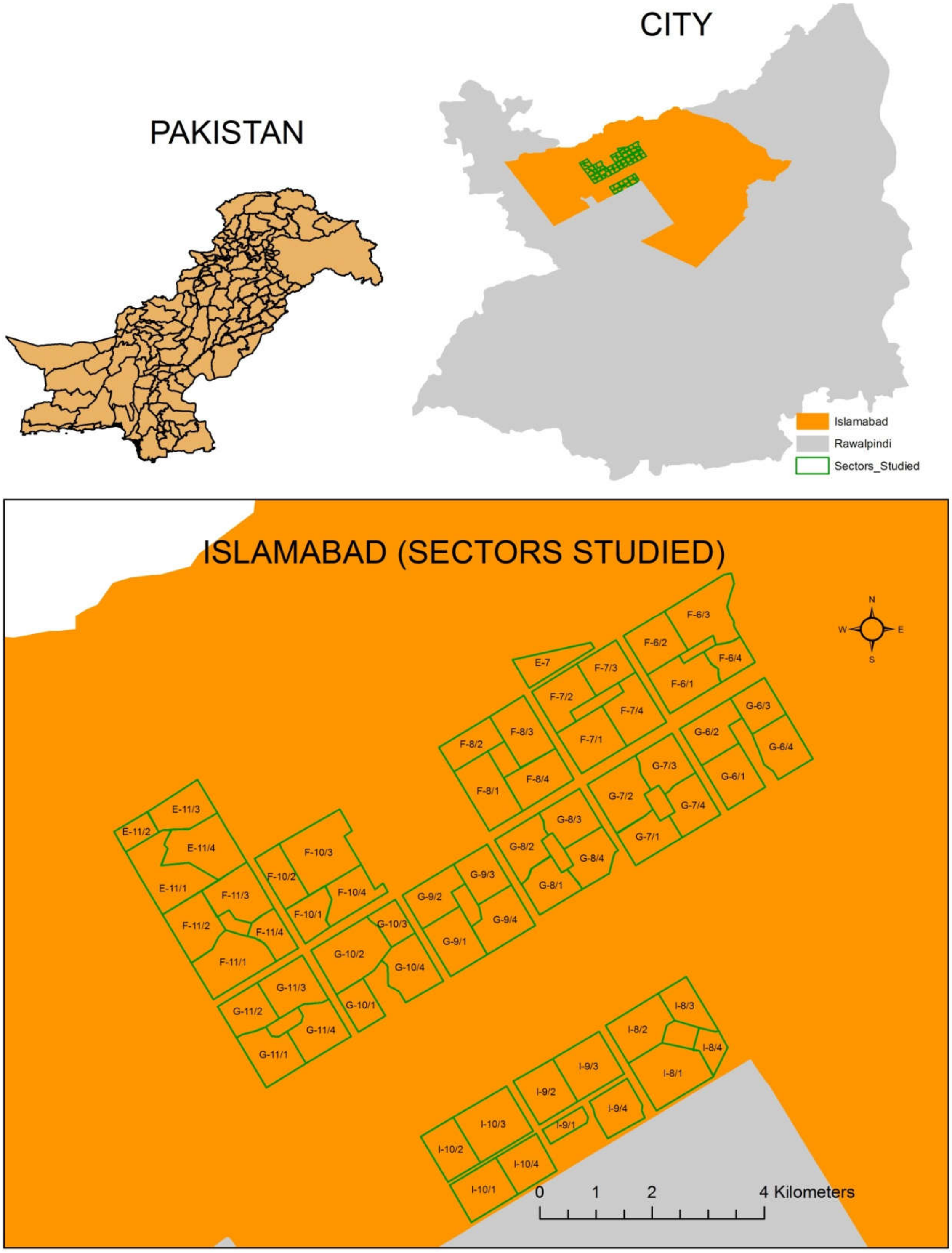


Figure 5: Islamabad's Location

The city is newly planned into several sectors from A to I (Figure 5), the extent of developed sectors is yet between 33°44′ N to 33°38′ N latitude and 73°05′ E to 72°57′ E longitude, each sector is further subdivided into four sub-sectors, average area of each sub-sector is approximately 0.67 Km^2.

This study focused on residential sectors (E-7, E-11, F-6, F-7, F-8, F-10, F-11, G-6, G-7, G-8, G-9, G-10, G-11, I-8, I-9 and I-10) in Islamabad city. Sector F-9 is dedicated park area, sector H-8, H-9 and H-10 have several institutes, universities, government departments, etc.

Figure 6: Sectors Studied

Sector E-8 and E-9 are under the control of armed forces. Sector F-5, G-4 and G-5 are comprised on government ministries and offices. Therefore, all those sector are not included in this research.

The total study area (Figure 6) examined during this research was comprised on approximately, 45 Km^2 of residential sectors and 0.88 Km^2 Slum dwelling within several residential sectors of Islamabad.

Population distribution datasets constitute an essential denominator required for many infectious disease studies in combination with number of clinical cases to model spatial progression on an epidemic and risk mapping (Tatem et al. 2012). Identifying the most exposed or affected populations becomes a key aspect of planning and targeting interventions (Tatem et al. 2012).

Last national census was conducted in 1998 for Pakistan (United Nations Statistics Division 2015). Islamabad' s population in 1981 was 340,286 and in 1998 was 805,235, the average population growth rate from 1981 to 1998 was 5.19% (PBS 2015). Keeping the same average population growth rate due to absence of actual figures, Islamabad must be having approximately 1.9 million persons living in the city in year 2015. Population density of Islamabad was 888.8 per square Km in 1998 (Non-Slum), now it has grown to approximately 2,100 per square Km based on the population estimates of 2015 and creating administrative challenges for Capital Development Authority (CDA) due to water scarcity, sanitation problems, waste dumping problems, etc. The population density used in this research for slum area is calculated as 145,741 persons living in km^2 (estimated from Appendix 2). Therefore, two population densities are being used in this research. Population of approximately 92,032 is covering the Non-Slum study area and population of approximately 128,543 is covering Slum study area (Table 5).

In last few decades, rapid growth of Islamabad city and its ever increasing anthropogenic changes put restraint on natural resources and deteriorated environment. Change in Land Use Land Cover (LULC) is visible as the urban development grew at the cost of vegetation (Butt et al. 2012). As a result of unprecedented increase in population, water supplying capacity of natural reservoirs has already gone beyond their planned limits, the availability of ground or surface water is decreasing and improper waste disposal is further polluting available water.

Surface sources of drinking water for Islamabad city are Khanpur Dam and Simly Dam (Qaiser et al. 2014), groundwater is also supplied to tabs through tube wells for the residents of the city (CDA 2016). The surface water is not considered reliable source due to high probability of being affected by seasonal fluctuations and contamination through anthropogenic changes (Lee and Jones-Lee 1999). Whereas groundwater is better quality, readily available and protected from direct contamination by surface anthropogenic changes (Morris and Lawrence 2003). CDA installed WFP in vicinity of Islamabad for its residents to have access to safe drinking water and each WFP is connected to ground water bore hole. A study revealed that bacteriological water quality of tube wells was satisfactory with only few exceptions in Islamabad (Kanwal et al. 2004). On the other hand all the dams were found to supply contaminated water having coliform (PCRWR 2008).

Keeping in view the estimated current population of the study area, effects of WFP must be studied in relation to diarrhea epidemics. Unsafe water is a very important public health issue in different sectors of Islamabad which are for the time being not documented and not noticed so far (Hisam et al. 2014). Proper chlorination and maintenance of residual chlorine through network is not maintained in water treatment plants supplying tab water in Islamabad (Qaiser et al. 2014). Due to lack of proper chlorination and increase in sewage contamination in drinking water, the water supply network of Islamabad is not as much reliable for drinking purposes, many residents are oblige to take potable water from WFP available near their residences in water containers. In this situation, more vulnerable are poor populations not having awareness and means to bring potable water for drinking purpose.

1.4 Limitations of the study

This study was limited to one year of data from a single hospital. The results could improve with the availability of data from more private and public sector hospitals for several years.

Residential addresses of patients were optimal in order to map the spread of disease. However to protect the privacy of each patient the exact residential addresses were not used, instead a random location at the center of each street was marked (geocoding) to represent a diarrhea incidence in developed sectors (Non-Slum). 151 meter was the mean length of all the streets used in this research and choosing the centre of each street means the probability of maximum displacement of approximately 75 meters. The buffer distances used for WDS and

WFP are 0-250m and 250-500m which are 3.3 times bigger in length than the probability of maximum displacement (75 meters displacement). By increasing the length of buffer (0-250m and 250-500m) instead of 100, 200, 300, 400 or 500m further decreased the chances of false representation. Overall, the probability of maximum average displacement for diarrhea incidence will remain within area of 0.005 Km^2. Each sub-sector in Islamabad covers approximately 0.67 Km^2 as mentioned earlier and the displacement of 0.005 Km^2 makes less than .007% of each sub-sector which would not undermine results for intended macro level.

Slum areas are created without any planning and streets numbers on illegally occupied lands. Diarrhea incidence mapped in 12 slums does not have street numbers and patients were randomly dispersed across each slum using slum name provided by the hospital against each incidence.

Geocoding of diarrhea incidence was done using basemap layer of Islamabad' s streets provided by Pakistan Telecommunication Corporation Limited (PTCL), the quality of geocoding also depends on the quality of basemap used.

Data quality for denominator (population at risk) data, can also cause inaccuracies in results (Best and Wakefield 1999). To be more precise for disease risk mapping and modeling, the highly accurate spatial population datasets are required to model the population at risk. In this research, the accurate population data was not available due to non-availability of latest census. Therefore, population for the year 2015 was estimated based on the actual population growth rate of past.

Incorporating socio demographic factors (age, sex, education, income etc) could further improve the results. Even the mobility of people from one place to another for work or pleasure can affect the results.

2. Data & Methodology

This section is comprised on:

2.1 Thesis Structure
2.2 Data Acquisition and Preparation
2.3 Concepts & Application

2.1 Thesis Structure

A stepwise methodology is summarized in flowchart (Figure 7) to support the implementation of processes using GIS techniques. The flowchart was sliced into three portions including Data Acquisition, Data Preparation and Data Analysis.

Data collection methodology was shown in Data Acquisition portion for spatial and non-spatial data. The spatial data was comprised on WDS, WFP, Slum, Non-Slum, Streets and Highways, and non-spatial data was based on diarrhea patients.

Data Preparation portion highlighted that WDS (polyline shapefile) were digitized using ArcGIS online World Imagery of Environmental System Research Institute (ESRI), Redlands, CA, USA. WFP (point shapefile) were marked and digitized using handheld GPS Garmin 12XL of GARMIN based in Olathe-Kansas, United States. Slums (poylgon shapefile) were digitized using GPS coordinates and ArcGIS online World Imagery of ESRI. Non-Slum (residential area) was already available through "Islamabad_Streets" basemap provided by PTCL.

In Data Analysis portion, DIR for WDS, WFP, Slum and Non-Slum were found using Patients Summer and Patients Winter separately for 0-250 meters and 250-500 meters distance.

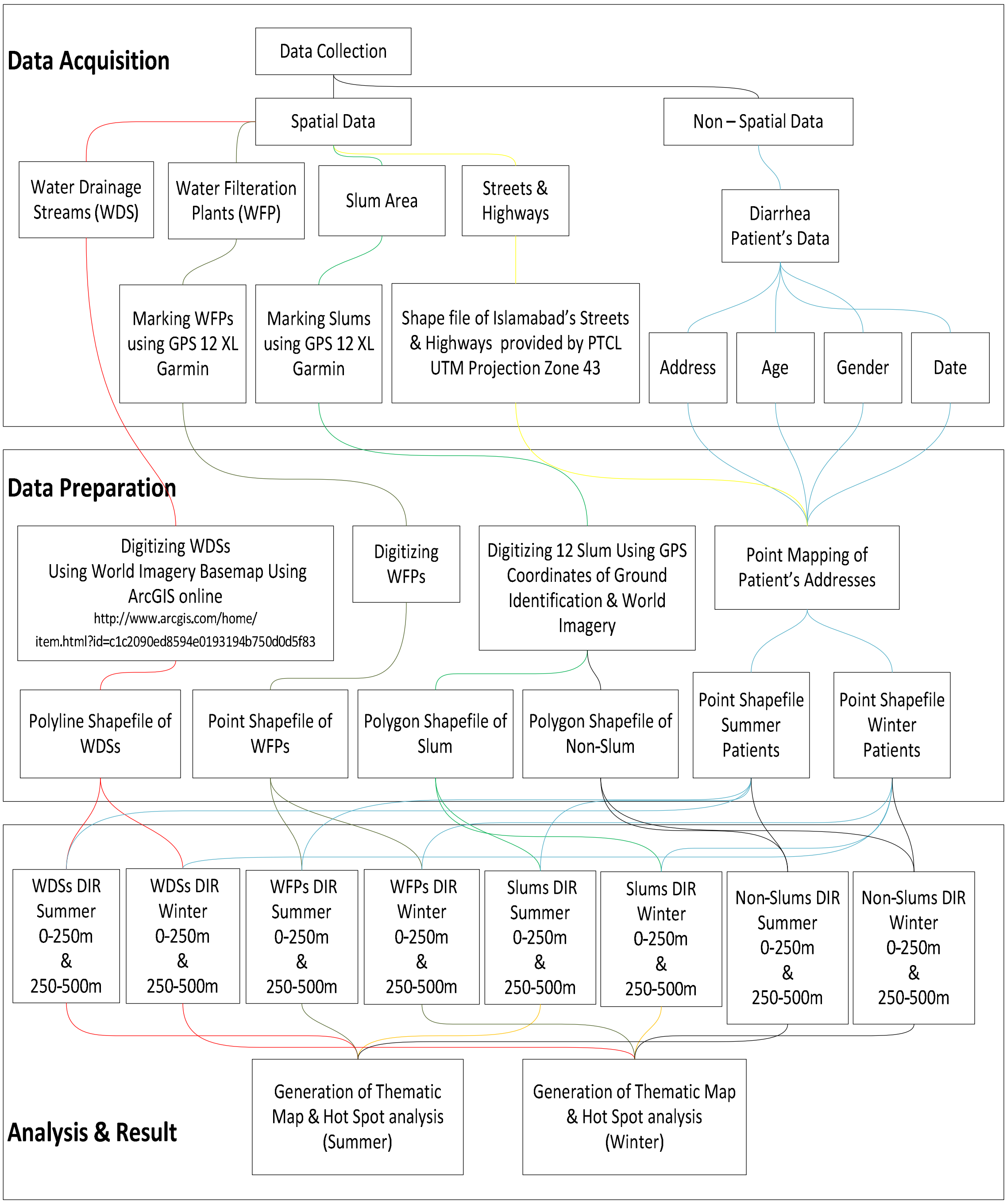


Figure 7: Flowchart of the Method Adopted using GIS

Thematic maps were created using Kernel Density (KD) for winter and summer separately and Average Nearest Neighbor (ANN) was performed to supplement KD results. Finally hotspot analysis was performed to highlight spatial dispersion of diarrhea.

2.2 Data Acquisition & Preparation

2.2.1 Patients

Seven governmental hospitals are available in Islamabad including, Pakistan Institute of Medical Sciences (PIMS), Federal Government Services Hospital (FGSH), Capital Development Authority (CDA) Hospital, National Institute of Health (NIH), Nuclear Medicine Oncology & Radiotherapy Institute (NORI), Nescom Hospital and Khan Research Laboratories (KRL) Hospital (CDA 2016).

NORI takes oncology patients; Nescom and KRL hospital provide medical facility mainly to armed personnel' s and their families. CDA hospital takes care of CDA employees and their families. NIH deals in allergies only. FGSH is available for Federal Government Employees and their families, FGSH lacking many medical specialties due to which patients are mostly referred to PIMS hospital for the treatment. All those hospitals are catering niche population and rest of the general public in Islamabad has PIMS and private hospitals. PIMS is one of the largest hospitals available with 24 hours emergency services and subsidized health care facilities for general public. It is a tertiary care hospital having 592 beds for patients and 22 medical and surgical specialties. Other hospitals refer patients to PIMS due to their limited capacity and lacking specialties. Therefore, majority of population reaches PIMS for its central location, medical specialties and health care facilities.

Diarrhea patient' s data was received from PIMS (Figure 8). The hospital provided data for 1192 diarrhea patients for one complete year from January, 2013 to December, 2013. The data was provided by hospital in Microsoft Excel spreadsheet format of Microsoft Corporation, Redmond, Washington, United States, including following column:

Table 1: Patient Variables

Date	Sex	AGE	SYMPTHOM	STREET	SECTOR	CITY
1-Jan	M	1	DIARRHEA	21	G-7/2	ISLAMABAD

Some information on patient identifiers are not disclosed by PIMS administration including patient' s name, father' s name, home addresses of each patient, ward in which each patient was admitted and treated, number of deaths of diarrhea patients, time of admission and serial number of each entry record due to hospital' s own privacy policy.

Patient' s privacy laws are not introduced in Pakistan till today, although protecting confidential information about the health of each individual is ethical even if the laws are not present. Several approaches of masking can be used to preserve the confidentiality of health records for location of individual health events (Armstrong et al. 1999), so that an individual may not be traced back to prevent disclosure of health related information. Therefore the general technique of random perturbation method was used in this study by displacing each patient’ s home address to a random distance (centre of each street) as argued by Armstrong al (1999).

Geo-referencing of epidemiological data provide structured approaches to data management (Kandwal et al. 2009), It’ s a procedure to assign data points with a spatial location (e.g. latitude and longitude) depending on some form of address (DeMers 2000). Geo-referencing enables a location on the map to be give address (Chrisman 2001), and the location of the cases are usually residential addresses (Tango 2010). Each patient was spatially referenced using point shapefile, so that every patient may be assigned coordinates for further analysis and research. The spreadsheet data received from PIMS was imported as table in ArcMap.

A shapefile was created using WGS_1984_UTM_Zone_43N projected coordinate system and joined with spreadsheet data received from PIMS.

Figure 8: Diarrhea Patients (summer & winter) & PIMS Hospital

Every diarrhea incidence was marked on a point shapefile using streets & sectors shapefiles as base map to locate the street level addresses provided by the hospital. The patients living in slum were without street number. Each diarrhea incidence in slum was recorded by randomly marking a location within each slum area using slum shapefile as base map.

Patients were segregated using winter (October, November, December, January, February, March) and summer (April, May, June, July, August, September) season so that DIR could be found for both seasons (Figure 9, 10).

Figure 9: Diarrhea Patients (winter)

Figure 10: Diarrhea Patients (summer)

A drawback for using GIS might be the time required to convert non-digitized data into a digital form (Nuckols et al. 1995), which was true in practical. Proper care was taken for geo-coding, although it is not uncommon for 7% of locations assigned to addresses within a basemap to be incorrect according to researchers (Cromley and McLafferty 2002).

2.2.2 Water Drainage Streams (WDS)

WDS were digitized using ArcGIS online World Imagery of ESRI (Figure 11).

Figure 11: WDS (Clipped)

A polyline shapefile was created using WGS_1984_UTM_Zone_43N projected coordinate system to digitize all WDS and then all WDS were clipped using Islamabad' s developed residential sectors (study area) so that extra length from WDS could be removed to be precise in analysis.

In order to calculate DIR for WDS, the study used diarrhea affected people (affected) and population under risk of disease (exposed) in focused area. Henceforth, Multiple Ring Buffer (MRB) was used on clipped WDS using 0-250 meter and 250-500 meter linear distance. Buffer area falling outside the study area was removed. Patients from summer and winter season were separately clipped using 0-250 meter and 250-500 meter linear distance buffers so that diarrhea affected patients can be identified in both buffer areas (Figure 12 & 13).

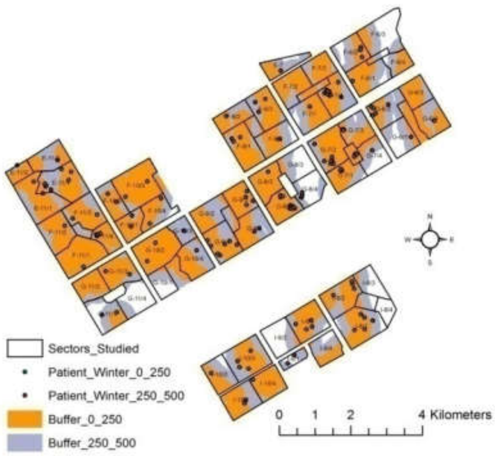


Figure 12: Patients during Winter Identified from 0-250m & 250-500m using MRB on WDS

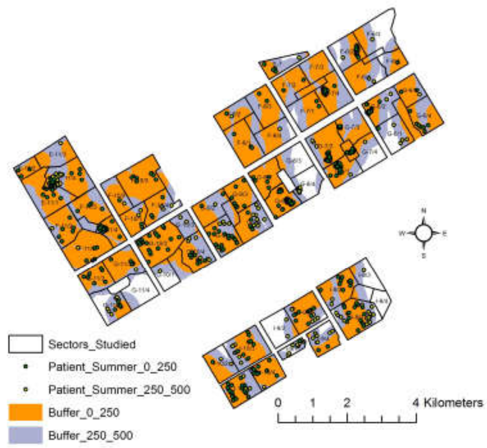


Figure 13: Patients during Summer Identified from 0-250m & 250-500m using MRB on WDS

2.2.3 Water Filtration Plants (WFP)

WFP were installed by CDA for the residents of the city to have clean drinking water. Majority of the residents in Islamabad bring their water containers/ bottles to fill filtered water for drinking purposes.

Twenty six (26) WFP' s were marked during this study. Twenty two (22) were operational and four (4) were un-operational. This study included (22) operational WFP' s.

Figure 14: WFP

All the WFP' s identified in this study were located by physically visiting the site locations and marking the position of each WFP using handheld GPS Garmin 12XL.

Figure 15: WFP (Studied) in Islamabad

To reconfirm the location of each WFP, help of Google Map of Google Inc, Mountain View, CA, USA was taken. Finally, all the points were digitized and geo-referenced in a shapefile using WGS_1984_UTM_Zone_43N projected coordinate system (Figure 15).

In order to find DIR, MRB was performed around each WFP (Figure 16). Extra area falling outside the study area was removed.

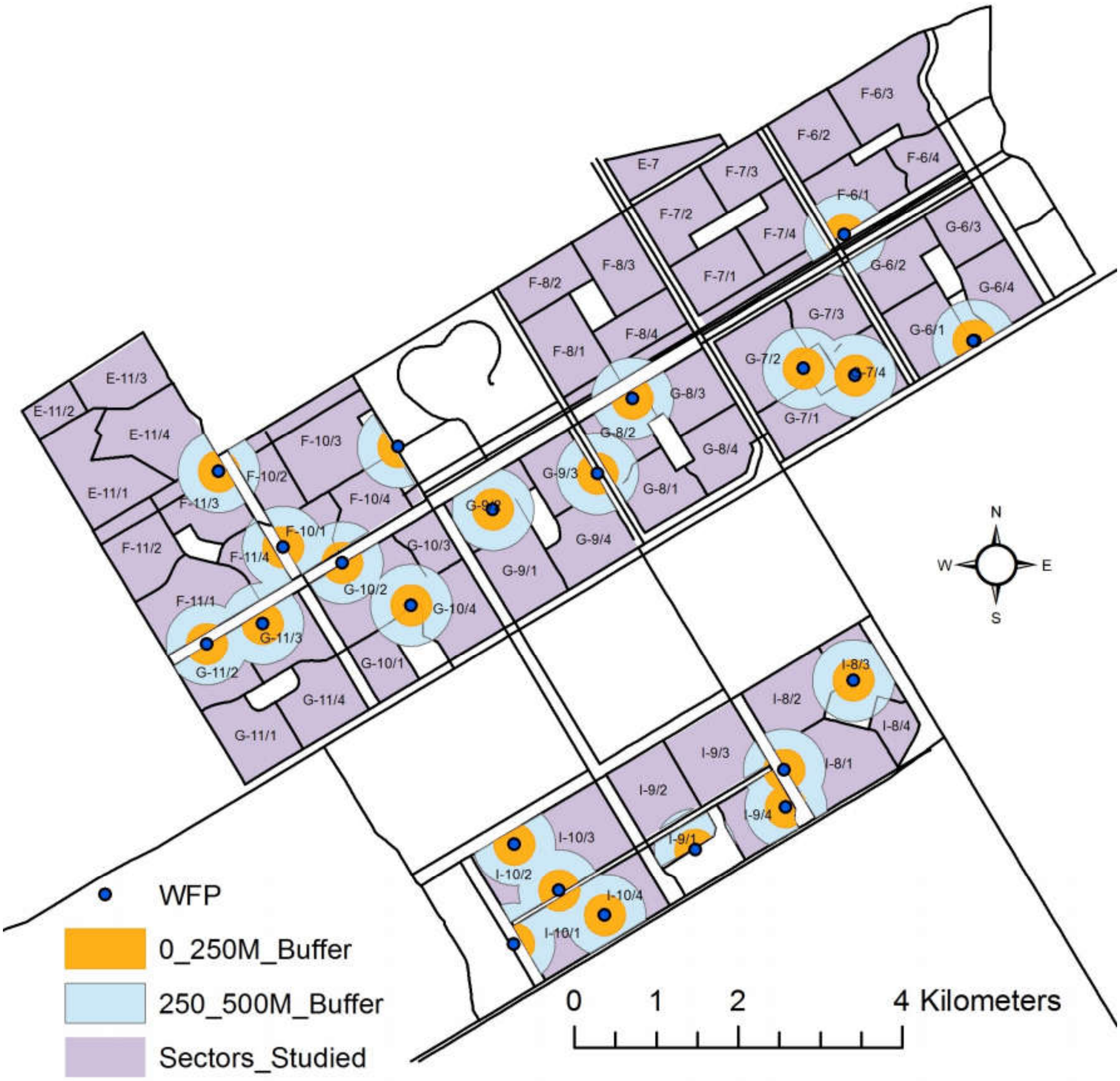


Figure 16: MRB on WFP

Patients in summer and winter season falling within the ring buffers (0-250 meter & 250-500 meter) were separated (Figure 17 & 18). The distance from 0-250 meters used in this research may be treated as convenient distance to fetch water and the distance from 250-500 meters as non-convenient distance. The people living farther away from 500 meters may be facing more hardship to fetch water.

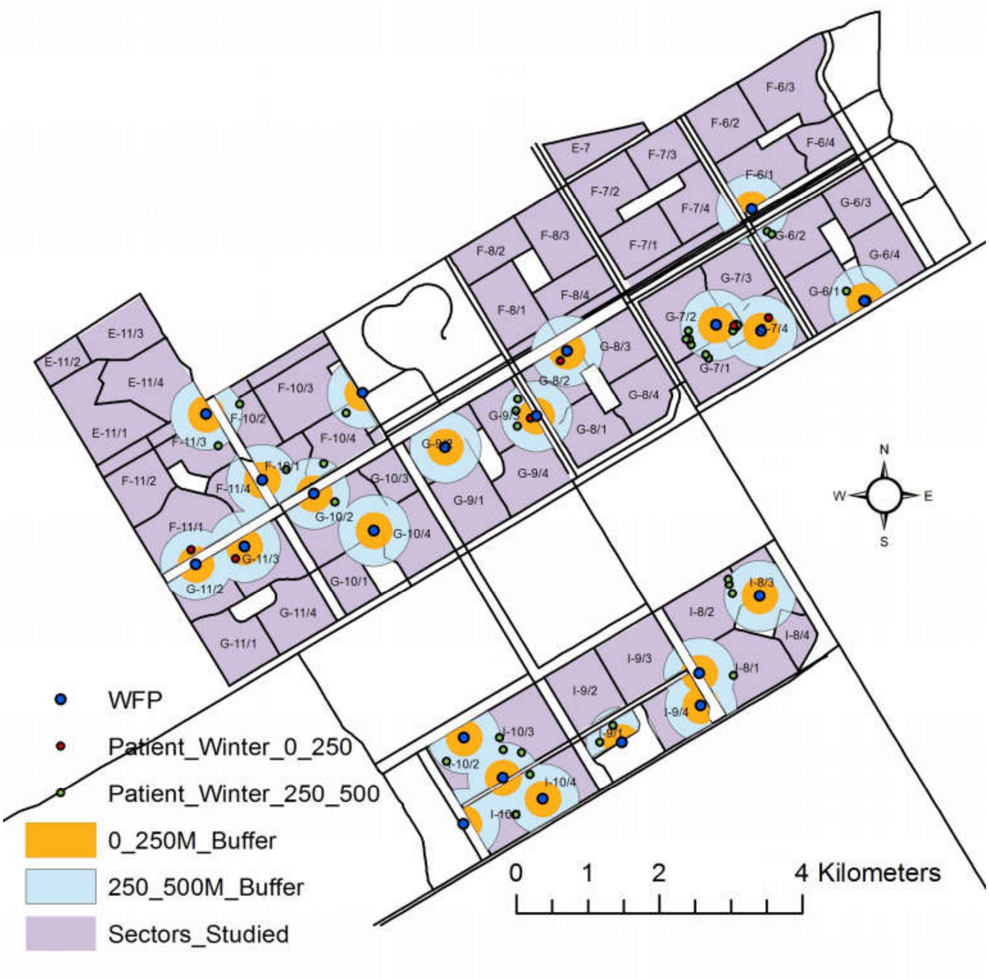


Figure 17: Patients during Winter Identified from 0-250m & 250-500m using MRB on WFP

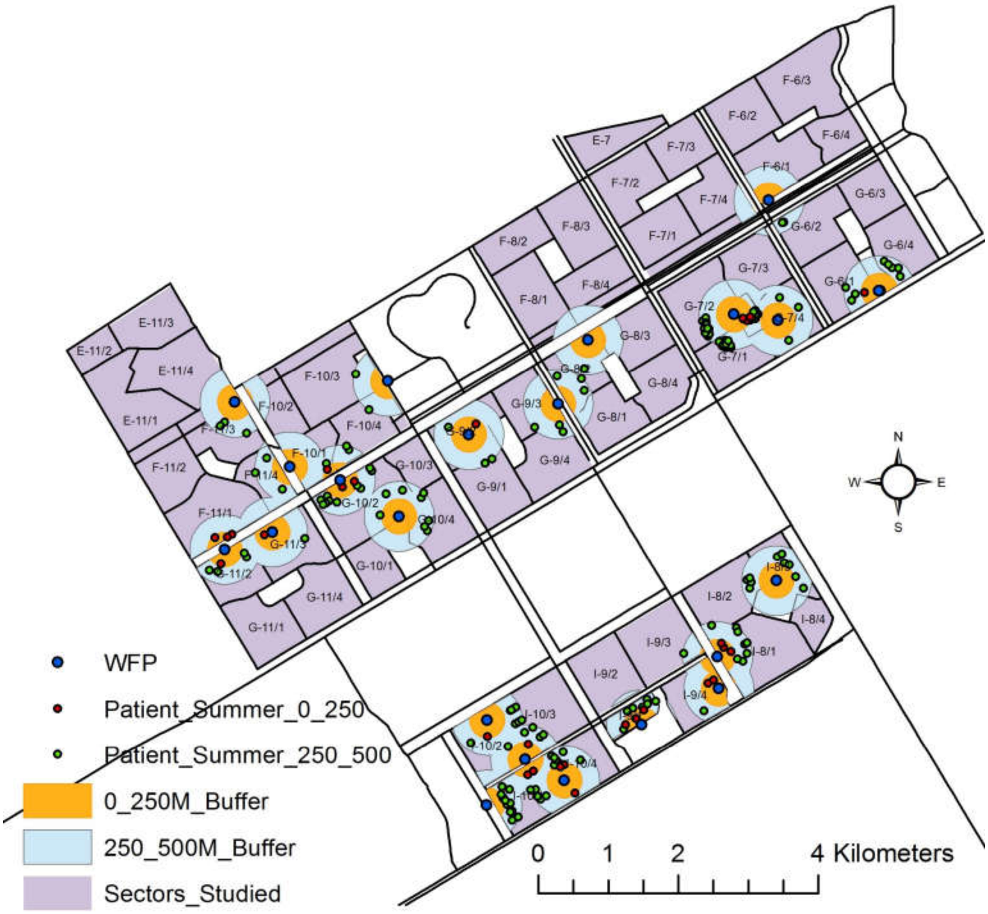


Figure 18: Patients during Summer Identified from 0-250m & 250-500m using MRB on WFP

2.2.4 Slums

Twelve (12) slums were identified (Figure 19); to confirm their existence in geographic locations, handheld GPS was used to mark the coordinates of each slum. Marking the complete boundary of each slum was difficult and unsafe, residents living in slums do not like outsiders to take any kind of statistics/ data; they believe the data is mostly used against dwellers. Another difficulty was the terrain; the WDS mingle on most of the slums and make it very difficult to move around, each slum having streets narrow on most of the places to pass only one person.

Therefore, all slums were digitized using ArcGIS online World Imagery available in ArcMap. A polygon shapefile was created for this purpose using WGS_1984_UTM_Zone_43N projected coordinate system and the coordinates earlier collected using GPS were used for location identification of each slum. Area of approximately 0.882 km is occupied by 12 slums identified and analyzed in this study, whereas the exact count for total slums present in Islamabad is not clear.

Figure 19: Slums (Kachi Abadi) in Residential Sectors of Islamabad

List of slums (Hussain 2014) provided detail of individuals living in each slum (Appendix 2), the population statistics for 1-6 slums are taken from the same article. Other slums (Slum no. 7-12) were estimated based on average population per square Km. Approximately, 145,741 is the average population density of residents living in slum area within a Km^2 which is much higher in comparison with the city' s general population density (2,100 per square Km). It shows that each living compound must be densely packed and having many families sharing toilet and drinking water facilities. An estimated population count was used for population living in slum no. 7 to 12 based on the figures provided by Hussain (2014).

For finding DIR for slums, clip function was used using slums and patient shapefiles for winter and summer separately, to identify the detail of each point source (diarrhea incidence).

2.3 Concepts & Application

The analysis of spatially referenced public health data involves the combination of at least three separate academic disciplines: statistics, epidemiology, and geography (Waller and Gotway 2004). Spatial statistical methods are more fruitful to evaluate change in the rate of disease in different geographic areas, identification of disease clusters and to understanding disease variability. The spatial variation of disease is geographically restricted due to physical and biological conditions (Tishkoff and Kidd 2004). The use of space and place in the study of disease can yield unique insights un-available from other sources. One only need to examine the history of John Snow' s study of cholera and his use of map to display the source as a single contaminated well to understand the power of the spatial perspective in medical analysis (Gilbert 1958). Several methods and datasets can be applied but still we need to map the disease as it has been a practice since John Snow' s classic study using conventional maps as a base for thematic maps showing socio-economic data by means of colors, symbols, graphs and charts (Tao 2010).

Spatial epidemiology is used to identify disease causes and correlates by relating spatial disease patterns to geographic variations in health risks (Jacquez 2000). Spatial disease patterns are the outcome of space - time processes, and several alternative processes may give rise to similar spatial patterns (Schærström and Anders 1996). Three distinctions in spatial epidemiology are suggested as: cluster detection, clustering and spatial variation in disease variability; separation between these three distinctions are often blurred (Diggle 2001). Clusters are characteristic of the distribution of a particular disease over a defined region during a specified period of time or region (Quataert et al. 1999). Disease clusters can be examined using four steps: it begins by characterize the data, decide the domain from which the data come, a Null hypothesis (H_0), and Alternative hypothesis (H_1) (Wartenberg and Greenberg 1993). Many dozen of cluster statistics are available that can be categorized as global, local and focused tests for cluster detection (Lawson and Kulldorf 1999; Jacquez et al. 1996), and those methods could be used to measure the spatial association of outbreak locations and their temporal change to identify hotspot of a disease (Lee and Rogerson 2007). Hotspot is a condition indicating some form of clustering in a spatial distribution (Chaikaew et al. 2009).

Global test is more useful to evaluate whether the (disease) points are randomly distributed or clustered and how dispersed they are?

Average Nearest Neighbor (ANN): ANN examines the distances between each point and the closest point to it (Fotheringham and Charlton 1994), and averages all the nearest neighbor distances. If the average distance is less than the average for a hypothetical random distribution, the features are clustered. If the average distance is greater than hypothetical random distribution, the features are considered dispersed. ANN is used to find how dispersed or clustered points are? It provides the ability to quantify and compare the spatial distribution of disease within a fixed study area over time. The average Nearest Neighbor Ratio (NNR) is given as:

$$ANN = \frac{D_O}{D_E}$$

Where Do is the observed mean distance between each feature and its nearest neighbor:

$$D_O = \frac{\sum_{i=1}^{n} di}{n}$$

And D_E is the expected mean distance for the features given a random pattern:

$$D_E = \frac{0.5}{\sqrt{n/A}}$$

In the previous equations, di equals the distance between feature i and its nearest feature, n corresponds to the total number of features and A is the total study area. The % ANN Z-score for the statistics is calculated as:

$$\% \, ANN = \frac{D_O - D_E}{SE}$$

where:

$$SE = \frac{0.2613\ 6}{\sqrt{n^2/_A}}$$

Trend is for clustering if ANN is less than 1, the trend is for dispersion if ANN is greater than 1.

In this study ANN was used on patients during winter and summer georeferenced point shapefiles to examine the degree of spatial dispersion of disease, and to analyze geographical spread objectively during winter and summer separately. The occurrence of diarrhea was segregated based on winter (October, November, December, January, February, March) and summer (April, May, June, July, August, September) season. Time is an important ingredient for the study of epidemics and medical analysis, spatial content alone is not sufficient alone (Shuai et al. 2006; Jacquez 2000); especially for diarrhea prevalence, it is reported that diarrhea cases during summer season increases and found least during winter (Ahmed et al. 2008). The segregation based on season may reveal different results due to change in temperature for WDS, WFP, Slum and Non-Slum area.

Kernel Density (KD): It is among the popular methods for analyzing the first order properties of a point event distribution because it is easy to understand and implement (Bailey and Gatrell 1995). It is a non-parametric way to estimate the probability density function of random variables. Non-parametric estimators depend on all the data points with no fixed structure for estimate. Finite data sample is used in this method to inference about a specific population smoothing. KD method centers a kernel function at each data point to remove the dependence on the end points of the bins in histograms. KD method smooth' s the contribution of each observed data point over a local neighborhood of the data points. Density function $f(o)$ of a random variable x works by assuming that we have n independent observations $x_1, \dots\dots, x_n$ from the random variable x . The KD estimator $f\ \ (x)$ for the estimation of the density value at point x is defined:

$$f\ \ (x) = \frac{1}{nh}\sum_{i=1}^{n} K\,(\frac{xi-x}{h})$$

$K(o)$ denoting kernel function, and denoting the bandwidth.

KD maps can be used to find the density raster of houses, crime reports, banks, etc. KD maps were created from point shapefiles to present density of diarrhea disease during winter and summer in a neighborhood in this study.

Diarrhea affected area in KD maps were classified using three classes (Low, Medium and High) using Jenks Natural Breaks (JNB) classification (McMaster and

McMaster 2002). JNB classification is useful for highlighting the areas having extreme differences so that the degree of data variation may be considered based on natural groupings inherent in the data. This method is used to determine the best arrangement of values into defined classes so that each class' s average deviation can be minimized within the class while maximizing average deviation from the means of other classes to maximize the difference between classes.

Global test do not specify where the clusters are located, and how the spatial variation of risk is defined (variation in disease rate) from one place to another. Focused test on the other hand addresses clustering in relation to identified locations where increased risk might be expected (Lawson 2006). Therefore using focused test technique the areas for investigation were selected first and then analysis for occurrence of disease was performed.

Methodological research on disease cluster techniques have gained popularity and spatial statistical software are increasingly integrated with GIS, making possible the interactive exploratory spatial data analysis (Bailey and Gatrell 1995). In this research, DIR calculated for Non-Slum (having good sanitation), Slum Area (having poor sanitation), area around WDS (having the possibility of water source contamination) and area around WFP (improved water source). The population of each focused area was estimated based on the area occupied.

Null hypothesis (H_0) on the other hand assume that location of the cases of disease reflect heterogeneous Poisson Distribution with equal risk from one place to another, it means there is no cluster of disease (Cromley and McLafferty 2002). It cannot be generalized that every person living in close proximity to reported cases may have suffered from the disease. On the contrary, increase in individual risk based on uneven distribution of disease (spatial heterogeneity) within an area may be defined by Alternative hypothesis (H_1) due to distance /proximity and density.

The understanding of the risk of a particular disease begins by addressing the occurrence of the cases in a particular population over a particular time (Waller et al. 1997); therefore DIR defined as ratio of observed diarrhea cases (o) to the population (n), this techniques was also used by Chaikaew et al (2009) in a study exploring spatial patterns of diarrhea in Chiang Mai, Thailand. Similarly, the methodology was adopted for determining DIR for Non-Slum, Slum, WDS and WFP also called focused areas with some modification:

DIR = o (observed diarrhea cases) /n (population)

Cumulative Incidence Rate method (occurrence of new diarrhea case registered in PIMS) was used in this research to determine the occurrence of disease using time as an integral part of denominator (summer/ winter). Since epidemiology is concerned with the occurrence of disease in a particular population with common characteristics i.e. residence, sector, religion, gender, age, socio economic status, residence near geographic features such as streams, lakes, island can also be used for this purpose.

In order to measure how commonly a disease occurs, epidemiologists have to consider three factors: number of people affected by disease, size of population from which the cases arrived, length of time that population is followed (Cases/

population/ year). In a disease rate the numerator is disease cases (Wartenberg et al. 1993), while population makes essential denominator necessary for many infectious diseases (Tatem et al. 2012).

WDS and WFP were studied in relation to the number of diarrhea affected patients coming from 0-250 meter and 250-500 meter linear distance around WDS in summer and winter season. The convenient and reasonable distance for collecting water in urban area is 200 meters from a residence (UN 2000). The recommended distance suggested by the United Nations may not encompass everything but a good starting point to define water access for WFP, the same distance buffer was also maintained for WDS to create consistency in study. Total area covered by 0-250 & 250-500 meters was calculated based on buffer length falling on Non-Slum (mostly) and Slum area (some). Then total population under risk of disease was calculated considering Non-Slum and Slum population. Another area selected for the focused test was slums within Islamabad's territory, diarrhea affected patients coming from twelve slum were identified separately for summer and winter season based on the population density found earlier for slums.

Henceforth, the area covering WDS, WFP, Non-Slum and Slums were calculated, the population per square Km was derived and DIR for each (WDS, WFP, Non-Slum and Slums) was calculated to understand the effects of those factors on diarrhea incidence.

Points containing DIR for WDS, WFP, Non-Slum and Slum during summer and winter were merged. Two separate point shapefiles were derived. Points coinciding at same place having more than one DIR for a single diarrhea incidence were separated and a mean value was taken. Finally, Hotspot Analysis was performed using DIR for summer and winter.

Getis-Ord GI*: Getis-Ord GI* statistics identifies clusters having points with higher than normal values in magnitude and eliminate probability of random chance (ESRIDN 2016) using z-score and p-value for each feature. High z-score and small p-value for a feature indicate spatial clustering of high values (Hotspots) and low negative z-score and small p-value indicates a spatial clustering of low values (Coldspots), z-score near to zero indicate not significant clustering.

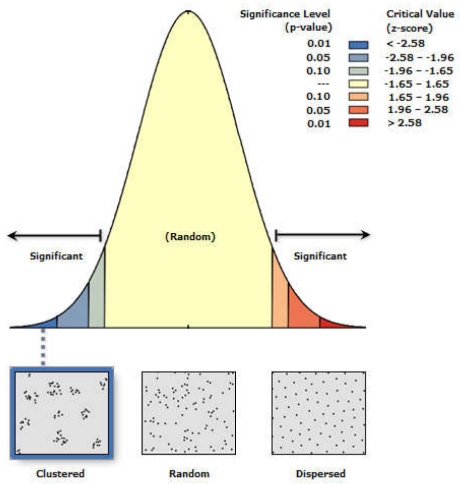
Getis-Ord GI* statistics method was used for the quantification of spatial patterns using Hotspots with high value (red color), Coldspots with low value (blue color) and Not-Significant output (yellow color).

3. Results

Total of 176 (15%) diarrhea patients were identified during winter season (Jan-Mar & Oct-Dec), whereas the diarrhea patient' s count during summer season (Apr-Sep) increased to 1016 (85%).

3.1 To explore whether diarrhea incidence are clustered, randomly distributed or dispersed, and its tendency to aggregate in space or in time?

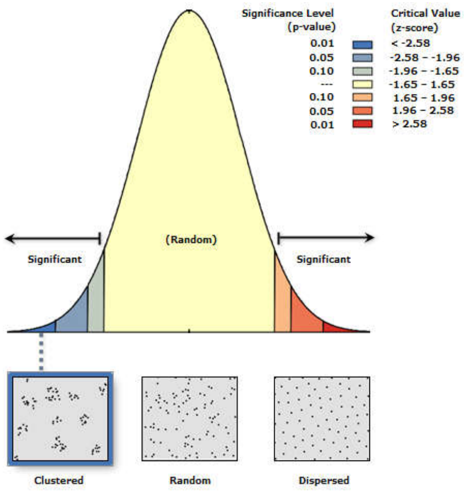
ANN for diarrhea incidence during summer (Figure 20) suggested strong indication of clustering with the NNR of 0.491 and Z-score of -30.998.



Observed Mean Distance	51.515 Meters
Expected Mean Distance	104.782
Nearest Neighbor Ratio	0.491
Z-score	-30.998
P-value	0.000
Given the z-score of -30.998, there is less than 1% likelihood that this clustered pattern could be the result of random chance, and reflects 99% confidence level.	

Figure 20: ANN Summary for Patients in Summer

Likewise, clustering was found in winter (Figure 21) having NNR of 0.720 with Z-score of -7.091.



Observed Mean Distance	181.406
Expected Mean Distance	251.755
Nearest Neighbor Ratio	0.720
Z-score	-7.091
P-value	0.000
Given the z-score of -7.091, there is less than 1% likelihood that this clustered pattern could be the result of random chance, and reflects 99% confidence level.	

Figure 21: ANN Summary for Patients in Winter

The visual maps (Figure 22 & 23) below represent the intensity and spatial dispersion of diarrhea during summer and winter season using KD method on incidences to present diarrhea density maps for simple visual inspection of geographic phenomenon using JNB classification. Area having low diarrhea incidence is shown with grey color, area having yellow color representing medium level of diarrhea incidence and area having red color is representing high diarrhea incidence.

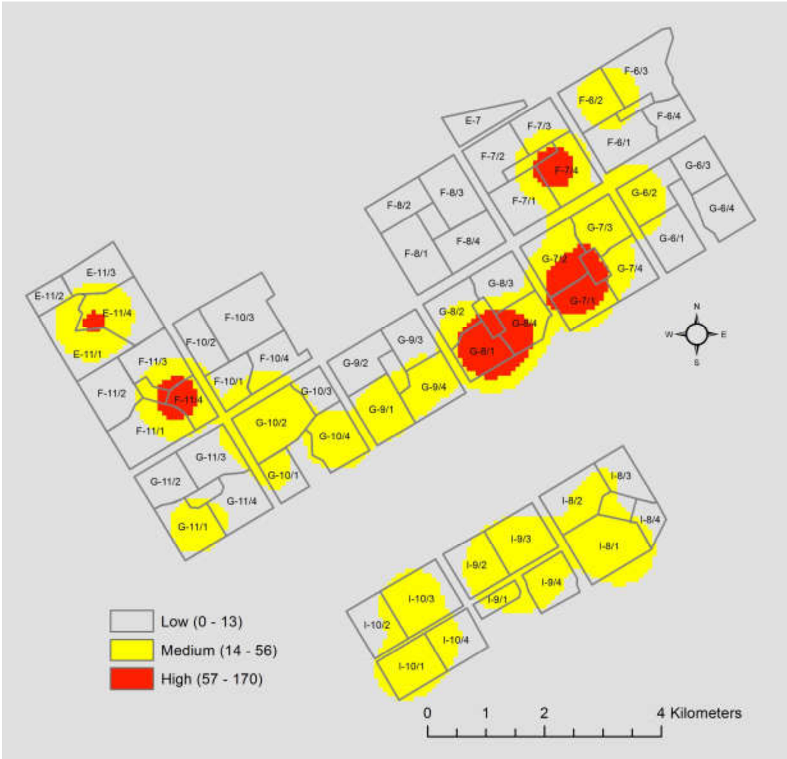


Figure 22: KD of Diarrhea Incidence during summer

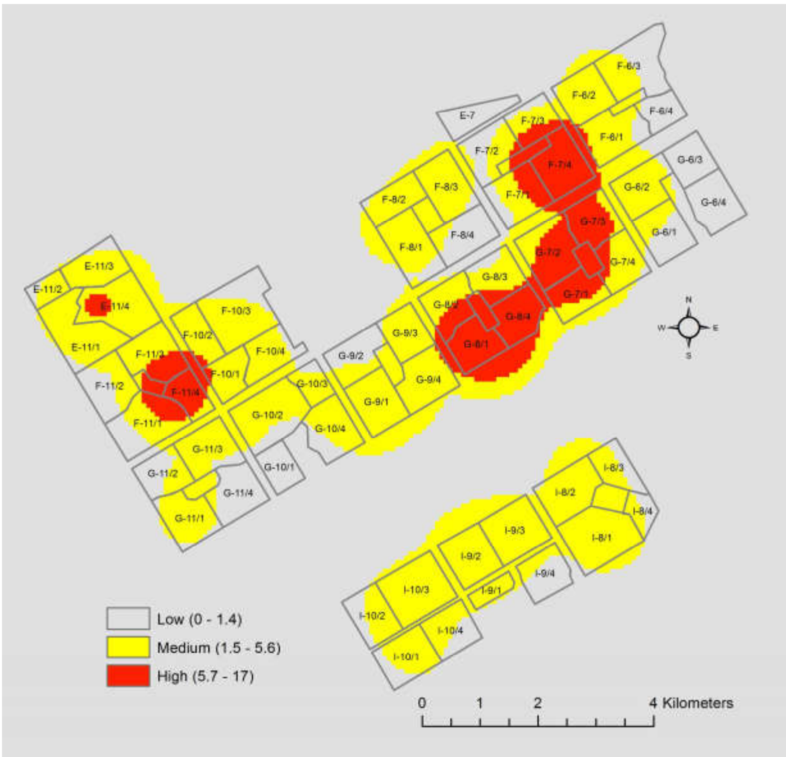


Figure 23: KD of Diarrhea Incidence during winter

The intensity of diarrhea shown in KD maps was higher in summer as compared to winter season. During the summer season, intensity of diarrhea was 0 – 170, whereas the intensity of diarrhea during the winter season was 0 – 17. Diarrhea intensity (diarrhea incidence) seems increased 10 times during summer of 2013.

ANN results for summer and winter season reinforce the KD visual maps by exhibiting statistically stronger indication of clustering during summer (NNR 0.491) as compared to winter (NNR 0.720). The low Z-score for both indicate that the observed spatial pattern is very unlikely to reflect the random pattern (H_o):

> Null hypothesis (H_o) $_{States}$: Diarrhea reflects distribution of disease with equal risk in all study area without clustering.

Furthermore, diarrhea incidence clearly shows the tendency to aggregate in space and in time. The clustering in landscape is the evidence of underlying spatial process at work. Results obtained above reject Null hypothesis (H_0) and suggest an Alternate hypothesis (H_1).

3.2 To explore DIR in Water Drainage Stream's (WDS) proximity?

In 0-250 meter buffer around WDS, diarrhea patients (incidence) during winter were 138 (15%) and 764 (85%) in summer. In 250-500 meter buffer around WDS, diarrhea patients (incidence) during winter were 29 (15%) and 172 (85%) in summer. The increase in diarrhea incidence is evident in summer for both 0-250 meter and 250-500 meter buffer around WDS.

The total number of patients recorded for 0-250 meter buffer around WDS for both season (winter & summer) were 902 (82%), whereas patients recorded for

250-500 meter buffer around WDS for both season were 201 (18%). Result shows that diarrhea incidence is higher near WDS, and decreases with the increase in distance from WDS.

Table 2: DIR around WDS

Season	Diarrhea affected patients within WDS_0-250 buffer	Diarrhea affected patients within WDS_250-500 buffer	Area (Km^2) within 0-250 meter buffer	Area (Km^2) within 250-500 meter buffer	Population under risk of disease for 0-250m	Population under risk of disease for 250-500m	DIR for 0-250m buffer	DIR for 250-500m buffer
Winter	138	29	23.633(Dev) 0.046(Slum)	12.328(Dev) 0.023(Slum)	49629(Dev) 6704(Slum) 56333	25888(Dev) 3352(Slum) 29240	0.0024	0.0009
Summer	764	172	23.633(Dev) 0.046(Slum)	12.328(Dev) 0.023(Slum)	49629(Dev) 6704(Slum) 54235	24859(Dev) 3352(Slum) 28211	0.0140	0.0060

The visual maps (Figure 24, 25, 26 & 27) represent density and spatial dispersion of diarrhea during summer and winter season using KD maps to present a general view of the spread.

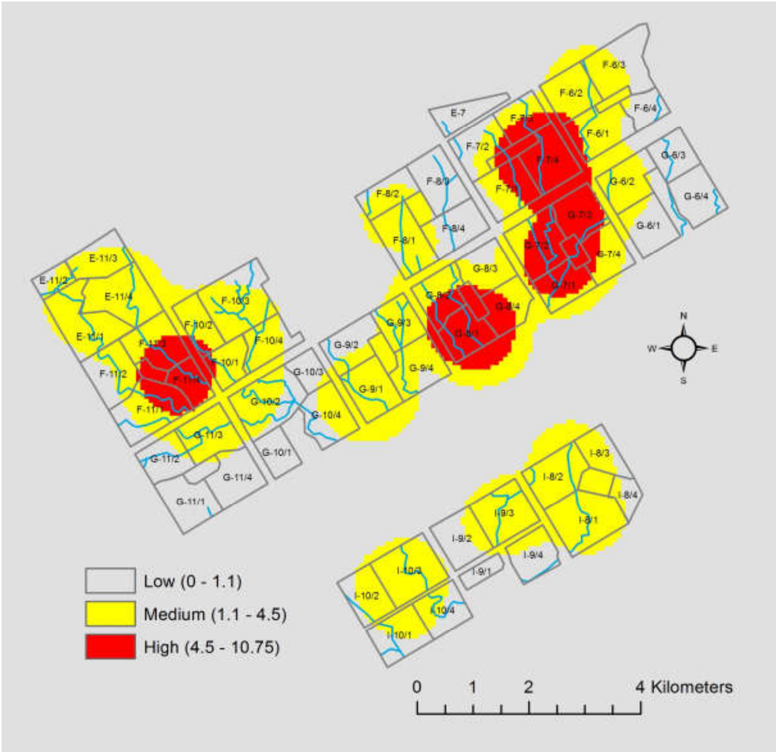


Figure 24: KD of Diarrhea around WDS (0-250m buffer) in winter

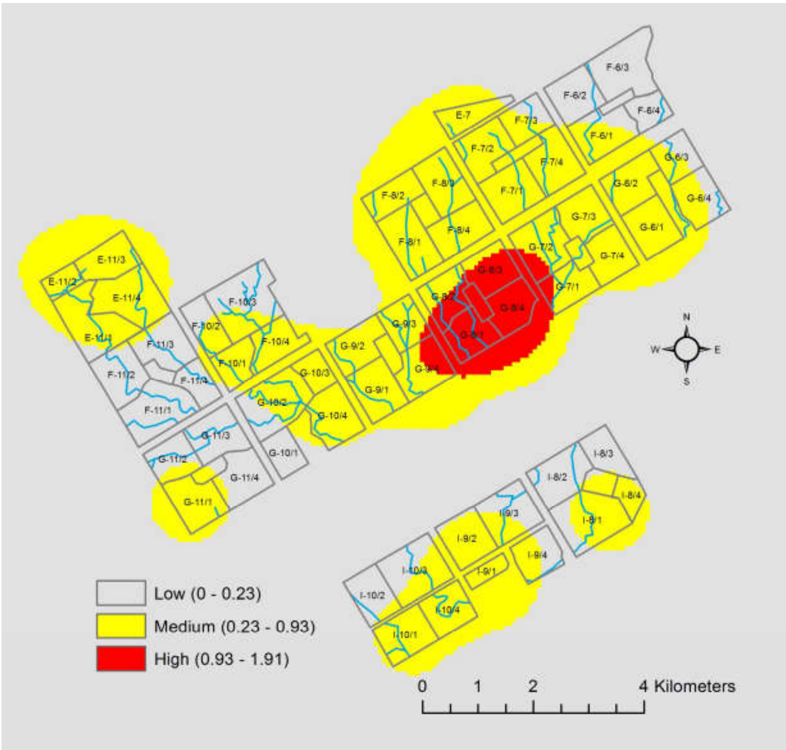


Figure 25: KD of Diarrhea around WDS (250-500m buffer) in winter

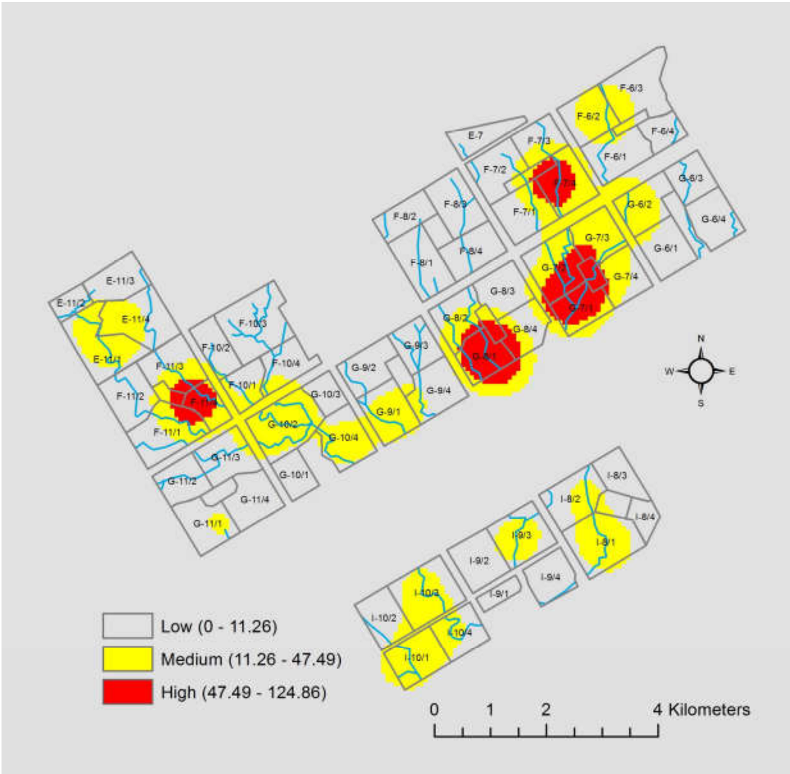


Figure 26: KD of Diarrhea around WDS (0-250m buffer) in summer

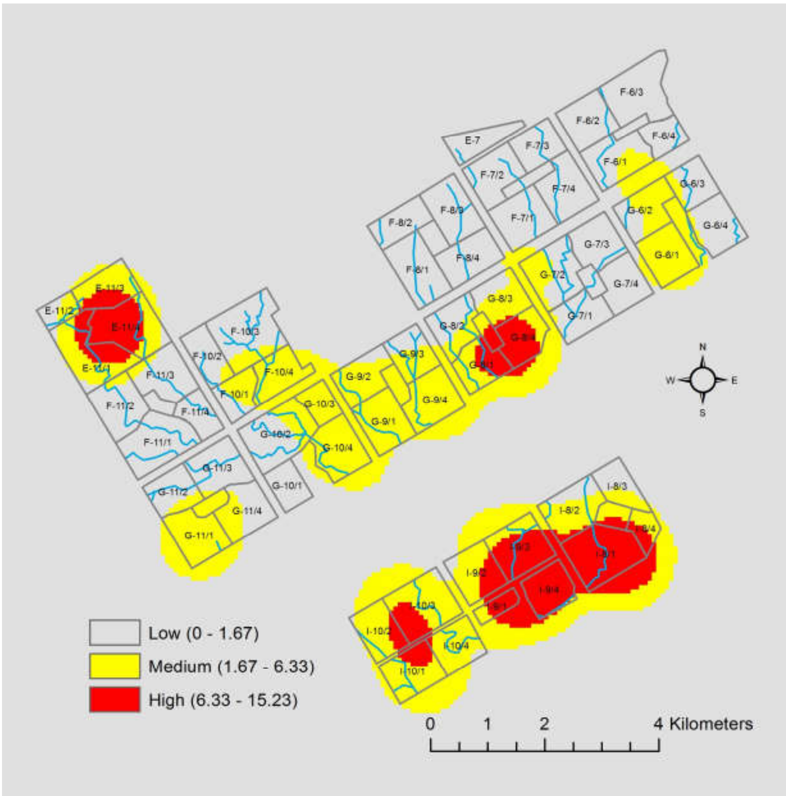


Figure 27: KD of Diarrhea around WDS (250-500m buffer) in summer

ANN result based on diarrhea incidences exhibit statistical indication of clustering (NNR 0.866) in winter for 0-250m with Z-score (-2.989 Standard Deviations) represents confidence level of 99% that the observed spatial pattern is too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of high dispersion (NNR 2.324) in winter for 250-500m with Z-score (13.644 Standard Deviations) represents confidence level of 99% that the observed spatial pattern too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of high clustering (NNR 0.488) in summer for 0-250m with Z-score (-27.059 Standard Deviations) represents confidence level of 99% that the observed spatial pattern too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of randomness (NNR 1.016) in summer for 250-500m with Z-score (0.401 Standard Deviations) represents confidence level of less than 90% that the observed spatial pattern too unusual to be the result of random chance.

Overall ANN results based on diarrhea incidences indicate that diarrhea patients (incidence) are high near WDS and decreases farther away from WDS. Indication of clustering changes into dispersion for winter season from 0-250m to 250-500m. Indication of clustering changes into randomness during summer season from 0-250 to 250-500m. However, indication of clustering was high for 0-250m in summer (NNR 0.488) as compared to winter (NNR 0.866).

3.3 To explore DIR in Water Filtration Plant' s (WFP) proximity?

In 0-250 meter buffer around WFP, diarrhea patients (incidence) were 6 (14%) during winter and 37 (86%) during summer. In 250-500 meter buffer around WFP, diarrhea patients (incidence) were 35 (13%) during winter and 240 (87%) during summer. The increase in diarrhea incidence is significant in summer for 250-500 meter buffer around WFP.

The total number of patients for 0-250 meter buffer for both season (winter & summer) were 43 (14%), and patients for 250-500 meter buffer for both season were 275 (86%). The result further demonstrates that diarrhea incidence is low near WFP and increases as we move farther away from WFP.

Table 3: DIR around WFP

Season	Diarrhea affected patients within WFP 0-250 buffer	Diarrhea affected Patients within WFP 250-500 buffer	Area (Km²) within 0-250 meter buffer	Area (Km²) within 250-500 meter buffer	Population under risk of disease for 0-250m	Population under risk of disease for 250-500m	DIR for 0-250m buffer	DIR for 250-500m buffer
Winter	6	35	2.851(Dev) 0.006(Slum)	8.473(Dev) 0.009(Slum)	5987 874 6861	17793 1311 19104	0.0008	0.0018
Summer	37	240	2.851(Dev) 0.006(Slum)	8.473(Dev) 0.009(Slum)	5987 874 6861	17793 1311 19104	0.0053	0.0125

The visual maps (Figure 28, 29, 30 & 31) represent density and spatial dispersion of diarrhea during summer and winter season using KD maps to present a general view of spread.

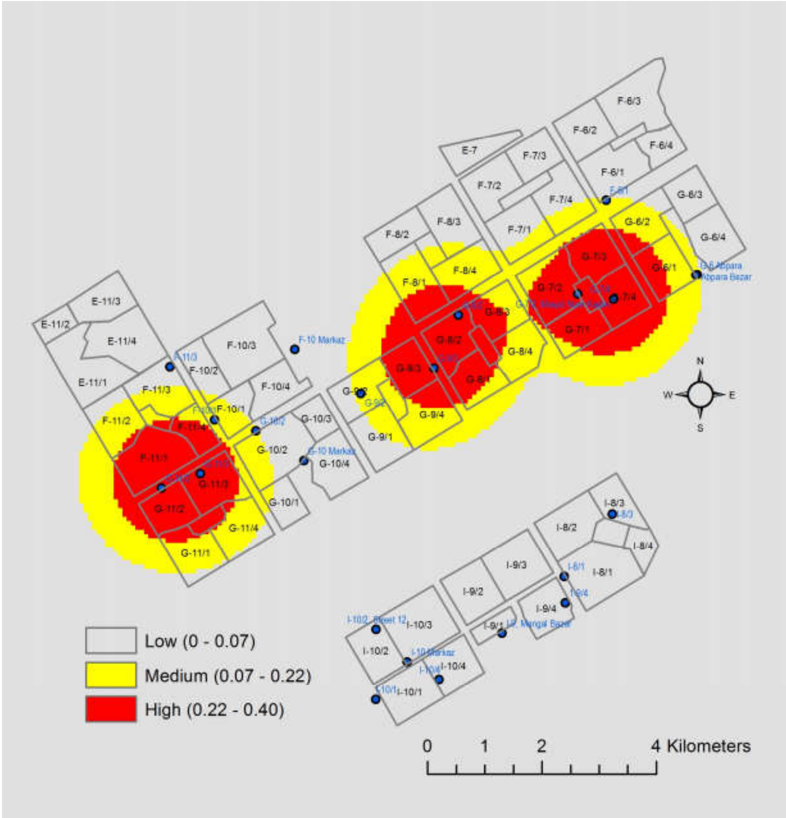


Figure 28: KD of Diarrhea around WFP (0-250m buffer) in winter

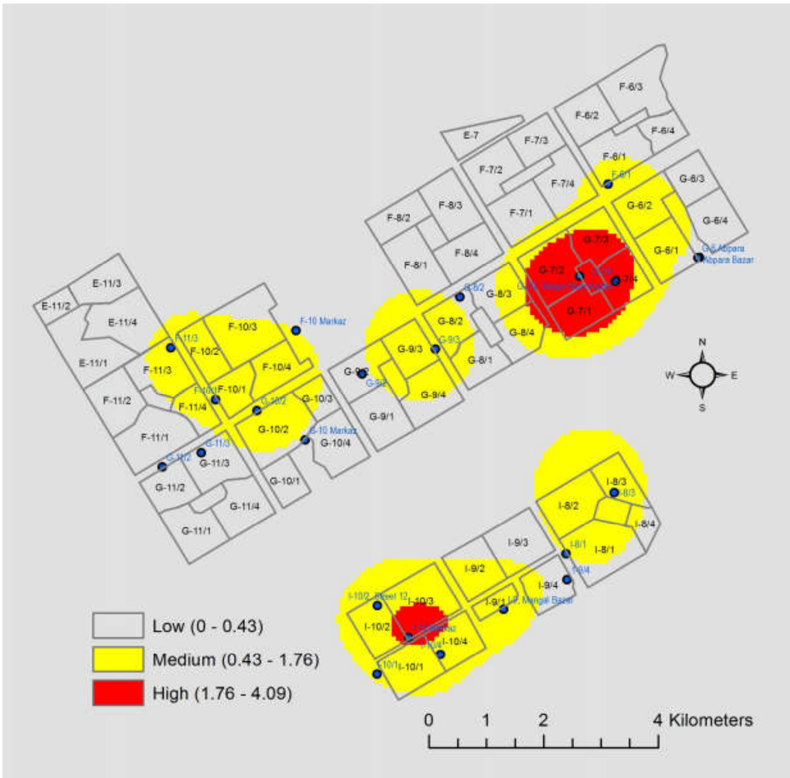


Figure 29: KD of Diarrhea around WFP (250-500m buffer) in winter

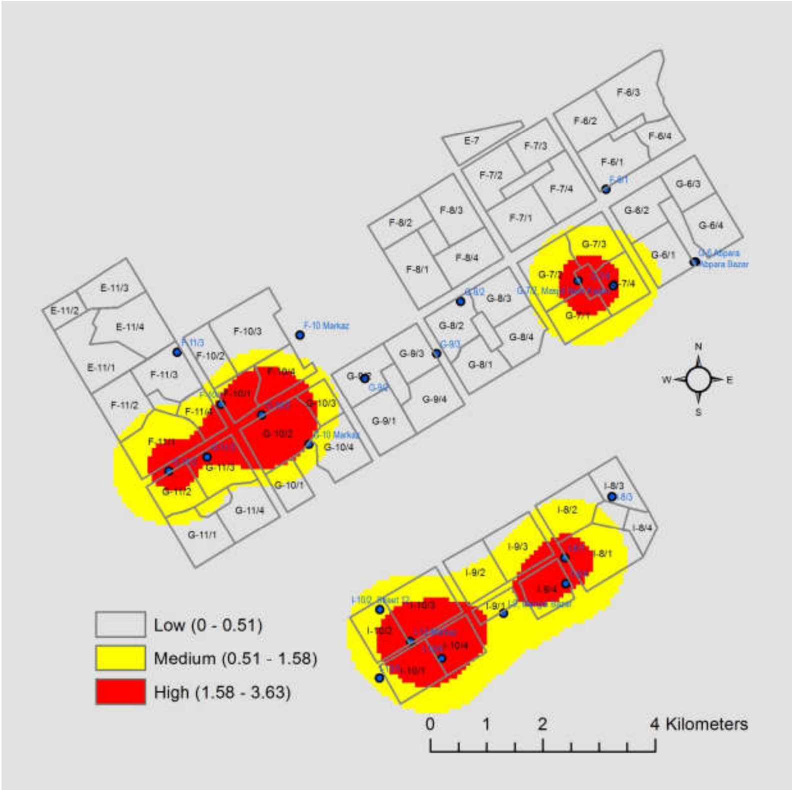


Figure 30: KD of Diarrhea around WFP (0-250m buffer) in summer

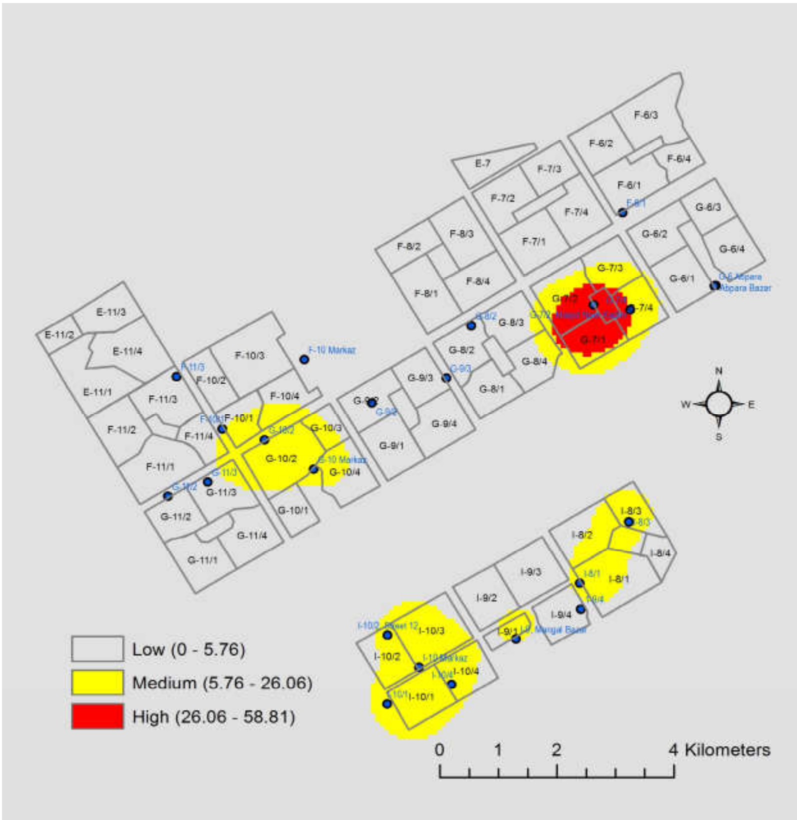


Figure 31: KD of Diarrhea around WFP (250-500m buffer) in summer

ANN result based on diarrhea incidences exhibit statistical indication of high dispersion (NNR 1.913) in winter for 0-250m with Z-score (4.280 Standard Deviations) represents confidence level of 99% that the observed spatial pattern is too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of dispersion (NNR 1.213) in winter for 250-500m with Z-score (2.413 Standard Deviations) represents confidence level of more than 95% that the observed spatial pattern too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of high dispersion (NNR 1.406) in summer for 0-250m with Z-score (4.725 Standard Deviations) represents confidence level of 99% that the observed spatial pattern too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of high clustering (NNR 0.665) in summer for 250-500m with Z-score (-9.907 Standard Deviations) represents confidence level of 99% that the observed spatial pattern too unusual to be the result of random chance.

Overall ANN results based on diarrhea incidences indicate that diarrhea patients (incidence) are low near WFP and increases farther away from WFP in summer season. Indication of dispersion changes into clustering for summer from 0-250m to 250-500m. Increase in distance from WFP (0-250m to 250-500m) does not present indication of clustering (not significant) during winter season. However, indication of dispersion was high for 0-250m in summer (NNR 1.406) and winter

(NNR 1.913) as compared to 250-500m in winter (NNR 1.213) and summer (NNR 0.665).

3.4 To explore DIR in Slum & Non-Slum?

Diarrhea patients (incidence) were 87 (16%) during winter and 533 (84%) for summer in slum area. Diarrhea patients (incidence) were 89 (18%) during winter and 483 (82%) for summer in non-slum area. The increase in diarrhea incidence is evident in both (slum & non-slum) during summer.

Total number of patients recorded for slum for both season (winter & summer) are 620 and the total number of patients recorded for non-slum for both season are 572. Population density of 2100 per Km^2 was used for non-slum area and population density of 145,741 per Km^2 was used for slum area to find DIR.

Table 4: DIR on Slum & Non-Slum Area.

Season	Diarrhea affected patients within Slum	Diarrhea Affected patients within Non-Slum	Area (Km2) within Slum	Area (Km2) within Non-Slum	Population under risk of disease within Slum	Population under risk of disease within Non-Slum	DIR for Slum	DIR for Non-Slum
Winter	87	89	0.882	43.825	128543	92032	0.0006	0.0009
Summer	533	483	0.882	43.825	128543	92032	0.0041	0.0052

The visual maps (Figure 32, 33, 34 & 35) represent density and spatial dispersion of diarrhea during summer and winter season using KD maps to present a general view of spread.

Figure 32: KD of Diarrhea in Slums during winter

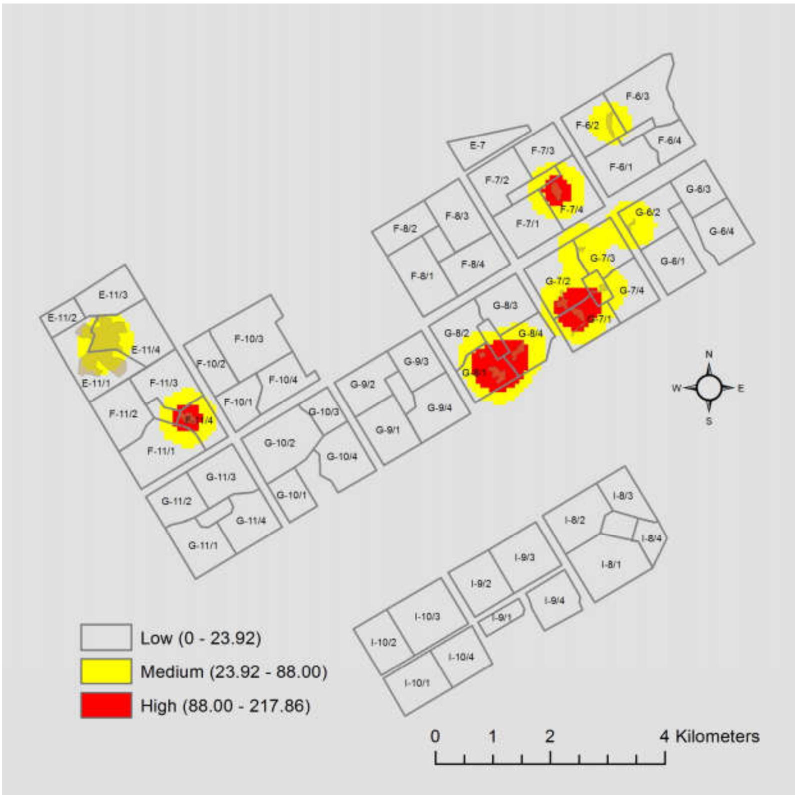


Figure 33: KD of Diarrhea in Slums during summer

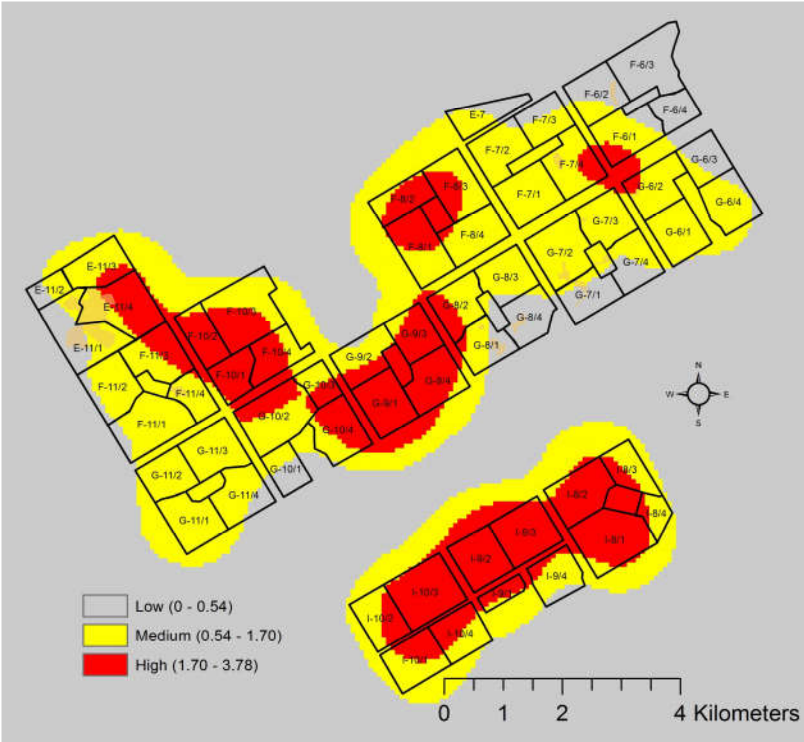


Figure 34: KD of Diarrhea in Non-Slum during winter

Figure 35: KD of Diarrhea in Non-Slum during summer

ANN result based on diarrhea incidences exhibit statistical indication of high clustering (NNR 0.635) in winter for slum with Z-score (-6.546 Standard Deviations) represents confidence level of 99% that the observed spatial pattern is too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of high clustering (NNR 0.585) in summer for slum with Z-score (-18.328 Standard Deviations) represents confidence level of 99% that the observed spatial pattern too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of randomness (NNR 1.012) in winter for Non-Slum with Z-score (0.215 Standard Deviations) represents confidence level of less than 90% that the observed spatial pattern too unusual to be the result of random chance.

ANN result based on diarrhea incidences exhibit statistical indication of high clustering (NNR 0.666) in summer for Non-Slum with Z-score (-14.006 Standard Deviations) represents confidence level of 99% that the observed spatial pattern too unusual to be the result of random chance.

Overall ANN results based on diarrhea incidences indicate that diarrhea patients (incidence) are high in summer for slum (NNR 0.585) and Non-Slum (NNR 0.666) with the indication of clustering. Diarrhea patients (incidence) for Non-Slum indicated randomness during winter (NNR 1.012). Diarrhea patients (incidence) for Slum indicate clustering during winter (NNR 0.635).

3.5 To study whether spatial dispersion of diarrhea is associated with the proximity to other covariate factors?

The ANN results from section 3.2, 3.3 and 3.4 indicate that spatial dispersion of diarrhea is associated with the proximity to covariate factors including WDS, WFP, Slum and Non-slum. Thus provide Alternate hypothesis (H_1).

Alternate Hypothesis (H_1) $_{States}$: Diarrhea patients (incidence) are high near WDS and decreases farther away from WDS. Indication of clustering changes into dispersion for winter season from 0-250m to 250-500m. Indication of clustering changes into randomness during summer season from 0-250 to 250-500m. However, indication of clustering was high for 0-250m in summer (NNR 0.488) as compared to winter (NNR 0.866).

Diarrhea patients (incidence) are low near WFP and increases farther away from WFP in summer season. Indication of dispersion changes into clustering for summer from 0-250m to 250-500m. Increase in distance from WFP (from 0-250m to 250-500m) does not present indication of clustering (not significant) during winter season. However, indication of dispersion was high for 0-250m in summer (NNR 1.406) and winter (NNR 1.913) as compared to 250-500m in winter (NNR 1.213) and summer (NNR 0.665).

Diarrhea patients (incidence) are high in summer for slum (NNR 0.585) and Non-Slum (NNR 0.666) with the indication of clustering. Diarrhea patients (incidence) for Non-Slum indicated randomness during winter (NNR 1.012). Diarrhea patients (incidence) for Slum indicate clustering during winter (NNR 0.635).

3.6 To explore Hotspot Analysis for diarrhea incidence during summer and winter?

The output from Getis-Ord GI* statistics for winter and summer represent the spatial dispersion of hotspots and coldspots:

Table 5: Getis-Ord GI result for winter*

Hotspot or Coldspot	Sectors	Comments
Hotspot >90% confidence	I-10/3 and I-8/1 **(Total Sectors: 2)**	Indication of statistically significant spatial clusters of high values (hotspots) surrounded by other features with high values.
Coldspot >90%confidence	G-8/1 and G-8/4 **(Total Sectors: 2)**	Indication of statistically significant spatial clusters of low values (coldspots) surrounded by other features with low values.
Not Significant	All the rest of the sectors in Islamabad **(Total Sectors: 57)**	

Figure 36: Getis-Ord GI statistics for winter*

Table 6: Getis-Ord GI result for summer*

Hotspot or Coldspot	Sectors	Comments
Hotspot >90% confidence	Sector F-11/1, F-11/2, F-11/3, F-11/4, F-10/1, F-10/3, F-10/4, F-7/1, F-7/2, F-7/4, G-11/3, G-10/2, G-9/1, G-9/3, G-8/2, G-7/1, G-7/2, G-7/3, G-7/4, I-10/1, I-10/2, I-10/3, I-10/4, I-8/2 and I-8/3. **(Total Sectors: 25)**	Indication of statistically significant spatial clusters of high values (hotspots) surrounded by other features with high values.
Coldspots >90% confidence	E-11/1, E-11/3, E-11/4, G-11/1,G-11/4, G-10/1, G-8/1, G-8/4, I-9/1, I-9/2, I-9/3, I-9/4, I-8/1 and I-8/4. **(Total Sectors: 14)**	Indication of statistically significant spatial clusters of low values (coldspots) surrounded by other features with low values.
Not Significant	All the rest of the sectors in Islamabad **(Total Sectors: 22)**	

Figure 37: Getis-Ord GI statistics for summer*

4. Discussion

This research presenting a method to analyze spatial epidemiology of diarrhea with respect to selected covariate factors in residential sectors of Islamabad using GIS. Hereof, the degree of spatial dispersion was examined for one year using ANN for summer and winter season in ArcMap. ANN is a test useful for the evaluation of randomness or clustering of disease points by examining the distance of each point from the closest point to it (Fotheringham and Charlton. 1994). ANN was used to find disease pattern, whether diarrhea was dispersed, random or clustered (Upton and Fingleton. 1985; Morales et al. 2008), and to resolve the questions presented in result section 3.1.

NNR of 0.491 was found during summer and NNR of 0.720 during winter with strong Z-score of -30.998 for summer and Z-score of -7.091 for winter (standard deviations away from the mean Z-score -1.65 to +1.65). The dispersion of diarrhea were found with indication of clustering during summer, winter and comply with previous studies reported about spatial clustering of diarrhea (Carter et al. 2000; Morrow 1985) by indicating the ability of diarrhea to aggregate in space and in time.

Usually, disease clusters are examined using Null hypothesis (H_0) and Alternate hypothesis (H_1) (Wartenberg and Greenberg. 1993). It' s a systematic framework followed by researchers for the study of disease clusters. The same framework was adopted by including H_0 and H_1 before going further deep into study.

Based on the evidence found in result section 3.1, the diarrhea incidence is not dispersed across the city, rather has strong Z-score to reinforce the fact that it is very unlikely that the pattern observed is the version of H_0. Mean Z-score represents a random chance with weak Z-score to reject H_0, whereas Z-score of -30.998 and -7.091 represents a longer tail of normal distribution with very weak chance of H_0 (ESRI. 2016). However, NNR for summer season show stronger clustering in comparison to winter season and indicate more confidence to reject H_0. Clustering suggests that diarrhea is not random; rather have disease patterns (H_1).

Furthermore, KD maps were used to demonstrate variability of diarrhea on different sectors of Islamabad during summer and winter. KD maps again confirmed clustering using visible pattern of diarrhea on several sectors of Islamabad with increased diarrhea intensity during summer as compared to winter. From the visual analysis of both KDs maps presented in result section 3.1, it is evident that almost all the same places are experiencing disease epidemic in both season having different intensities indicate that covariate factors must be studied further for H_1. There must be some covariate factors having their influence on the geographic spread of diarrhea if diarrhea incidence is not random? Result for section 3.1 further led to the conclusion that diarrhea incidence are aggregated (clustered) in space and in time based on clustering result found for summer and winter.

Had diarrhea incidence lacked the tendency to aggregate in space or in time, the methodology applied in this research had little relevancy due to equal risk without clustering. If diarrhea had an equal geographic distribution of disease then the possibility of clustering was nil. If diarrhea had an equal distribution of disease in summer or in winter then further questions were irrelevant, whereas ANN results found in result section 3.1 rejected the H_0 confidently and suggested H_1.

Overall the results adhering to other studies and suggest phenomenon of increase in diarrhea during summer (Gupta et al. 2007; Ramakrishnan et al. 2011), and decrease during winter (Ahmed et al. 2008). In developing countries, enteric parasites and bacteria are more prevalent than viruses and typically peak during summer months (Farthing et al. 2012). People tend to drink more water in warm and humid weather to counter-balance water evaporation due to heat and sweating, etc. The increased intake of contaminated water during summer can be linked to increased diarrhea incidence. The contaminated water was among the important risk factors identified by Griffith et al (2006).

ANN and KD maps provide indication of clustering for diarrhea in several sectors of Islamabad, and provided basis for further investigation of covariate factors influencing spatial dispersion of diarrhea. Spatial clustering in landscape is the evidence of underlying spatial processes at work. To further understand the relevance of each covariate factor (WDS, WFP, Non-Slum and Slum) and the spatial dispersion of diarrhea in Islamabad, focused test method was used using DIR, ANN and KD maps for WDS, WFP Non-Slum and Slum. A similar methodology was adopted by Chaikaew et al (2009) in another study.

Focused test method was used further using covariate factors to find clusters in residential sectors of Islamabad so that answer for the result section 3.2, 3.3 and 3.4 could be found. Hereof ANN and KD maps were used on focused areas to find the relevance of selected covariate factors on diarrhea incidence.

The results (H_1) indicated that:

- Increase in distance of a household from WDS decreases diarrhea clusters in both summer and winter season. The 250-500 meter distance from a household had NNR of 2.324 for winter and NNR of 1.016 for summer. Whereas, the distance between 0-250 meter had NNR of 0.866 for winter and NNR of 0.488 for summer. Therefore, the close proximity of a residence from WDS could be a factor contributing towards increased diarrhea exposure. However, the season may not have much effect on diarrhea vulnerability as compared to proximity which is more pronounced for WDS.
- Increase in distance of a household from WFP increases diarrhea clusters in summer season, the same could not be seen during winter season. The 250-500 meter distance from a household had NNR of 1.213 for winter and NNR of 0.665 for summer. The distance of 0-250 meter had NNR of 1.913 for winter and NNR of 1.406 for summer. Therefore, the close proximity of a residence from WFP could be a factor contributing towards the decrease in diarrhea exposure. Previous researches also reported that poor access to good water source affects the diarrhea disease variability (Pande et al. 2008), and decrease in distance from the tube well is linked with the decrease in diarrhea cases (Wu et al. 2011). However, the distance may not have much

effect on diarrhea vulnerability during winter, and indicate insignificance of proximity to WFP during winter. But the distance may have significance of proximity to WFP during summer. Rowland (1985) noted that some bacteria causing diarrhea can multiply in nutrient rich and warmth environment (summer).

- The increased diarrhea clusters were observed in slum during summer and winter with NNR of 0.585 during summer and NNR of 0.635 during winter. The Non-Slum indicated increased diarrhea clusters during summer and no influence of clustering during winter with NNR of 0.666 recorded during summer and NNR of 1.012 during winter. Therefore, it can be concluded that diarrhea vulnerability is insignificant in Non-Slum during winter but diarrhea vulnerability increases during summer. However, Slum seems to have high diarrhea vulnerability in both season.

KD maps further demonstrated clustering using visible pattern of diarrhea on several sectors of Islamabad and confirmed the results for 3.2, 3.3, and 3.4. The usage of KD maps to demonstrate the spread and intensity of diarrhea is more convenient for general public with little awareness/ background to the problem. The observed association between diarrhea incidence and urban environmental conditions are consistent with findings from other researches (Baragatti et al. 2009; Masendu et al. 2000), hence recognize the need to increase disease control programs in low income countries (Fobil et al. 2012).

The result from section 3.2, 3.3 and 3.4 indicate the covariate factors (WDS, WFP, Non-Slum and Slum) having influence on diarrhea incidence and presented Alternate hypothesis (H_1) for result section 3.5.

Furthermore, hotspot analysis (Getis-Ord GI*) results for winter and summer were obtained using cumulative DIR from WDS, WFP, Non-Slum and Slum in result section 3.6. The spatial pattern presented hotspots and coldspots during summer and winter season with increased diarrhea incidence during summer. The results clearly indicate that some sectors having more diarrhea vulnerability as compared to others from prospective of combined covariate factors. More clear understanding of spatial dispersion of diarrhea incidence in Islamabad may help in preventive measures by identifying area and population at elevated risk. This research could assist public health authorities in their efforts to control and prevent diarrhea epidemics.

Spatial modeling and mapping of disease is increasingly being used to find health matrices, guide intervention strategies and advance epidemiological understanding (Tatem et al. 2011). The usage of GIS in health sciences provides scientific and accurate ways to register, analyze, and map disease information (Naves et al. 2013).

Similarly, this study demonstrated usefulness of GIS for highlighting existing health data and conducting spatial analysis based on the data to understand and take preventive measures. Further research in this direction using other covariate factors can be conducted for more clear understanding of diarrhea epidemic in Islamabad or other cities, and for other diseases spread through water contamination. The other covariate factors assertain diarrhea risk are: education level, sanitation, waste generation, housing type and construction material, etc (Fobil et al. 2012).

The usability of ArcMap was explored in this research for finding disease patterns in relation to covariate factors responsible for diarrhea spread. ArcMap provide many useful tools to present thematic maps and spatial statistics with the ability to layer several features above each other, spatial data (point, line and polygon) can be used with attribute data (description/ information) for the creation of thematic maps and gives the ability to easily manage, analyze and present information.

Overall, GIS is an important tool for health research, surveillance, information management and analysis based on geo-referenced structured data, it can be used for other studies using the available structure in relation to surrounding environment, existing health and social infrastructure (Kandwal et al. 2009), its use in health sector of Pakistan has not been explored and there is a dire need to demonstrate the usability of GIS in health studies for developing countries.

This research highlights the role of GIS in monitoring and prevention of diarrhea epidemic (water-borne disease). The other water-borne diseases including Malaria, Shigellosis, Hepatitis, Dengue, Leptospirosis and Typhoid can also be studied using methodology presented in this research with some modification. Diarrhea and malaria both share common risk factors including environmental sanitation infrastructure and socioeconomic conditions (Fobil et al. 2012). The appreciation of GIS in planning suitable interventions for controlling epidemics is important (Kandwal et al. 2009).

This research clearly identified Islamabad' s residential sectors requiring more preventive action from diarrhea and also indicated that municipalities of the cities in developing countries should plan residential sectors farther away from WDS, ensure the availability of WFP near to residential areas, Slum should be avoided due to having more vulnerability of diarrhea during summer, and the risk of diarrhea is also present for Non Slum area especially during summer.

5. Conclusion

The study presented Alternate hypothesis (H_1): Increase in distance of a household from WDS decreases diarrhea clusters in both summer and winter season, the season may not have much effect on diarrhea vulnerability as compared to proximity which is more pronounced for WDS. Increase in distance of a household from WFP increases diarrhea clusters in summer season, the same could not be observed during winter season, the season may not have much effect on diarrhea vulnerability as compared to proximity which is more pronounced for WDS. Increased diarrhea clusters were observed in slum during summer and winter. Diarrhea vulnerability is insignificant in Non-Slum during winter but diarrhea vulnerability increases during summer

The method presented in this study could be used for other researches using GIS for more clear understanding of the involvement of covariate factors in the spatial dispersion of diarrhea and other diseases spread through contaminated water in other cities, for devising effective disease control measures.

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Appendix

Sr. No	Location	CDA_Id	Status
0	G-9/2	3	operational
1	F-10, Markaz	13	operational
2	F-10/1	14	operational
3	G-10/2	10	operational
4	F-11/3	34	operational
5	G-11/2	11	operational
6	G-10, Markaz	15	operational
7	G-7/4	6	operational
8	G-7/2, Masjid Noor Kadim	29	operational
9	F-6/1	8	operational
10	Abpara Bazar	30	operational
11	G-6, Abpara	7	operational
12	G-8/2	22	operational
13	G-9/3	4	operational
14	G-11/3	12	operational
15	I-10/4	18	operational
16	I-10, Markaz	16	operational
17	I-10/2, Street 12	20	operational
18	I-10/1	17	operational
19	I-9, Mangal Bazar	19	operational
20	I-8/1	21	operational
21	I-8/3	1	operational
22	1-9/4	2	Operational
	Total 1-22		

Appendix 1: Detail of Water Filtration Plants used in this Study

Slum No.	Slum Name	Location	Area (Km2)	NO of Individuals
1	France Colony	F-7/4	0.037	6000
2	Christian Colony-100 Quarters	F-6/2	0.032	6150
3	Kachi Abadi-48 Quarters	G-7/3	0.005	2390
4	Kachi Abadi-66 Quarters	G-7/2	0.034	4100
5	Shopper Colony	G-7/1	0.038	3700
6	Dhobi Colony	G-6/2	0.009	250
7	J Salak Colony	G-8/1	0.008	1165 (estimated)
8	Bheka Saiyidaan	F-11/4	0.041	5975 (estimated)
9	Golra	E-11/1	0.577	84092 (estimated)
10	Kachi Abadi	G-8/4	0.032	4663 (estimated)
11	Kachi Abadi	G-7 Markaz	0.018	2623 (estimated)
12	Christian Colony	G-8/1	0.047	6849 (estimated)
	Total 1-12		0.882	127,957

Appendix 2: Detail of Slums used in this Study

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