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Spatio-Temporal Extension and Spatial Analyses of Dengue from Rawalpindi, Islamabad and Swat during 2010–2014

Nadeem Fareed [1,2,*], Abdul Ghaffar [3] and Tahir S. Malik [4]

[1] Department of Meteorology, COMSATS Institute of Information Technology, Park Road Chak Shahzad, Islamabad 44000, Pakistan
[2] Department of Earth Sciences, Quaid-e-Azam University, Islamabad 44000, Pakistan
[3] Department of Meteorology, COMSATS Institute of Information Technology, Park Road Chak Shahzad, Islamabad 44000, Pakistan; aghaffar@comsats.edu.pk
[4] Dengue Ward, Holy Family Hospital, Rawalpindi 46000, Pakistan; tahirsharif55@yahoo.com
* Correspondence: nadeemfareed32@gmail.com; Tel.: +92-324-500-8638

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Abstract: Climate change and Land-Use Land-Cover change (LULC) has significantly displaced the local rainfall patterns and weather conditions in Pakistan. This has resulted in a different climate-related problem, particularly vector borne diseases. Dengue transmission has emerged as one of the most devastating and life threatening disease in Pakistan, causing hundreds of deaths since its first outbreak. This study is designed to understand and analyze the disease patterns across two distinct study regions, using Geographic Information System (GIS), Satellite Remote Sensing (RS) along with climate and socio-economic and demographics datasets. The datasets have been analyzed by using GIS statistical analysis techniques. As a result, maps, tables and graphs have been plotted to estimate the most significant parameters. These parameters have been assigned a contribution weight value to prepare a model and Threat Index Map (TIM) for the study areas. Finally, the model has been tested and verified against existing datasets for both study areas. This model can be used as a disease Early Warning System (EWS).

Keywords: climate change; dengue; spatial analyses; spatial epidemiology; statistical analyses; EWS; GIS; RS; tropical diseases

1. Introduction

Dengue fever has become one of the most prominent infectious diseases in the world. The disease is present in almost 120 countries of the world [1]. Dengue is the second prevailing *Flavivirus* infection after malaria. Dengue Fever (DF) is responsible for 400 million cases and at the same time, Dengue Hemorrhagic Fever (DHF) affects from a few hundred to thousands of cases each year. In the past 50 years, the disease has increased 30-fold with an annual increment of 50 million cases [2]. DF is a fast growing and spreading infectious disease in tropical and subtropical countries [3,4]. In Pakistan, the very first epidemic of Dengue has been reported for two consecutive years 2005–2006 in the Southern part of the country, 3640 cases have been diagnosed with signs and symptoms of Dengue fever and 40 deaths have made it an unprecedented outbreak [5]. Therefore, it is important to know the spatial distribution, the behavior of the climate and the social covariant towards the spread of this disease at the micro level to indicate the high-risk areas from Rawalpindi, Islamabad and Swat. Though Dengue has become the most important vector-borne disease in Pakistan over the last decades, the published scientific research is still inadequate to address the local situation regarding the outbreak patterns of Dengue spread [6–8].

The Dengue vector is very sensitive to meteorological and seasonal conditions, which directly affects its distribution patterns [9]. Temperature can exert considerable influence over mosquito population dynamics, feeding habits and virus development [10]. Egg and immature mosquito development and ovarian development at all stages of mosquito life are governed by temperature. The female mosquito's reproductive cycle is also greatly influenced by ambient temperature, for instance fertilization also decreases when temperature is less than 20 °C. *Aedes Aegypti* needs a blood meal for ovarian development, which is also affected by temperature. Feeding activity ceases at a temperature less than 15 °C. Exposure to extreme temperatures causes increased mortality of adult mosquitos [11]. *Aedes Aegypti* egg, larvae and papua development rates increase at higher temperatures and cease at less than 8.3 °C [12]. Water temperature plays an important function for mosquitos breeding and reproduction: *Aedes Aegypti* prefers cooler water and a shaded container to lay the egg [13,14]. *Aedes Aegypti* sustains across a wide range of temperatures and humidity while *Aedes Albopictus* does not. This is the reason that *Aedes Aegypti* is dominant in urban settings while *Aedes Albopictus* prefers Peri-urban settings [15]. Temperature and rainfall work interdependently; rainfall provides the habitat for mosquito early life and at the same time, higher temperature increases the evaporation process and decreases stagnant water. The combination of higher temperature and rainfall increases the evaporation process. As a result humidity increases and higher humidity causes higher feeding rates, survival and better development of *Aedes Aegypti* [10]. Competition for space and nutrients grows higher, when temperature and evaporation rates increase, making a habitat less ideal for egg laying [16]. Dengue vector lays the egg in water, precipitation provides an important habitat for mosquito early life cycle and development. Containers in the urban environments provide an excellent habitat for larval production [17]. Mosquito range expands during wet conditions (La Nina) and declines during dryer conditions (El Nino) [18,19]. The geographic variations in the intensity of transmission of vector-borne diseases have been observed all over the globe [20]. Generally, it is accepted that targeting the transmission hotspot, and vector ecology, details are important components for vector eradication and elimination strategies [21]. The number of nutrients in stagnant water is an important factor for *Aedes Aegypti* larval development and survival. Containers with higher organic content increase the larval development rate, growth and survival [11]. Climatic factors also promote competition between different species of mosquito. *Aedes Aegypti* and *Aedes Albopictus* have overlapping habitat distributions. The sign and strength of climate-DENV associations depend largely on local climate context [22]. Specific and relative humidity increases along the rivers and streams running through urban areas. Humidity impact is dominant over a 100 m distance from a river or stream. Other urban areas have a lower relative humidity [23].

Most environmental factors currently included in disease outbreak models are related to meteorological or climatic conditions [24]. Land-Use-Changes (LUC) have been noted to contribute in emerging and reemerging of different vector-borne diseases. Many disease outbreak models do not depict the impact of land cover on vectors, nor do they show land-use as a predictor of human activities. DF used to be confined to the urban area of Thailand but recent studies suggest that it has moved to Peri-urban and rural areas as well, which is a result of better and faster transport facilities, but another reason for this change in the space and time of this disease is land-cover change. Large areas of forests in Thailand have changed to agricultural land, ultimately resulting in housing and living in mosquito's habitat [25,26]. A close relationship has been identified between moisture content, vegetation canopy and mosquito breeding sites. *Aede's* egg and adults survive in places; where sufficient moisture content is available. Canopy cover is associated with a high density of Dengue egg and larval occurrence. The canopy cover reduces wind speed and protects *Aede's* habitat from direct sunlight. Several studies suggest a strong link between poverty and Dengue occurrence and transmission in rural as well as in urban settings. Poor localities have some specific characteristics, which favor Dengue transmission. Poorer localities in any locale cannot support and manage their local environment, basic living standards, sanitation and reliable water supply. Lack or all these characteristic conditions may contribute to high Dengue transmission. Thus, areas with higher relative poverty are expected to be more vulnerable to Dengue occurrence and transmission.

Introduction and reintroduction of the Dengue virus have been strongly attributed to human movements at different national and international scales. The global spread and transmission of Dengue virus occur due to the large-scale, periodic and spatial displacement of goods. Globalization has played an important role in the rapid dispersion of both vectors and hosts at climatically suitable locations. The urban environment is composed of many factors which are favorable for Dengue transmission. These factors include rapid population growth, vector breeding sites due to poor hygiene, household management and local environment management, particularly in public places and facilities [16].

Satellite Remote Sensing (RS) provides cost effective datasets, which can easily be obtained, and available at different spatial and temporal resolutions. It is particularly important to understand the regional hydrology, vegetation cover, elevation and topography [27].

The objective of this study is (1) to study the social, climate and demographic covariant on Dengue outbreak, (2) to discover the associations between different environmental and manmade parameters using statistical analysis using univariate and bivariate analysis among all the possible variables associated with outbreaks, (3) the Identification of parameters which can be controlled by human contribution through EWS and awareness, the identification of indoor-outdoor breeding sites, and to find out why the disease has been extending toward higher latitudes.

2. Materials and Methods

2.1. Study Area

The study areas consist of two different and diverse locations in Pakistan. The first locations are the Rawalpindi-Islamabad also named twin-cities, while the second location is the Swat district of Khyber Pakhtunkhwa (KP) Province.

Islamabad Capital Territory (ICT) of Pakistan, located north of Rawalpindi is spread over an area of 902 km^2 and has an elevation of 311–2286 m above the sea level. Islamabad is a well-planned city whose foundation was laid in 1960. On the other hand, Rawalpindi is a much older and larger city covering a total area of 5258 km^2 [28].

The Swat is an administrative district located in the north of KP Province. The district is situated within the high mountains of Chitral and Gilgit in the north, Dir in the west and Mardan in the south while the Indus River separates the district from the Hazara district in the east. The Swat district consists of two administration levels (Tehsils) namely Matta (683 km^2) and Swat (4654 km^2). Topographically, Swat is a hilly region with mountain ranges (734 m–5946 m) (Figure 1) [29].

According to population census of Pakistan, Population for both study areas is rapidly increasing with time (Table 1). Due to growing population in both regions, Dengue cases have also been increased dramatically (Table 2).

Table 1. Population profile of the Rawalpindi-Islamabad and Swat [30].

Year	Swat (Population)	Rawalpindi (Population)	Islamabad (Population)
1998	1,257,602	3,363,911	529,180
2013 *	2,137,000	4,786,392	919,000

* estimated values.

Table 2. Dengue Fever (DF) Cases in the Rawalpindi-Islamabad and Swat [31,32].

Year	Rawalpindi (Cases)	Islamabad (Cases)	Swat (Cases)
2010	0	0	0
2011	666	201	0
2013	784	180	6376
2014	1118	254	306

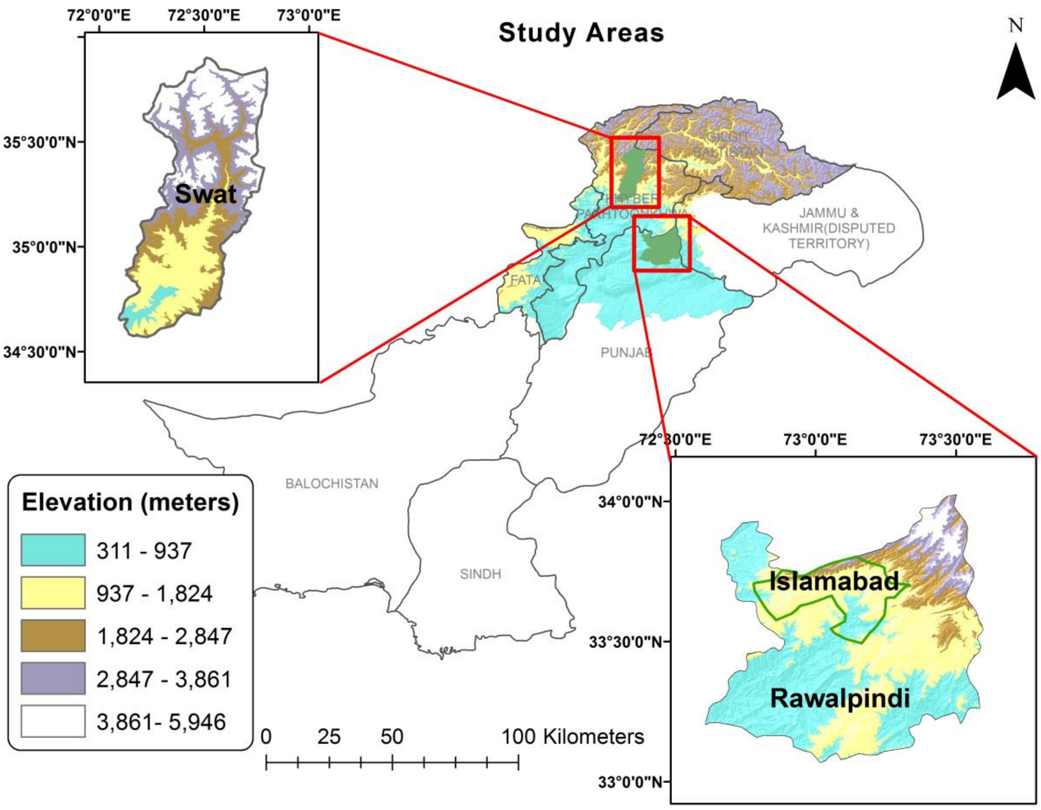


Figure 1. Location map of the two study areas, Rawalpindi-Islamabad Punjab and Swat.

2.2. Methods

The Dengue cases data for the first study area, Rawalpindi city, has been collected from the District Coordination Officer (DCO), Holy Family Hospital Rawalpindi, Benazir Bhutto Hospital Rawalpindi and data for Islamabad have been collected from Polyclinic Islamabad [33,34]. The second study area was the district of Swat. The Dengue cases data has been collected from Saidu Sharif Hospital Mingora Swat [35]. All the Dengue cases have a temporal signature (day) and have been geo-referenced by using Google earth's places and entered into GIS database in terms of their latitude and longitude. Most of the cases have been geo-referenced up to street, road and town level. This level of administration falls under the category 5 administration level. This administration scale has been set as a study unit.

The climate data (temperature, rainfall) has been collected from Pakistan Meteorological Department (PMD) Islamabad [36]. To map and plot the Dengue cases against climate indices, the above-mentioned data was collected for the full 365 days of each year from 2010 to 2014. However, the above-mentioned data was only extracted and used for six months from July to December. In Rawalpindi-Islamabad and Swat, most of the Dengue cases happen between these time periods. The Landsat 30 m resolution data has been acquired for years 2010 to 2014 for Rawalpindi-Islamabad. The data consisted of different Landsat sensors (TM4, TM5, ETM-7+, OLI). The data for two years, 2010 and 2014, has been acquired and classified to find the LULC changes for Swat [37]. Digital

Elevation Model (DEM) has been acquired for both study areas. The elevation data has been obtained from the ASTER sensor of the MODIS Terra satellite [38]. Similarly, different vector datasets have been acquired from diverse sources including OpenStreetMap (OSM), DIVA-GIS and Geocommons. OSM data consisted of roads, railways, parks, schools, mosques, graveyards, playgrounds, forest covers and places While, DIVA-GIS and Geocommons have been used to download the admin boundaries for respective study areas. Other vector datasets, which have been acquired from different sources, includes town-level administration boundaries for Rawalpindi and Swat. Datasets have been formatted, cleaned and managed in a GIS database. The satellite data has gone through different processes, which include, layers stacking and mosaicking, subsetting and radiometric corrections. Similarly, vector datasets have gone through a process of clipping, classification and cleaning. Remotely sensed data has been classified using supervised classification schemes. In this process, training areas for different classes have been selected from different locations of the image. Each training area represents a particular land-cover. Elevation data has been used to extract drainage patterns of the Rawalpindi-Islamabad as well as the district Swat. Finally, all the processed data has been entered into a GIS database. The data has been managed into different layers to perform statistical and GIS analysis (Figure 2).

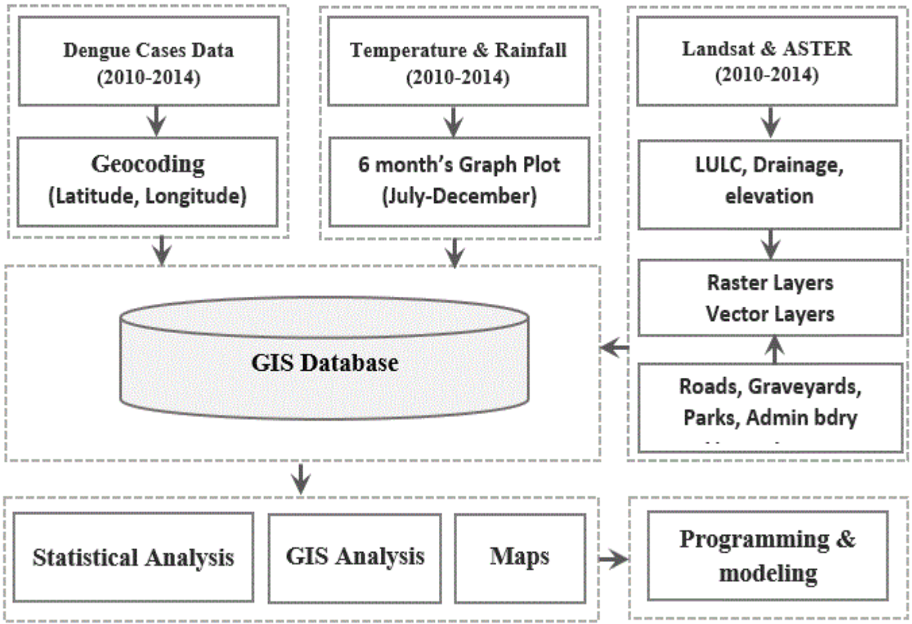


Figure 2. Flow diagram of data collection, pre-processing, processing and analysis.

In the case of inside breeding sites locations, multiple variables have been collected through telephonic and door-to-door surveys. More than 500 people have been interviewed around the city for the time period (2011–2014). The collected variables include house type, house population, the number of Dengue patients, house's garden, flower pots, in-house water storage containers, the number of the washroom, the number of rooms and the number of buildings. The most frequent variables which have been identified during the survey were: empty plots, playgrounds, cemeteries (Graveyards), parks, building construction sites and mosques. The real location data has been collected by using smartphone GPS with the help of an android application named "Geopaparazzi" [39]. This sample data has been used to conduct the regression analysis to find the impact of indoor and outdoor breeding sites.

The Rawalpindi-Islamabad have more than 124 cemeteries (graveyards) in the urban areas. Similarly, parks also provide a habitat for *Aedes*. They have plenty of trees, plants, shrubs, water fountains and tube-wells. These parks have proven to be an excellent breeding site for *Aedes*. The other variables include forests, planned and unplanned urbanization, House Density Index (number of houses in 100 m radius), and house types in urban areas like independent houses, mixed houses and interconnected houses. The independent houses have a good gap to the next neighbor. The areas having independent as well as inter-connected houses are named as mixed houses and finally, areas with a high density of inter-linked houses are known as interconnected houses. The independent houses have a minimum impact in DF occurrences while interconnected houses have a high impact due to high population, poor drainage, high humidity and high temperature in the monsoon season. Each variable has been converted into a raster layer with its weighted values. Weights have been assigned on the basis of feature threat index. A low value means a lower threat index while a higher value means a higher threat index.

Finally, a number of GIS analyses were performed. Theses analyses includes: Point pattern analysis (Density analysis), hotspot analysis, Spatio-Temporal analysis, regression analysis and overlay analysis. The prepared datasets consist of two formats, namely, point format and polygon format. In Density analysis, the point data has been used to find the hot areas for DF outbreaks. Density analysis can be run against point or line data, which result in a raster dataset. This raster dataset shows the areas with maximum to the minimum occurrence of a particular problem. Hotspot analysis is similar to density analysis in terms of results, but this analysis can be performed for a polygon vector dataset. This analysis also runs against the total number of DF cases for each administration. This analysis is more useful than density analysis when the input dataset consists of polygons instead of point's clusters. The variables, namely: graveyards, parks, water-bodies and stream channels, House Density Index, urbanization type and house type were involved in the study. Overlay analysis tools of spatial analyst extension of ArcGIS 10.2 (ESRI, Redlands, California, United States) have been used to perform weighted sum and weighted overlay analysis. The climate indices have been plotted against temperature, rainfall and DF cases for both study areas. The Ordinary Least Square (OLS) regression models have been run against collected variables. This analysis has been performed against indoor variables, outdoor variables and finally combined analysis in which both types of variables were involved.

3. Results

3.1. Relationship between Temperature, Precipitation and Dengue Cases

The Dengue incidence is much longer for the Rawalpindi-Islamabad, which lasts for six months from July to December. This time period is much shorter for Swat which lasts for three to four months. July and August are months of heavy rainfall, with few DF cases for the Rawalpindi-Islamabad, while the DF occurrence is a little higher in the Swat for these months. The temperature for these months fluctuates between 20 °C and 38 °C for Rawalpindi-Islamabad. However, it is a little bit lower for Swat, which ranges from 18 °C to 37 °C. Most of the DF cases were recorded in the months of September, October and November for the Rawalpindi-Islamabad. These months showed low rainfall periodically, with temperature ranges from 20 °C to 30 °C. On the other hand, DF cases have been noticed only for August, September and October in Swat. Both study areas have clearly shown a sharp peak of DF cases after rainfall in these months. Moreover, the length, size and interval of DF outbreaks for each month are highly correlated with the patterns of rainfall. In 2013, a more serious Dengue outbreak has been recorded in Swat with 6376 confirmed DF cases [32]. A very unique 12 mm rainfall spell has been observed in the month of July and some smaller spells in August and September 2013 in Swat. This unique rainfall spell has provided excellent breeding sites in terms of ample stagnant water. The consecutive smaller spells have made the conditions stable and long lasting during August and September. The graph plot also indicates that Dengue was absent during rainy season. On the other hand, in the Rawalpindi-Islamabad, a similar unique 20 mm rainfall spell has also been observed in September 2011. The DF outbreak in 2011 was very significant for the Rawalpindi-Islamabad. Furthermore, the years 2013 and 2014 have shown similar weather trends and DF occurrence for the Rawalpindi-Islamabad (Figure 3a–c).

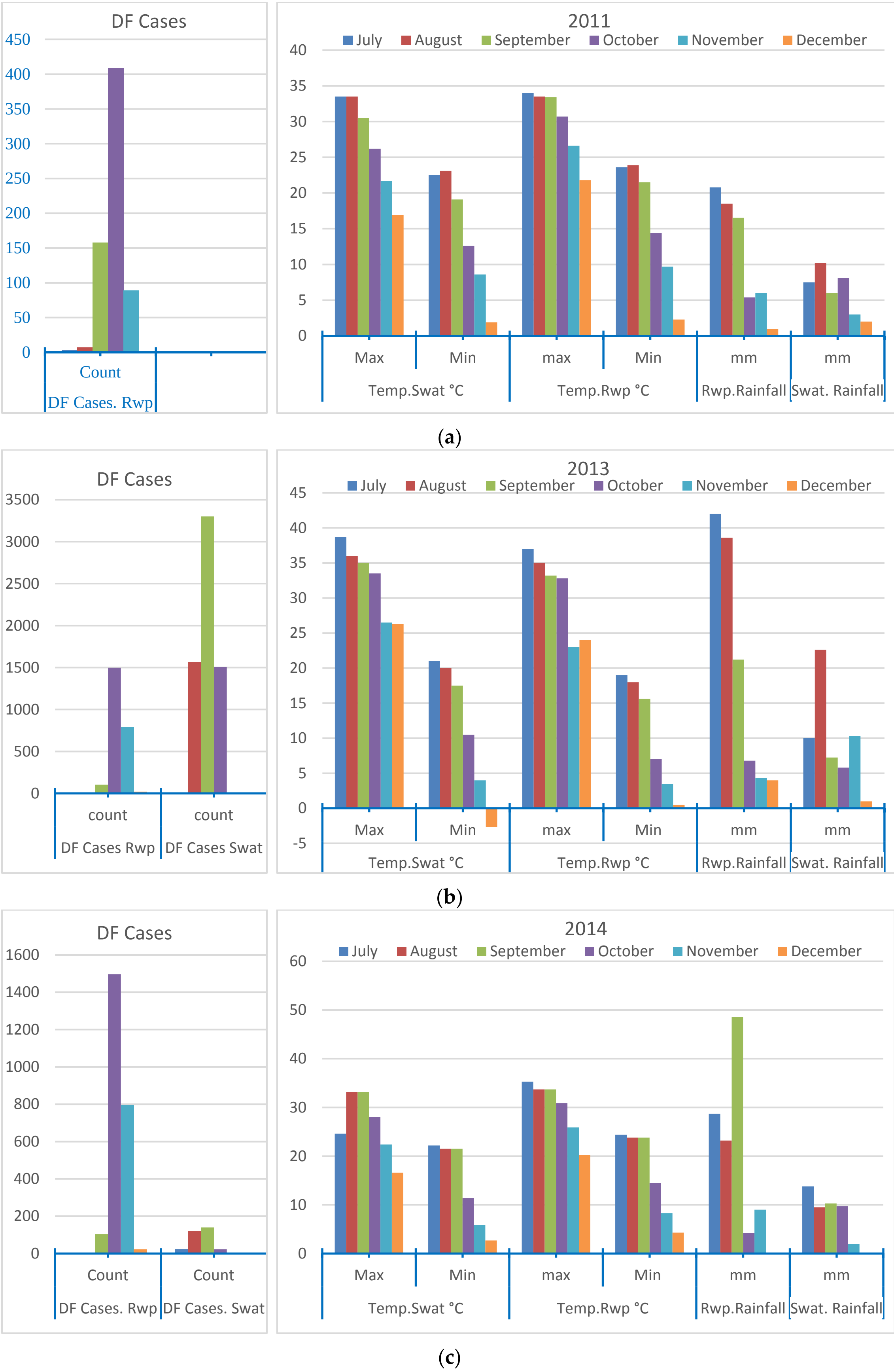


Figure 3. Climate indices for Rawalpindi-Islamabad and Swat *vs.* DF cases for year 2011, 2013 and 2014. (**a**) 2011; (**b**) 2013; (**c**) 2014.

In terms of years, 2010 and 2012 have been observed as particularly clean years with few DF cases for both study areas. The climate indices clearly depict a very long and heavy rainy season that started in July and terminated at the end of December (6 months long) for both years. The precipitation intensity was much higher for these months with maximum 45 mm and minimum 7 mm (Figure 4a,b).

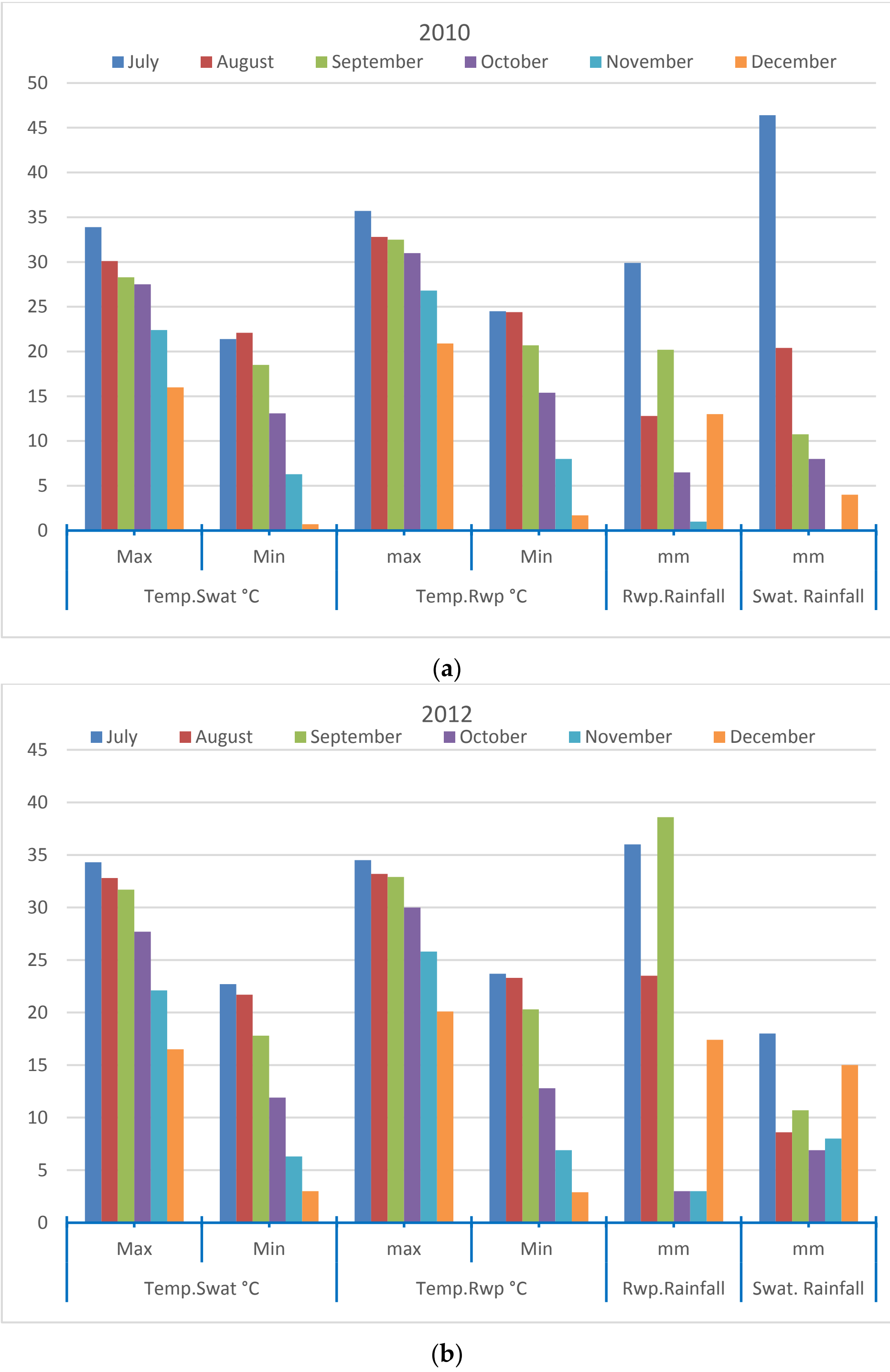


Figure 4. Climate indices for Rawalpindi-Islamabad and Swat for year 2010 and 2012. (**a**) 2010; (**b**) 2012.

3.2. Relationship between Elevation, Drainage Patterns, and Dengue Cases

The elevation profile of the Rawalpindi-Islamabad and Swat has also been thoroughly observed: cases were occurring in the elevation ranges from 281 m to 688 m for the Rawalpindi-Islamabad, while this range was much higher for Swat, which ranged from 712 m to 1600 m. However, in both study areas, DF cases were happening in low-lying urban areas.

The detailed drainage network of both study areas clearly demonstrates that most of the DF cases were reported in high-density drainage areas. Both study areas have streams and canals running through the urban areas. In the Rawalpindi-Islamabad, DF cases occurred where most of the streams and canals terminated in Nala Lai. A similar situation has been observed in the Swat. Due to the mountainous topography, both study areas are composed of very dense drainage-patterns (Figure 5a,b).

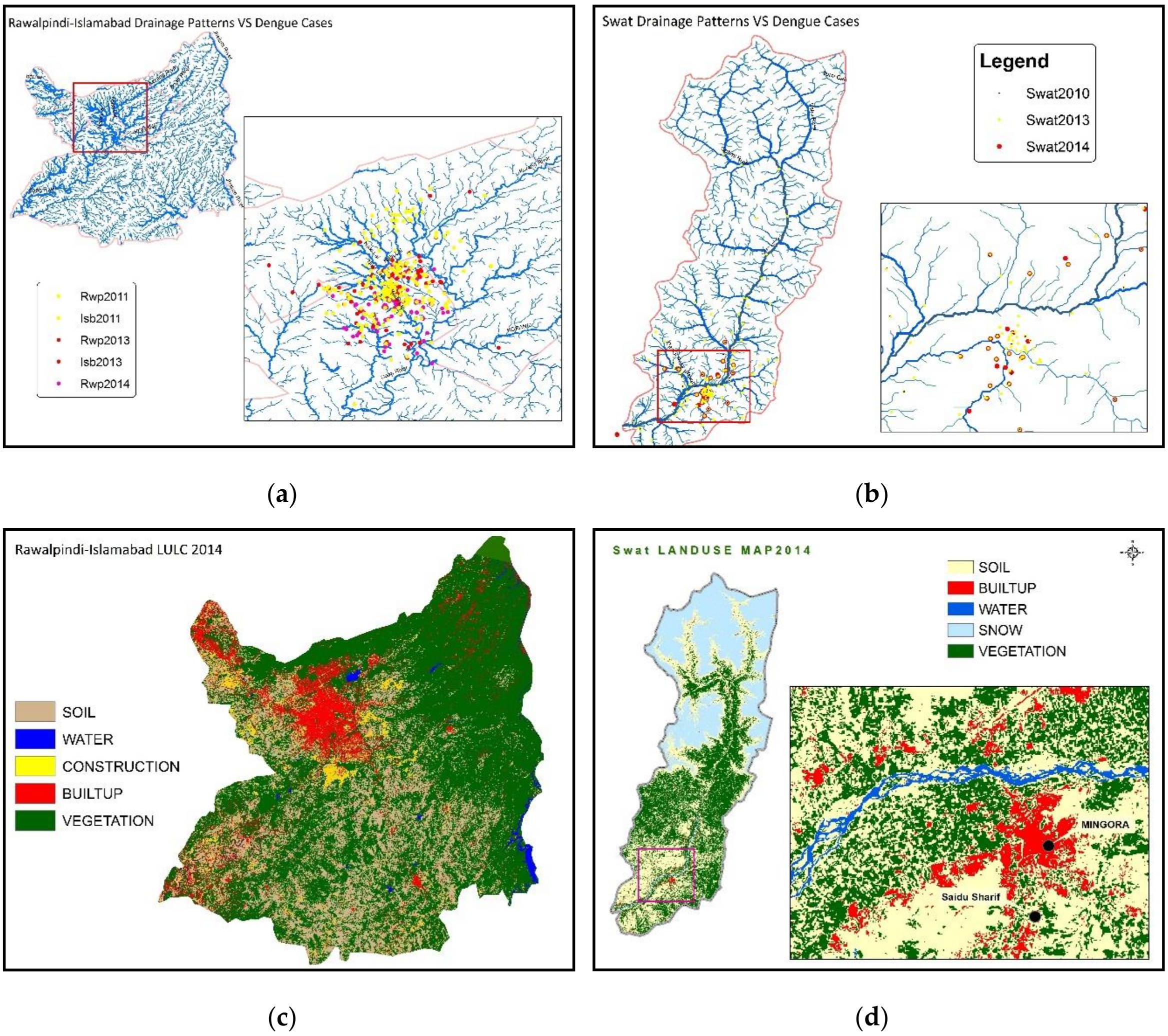


Figure 5. Dengue Cases Distribution and their relationship with Drainage patterns and Land-Use-Land-Cover (LULC) for Rawalpindi- Islamabad and Swat. (**a**) Drainage Pattern Rawalpindi- Islamabad *vs*. Dengue cases; (**b**) Drainage Pattern Swat *vs*. Dengue cases; (**c**) LULC Rawalpindi-Islamabad 2014; (**d**) LULC Swat 2014.

3.3. Impact of LULC on Dengue Transmission

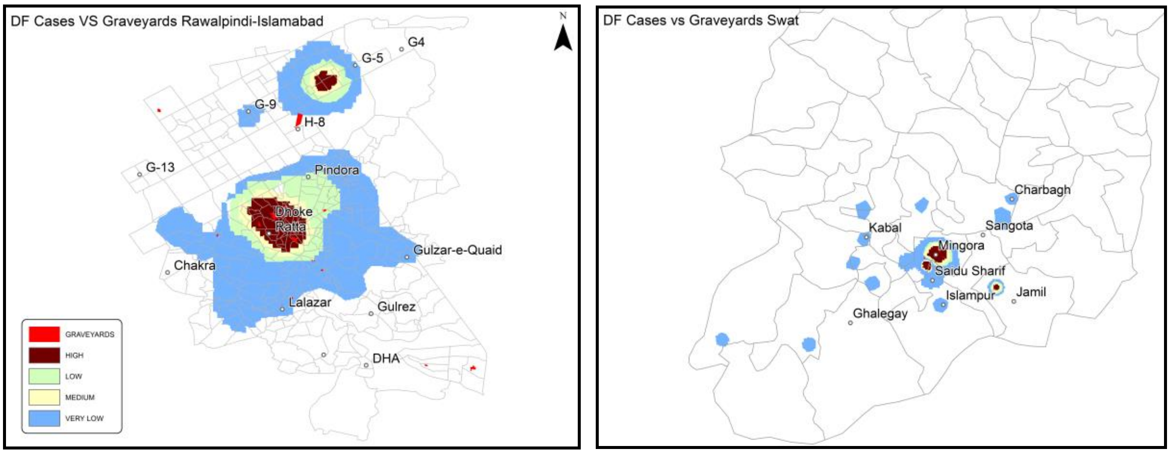
In both cities LULC has been analyzed for time periods of five years (2010–2014). In the Rawalpindi-Islamabad, the urbanization was 224.8 km^2 in 2010, which has been increased by two-fold, resulting in 345 km^2 in 2011. Urbanization gradually increased, terminating at 522 km^2 in 2014.

Additionally, a Metro-Bus project has also been initiated through the city during same time period. Construction activities have remained at their peak during this time span. On the other hand, no significant LULC changes have been noticed in Swat. The urbanization has increased to 47 km^2 in 2014, which was 41 km^2 in 2010. There are sharp changes in other LULC features like soil, water and vegetation. However, most of the Dengue cases are not happening in regions of high construction activities (Figure 5c,d).

3.4. Point Pattern Analysis of Dengue Transmission

Hotspot mapping is an important technique to map and model crime and other socio-economic data. Kernel Density Estimation (KDE) is one of the most widely accepted methods to generate continuous hotspot surfaces maps [40,41].

The areas with high occurrence are shown with red color and locations with a minimum occurrence of the problem are shown with blue color. There is a gradual transition from low values to high values, which can be seen by changing colors. This type of analysis helps to identify the hottest locations of the study area. The same analysis has been used to identify the locations of high DF occurrence. The analysis has been done yearly to find the most consistent high DF occurrence areas. Finally, a composite density analysis has also been done to find the overall effect of disease in the study area. The density analysis output has also been correlated with other land-cover variables like cemeteries (graveyards) and drainage patterns. Density analysis for the five years clearly predicts that the same areas are suitable for DF occurrence. There are two hotspots for the Rawalpindi-Islamabad; one in Rawalpindi and the other one in Islamabad. In a similar way, Swat also has shown two hotspot areas (Figure 6a,b) [42].

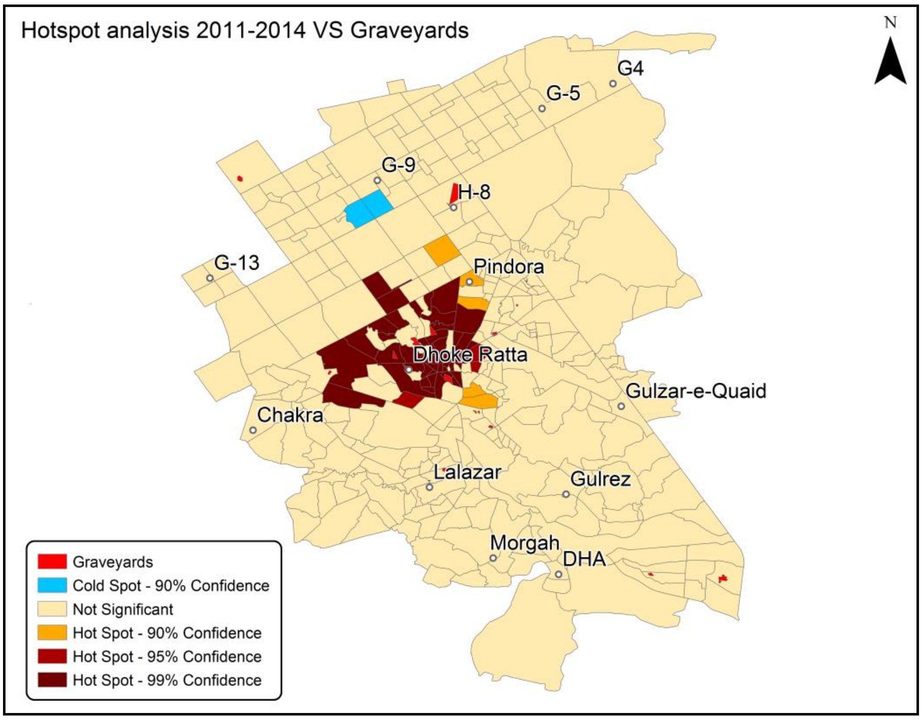


(**a**) (**b**)

Figure 6. Density Analysis of Dengue cases for five years (2010–2014) and their relationship with graveyards [37]. (**a**) Rawalpindi-Islamabad; (**b**) Swat.

3.5. Spatio-Temporal and Hotspot Analysis of Dengue Transmission

Density analysis suggests a clustering in datasets but not their statistical significance. Hotspot analysis provides statically significant hot and cold areas in datasets. This analysis works statistically and maps the areas into three categories: areas with a high occurrence of DF cases in red color as well with percentage confidence level. Similarly, areas with low or minimum DF occurrence are shown in blue color and finally, areas, which do not show any significant DF cases occurrence were marked as not significant (Figure 7a,b). Similarly, point events like disease and crime do happen in space with different time lapses, if both time and location data are available for such events. Temporally, they can be modeled as space-time point processes [43,44]. The DF Cases have been recorded in space with their time of the incident. The data cover a span of five years, which have been plotted yearly to find the spatiotemporal relationships. These relationships predict the shift in disease location with time. The spatiotemporal analysis was carried out to find the cases distribution in real time. These analyses also suggest that the disease has been shifting itself spatiotemporally to neighboring towns and peripheries every year (Figure 8a,c).



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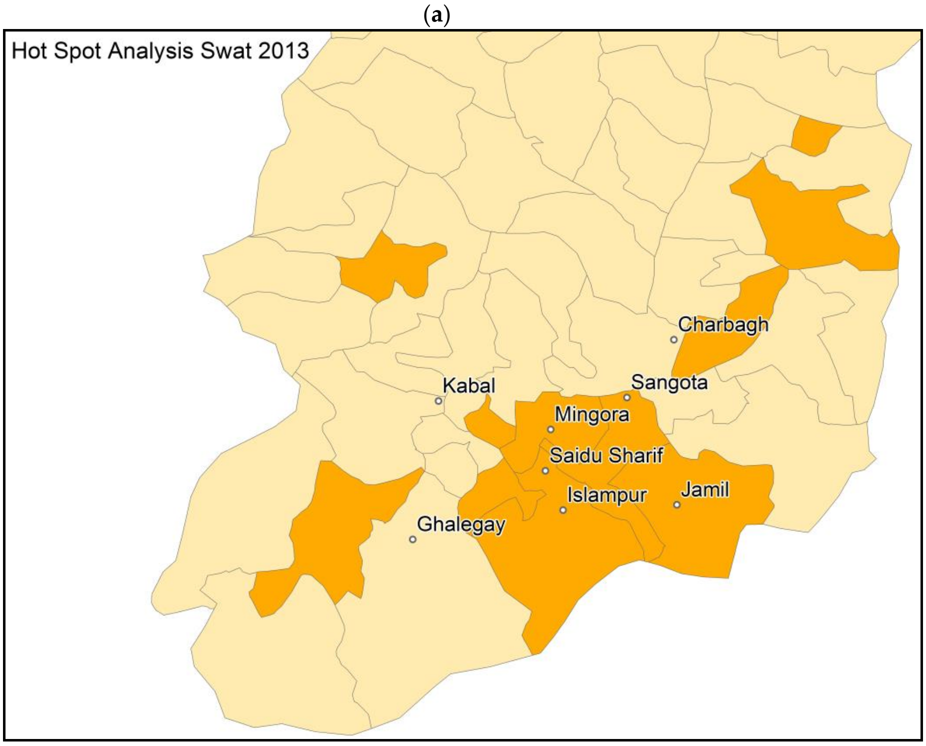
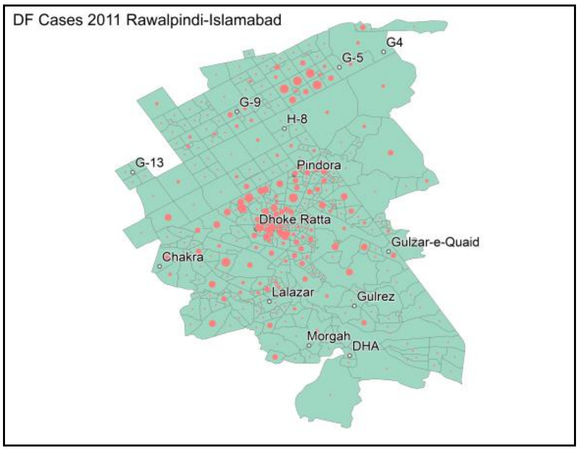


(**b**)

Figure 7. Hotspot analysis for Rawalpindi-Islamabad and Swat its relationship with graveyards. (**a**) Rawalpindi-Islamabad 2011-2014; (**b**) Swat 2013.



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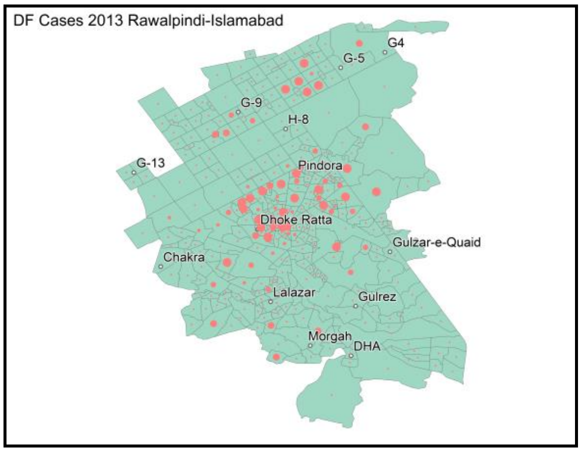

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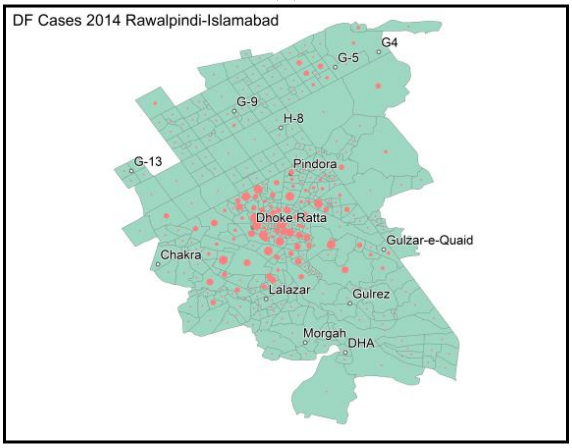

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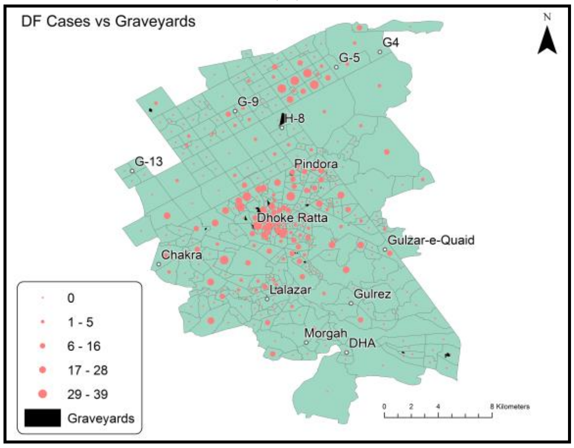


(**d**)

Figure 8. Spatio-temporal analysis for Rawalpindi-Islamabad and its relationship with graveyards. (**a**) 2011; (**b**) 2013; (**c**) 2014; (**d**) DF cases *vs*. Graveyards.

3.6. Regression Analysis and Dengue Transmission

Regression analysis is a statistical analysis technique, which is defined and designed to estimate and assign the weight of independent variables with dependent variables [40]. OLS regression models have been run against surveyed data for indoor and outdoor habitats. The results have been displayed in Table 3.

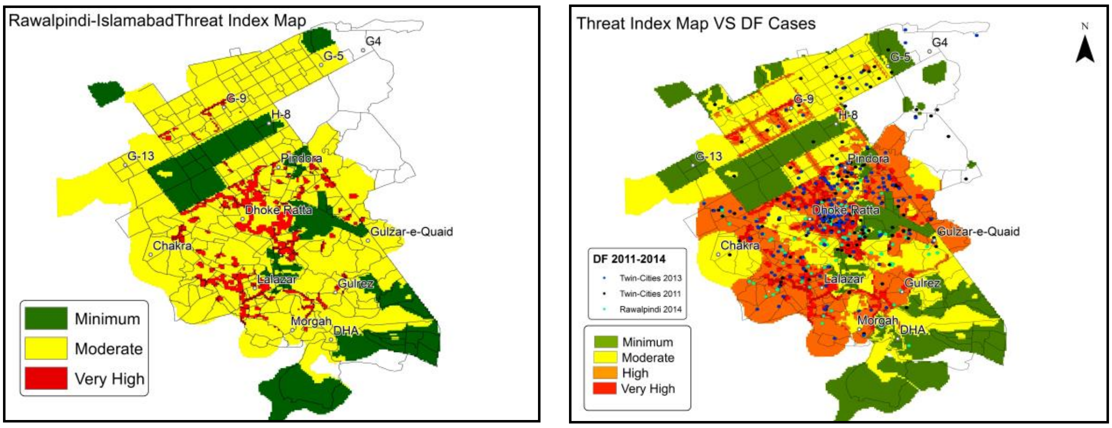
Table 3. OLS *R*-value results for indoor and outdoor variables.

Variable	R^2	Adjusted R^2	Distribution
indoor	0.54	0.39	Normal
outdoor	0.28	0.12	Normal
Indoor-outdoor	0.60	0.30	Normal

3.7. Overlay Analysis

Finally, overlay analyses have been done on the basis of identified variables involved in the DF outbreak. There are a further two types of overlay analyses; weighted sum and weighted overlay. This type of analysis required different layers with their respective weight or threat index number to indicate their impact on the study area. These layers were multiplied or summed-up with each other to produce a final map. In the case of DF occurrence, the outcome has been categorized as

Minimum, Moderate, High and Very High. The Dengue cases have been plotted against the model results (Figure 9a,b). The weights have been assigned on the basis of literature review, ground survey, patient's interviews and spatial analyses. The two analyses can be performed to find the threat zones or suitable areas using different layers and their respective weight values to produce one final map. On the basis of survey results and multivariate statistical analyses, multiple habitat and habitat supporting variables have been identified. These variables are graveyards, parks, empty plots, water bodies, construction sites and playgrounds. Additional factors which strongly influence the DF occurrence, are house density index, urbanization type and House types (Figure 10).



(**a**) (**b**)

Figure 9. Threat Index Map (TIM): (**a**) Weight Overlay; (**b**) Weighted Sum *vs.* DF cases data.

3.8. TIM Geoprocessing Model

An automated model has been implemented which takes different raster input layers and produces a Threat Index Map. These layers have been assigned a weight value as indicated in Table 4. The layers have been shown in Figure 10. This model is useful for any study area facing Dengue epidemics.

Table 4. DF raster input layers and their respective weight value [45].

Number	Raster Layer		Threat Index
1	Parks	Playground/play land	1
		Small park	1
		Small park with trees	2
		Public park	3
2	Urbanization Type	Planned	1
		Unplanned	3
3	Houses Types	Independent	1
		Mixed	2
		Interconnected	3
4	House Density Index	Low	1
		Medium	2
		High	3
5	Graveyards	Old (High)	3
		Medium (Medium)	2
		New (Low)	1
6	Water bodies	Nala/River	2
		Pond/stagnant water	3

The minimum value shows low-risk factor while higher value indicates high-risk factor.

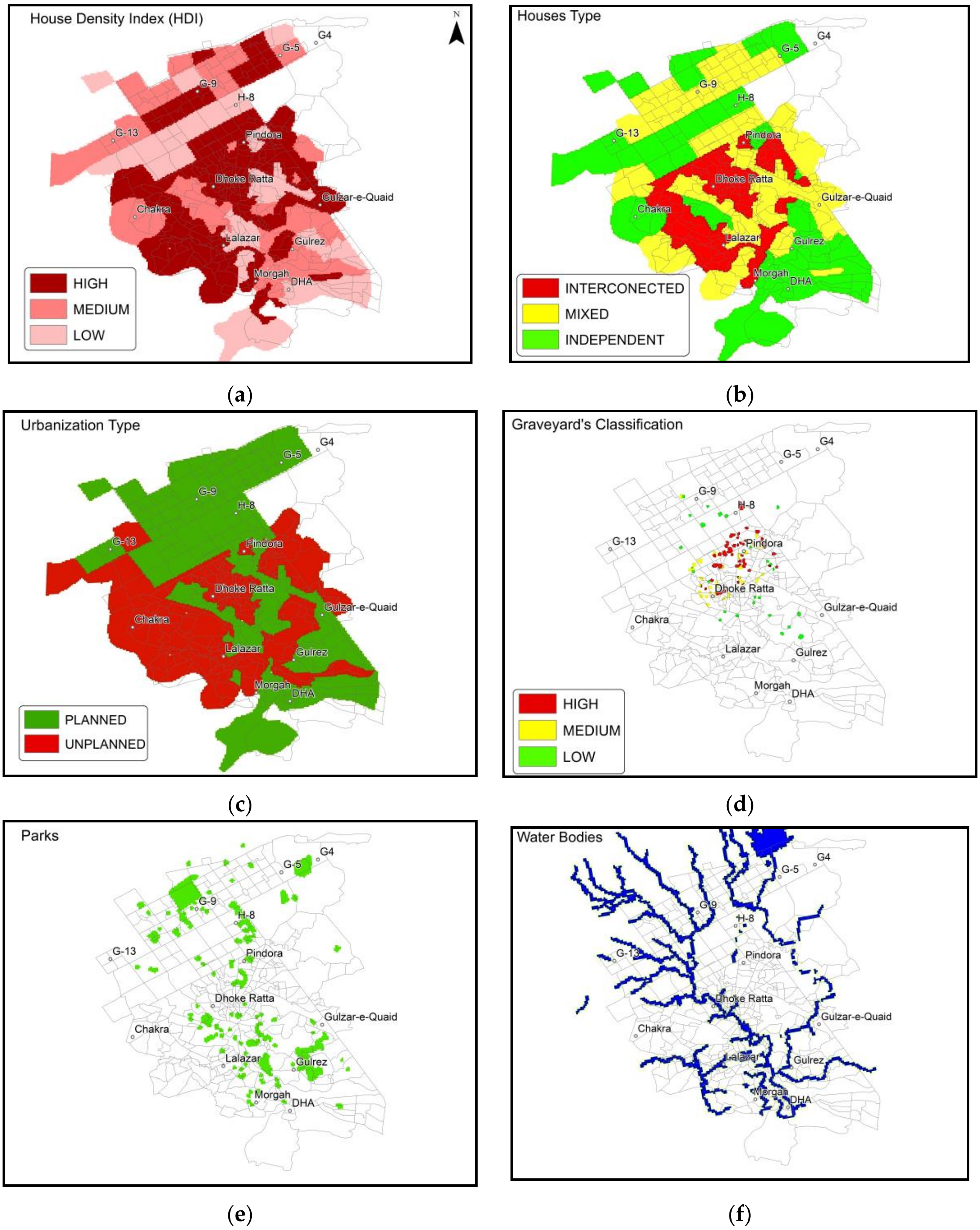


Figure 10. The raster input layers to produce Threat Index map. Each layer has been assigned a weight value and layers have been overlaid by two methods: weighted sum; weight overlay [46]. (**a**) HDI; (**b**) House type; (**c**) Urbanization type; (**d**) Graveyards; (**e**) Parks; (**f**) Water bodies.

4. Discussion

The change in LULC was significant in terms of urbanization for the entire time period from 2010 to 2014 for Rawalpindi-Islamabad. Many large construction projects have been initiated in the Rawalpindi-Islamabad. These include housing society's projects like Bharia Town Islamabad and DHA Islamabad, which are still growing and expanding in the Eastern side of the Rawalpindi-Islamabad.

The population Census 1998 and 2013 population estimation by Pakistan Bureau of Statistics clearly indicates the population growth at unprecedented rate for Rawalpindi-Islamabad and Swat. The population has doubled for both study areas in a time period of 15 years (Table 1). Many local house construction projects within the urban areas are also growing rapidly. On the other hand, the Metro-Bus project that was initiated in 2013 in the Rawalpindi-Islamabad has also contributed to DF outbreaks by providing larvae breeding sites. In contrast, there were no significant changes in land-cover for Swat. However, local house construction activities have been noted too similar with the Rawalpindi-Islamabad. Additionally, construction activities altered the local Drainage patterns of all study areas by providing more places for stagnant water, which is a perfect place for *Aedes* larvae production after the rainy season in both study areas. Most of the DF cases happened in low-lying urban areas. The low-lying urban areas have many particular characteristics like: low slope, low elevation differences as compared to neighboring areas, poor drainage patterns and High House Density Index, unplanned urbanization, mixed and interconnected houses, which help and promote DF habitats. As compared to low-lying urban areas, the rest of the study area for both locations consist of sparse houses, high slope and elevation difference, excellent drainage patterns and very low population density making them less vulnerable to DF occurrences. Additionally, these areas have high wind speed, moderate or low-temperature profile, comparatively cleaner surroundings and the environment. However, few DF cases have been reported from Murree, Kotli Sattian from Rawalpindi district. Similarly, DF cases have also been reported from Shangla, Malam Jabba and other high elevation areas of Swat.

The occurrence of DF in these areas has been attributed to traveling to infested urban areas. The rapid transport facilities and frequent visits to infested areas have been confirmed in previous studies [22,47]. Hydrology or physical existing water channels like rivers, streams and canals play an important role in ambient temperature and humidity profile of a locale [48]. Both study areas consist of many rivers, canals and streams of different lengths and sizes running through the heart of urban areas. Heavy rainfall has been noticed in both study areas for the months of July and August. The results for the Rawalpindi-Islamabad range from a minimum of 10 mm to a maximum of 70 mm and rainfall is very frequent and intense in these months (Figure 3a,b). In contrast, in Swat, the rainfall intensity and duration is much lower than in Rawalpindi-Islamabad. Furthermore, the maximum temperature for the Rawalpindi-Islamabad is little higher as compared to Swat. Moderate temperature and rainfall make Swat more stable for DF occurrence in the months of July and August. Therefore, more DF cases have been reported in Swat for these months as compared to the Rawalpindi-Islamabad. The Rawalpindi-Islamabad achieve this status in the months of September, October and November when the temperature ranges from 25 °C to 30 °C. This temperature range is more suitable for DF occurrence. The DF cases diminish when the temperature drops below 20 °C in the last week of November in the Rawalpindi-Islamabad, while in Swat it terminates in the month of October (Figure 3a–c). Finally, Swat is less stable and short lived for DF occurrence, because weather changes are abrupt in this region. At the same time, the Rawalpindi-Islamabad Weather changes slowly and gradually, making it more vulnerable to DF occurrence. Hence, the epidemic stays here for a longer time. A much-extended rainfall period of up to 6 months for years 2010 and 2012 caused a reverse impact on the DF occurrence in both study areas (Figure 4a,b) [13].

According to the results and statistical analyses, cemeteries and graveyards have been identified as primary breeding sites in both study areas. Due to unplanned urbanization, most of the graveyards in the twin cities have not been planned nor have they been cleaned or monitored for years. As a result, these graveyards are very prominent in DF occurrences. Old graveyards with different types of graves, presence of trees and shrubs, poor drainage, presence of vegetation, which supply the organic content for larvae production, are ideal locations for *Aede's* habitat (Figure 8d) [11].

Park and recreational areas also provide the *Aede's* habitat. Most of the parks have good tree cover, flower pots, nurseries and fountains. However, the cleaning activities and drainage system of parks are far better as compared to graveyards. Many tube-wells are located inside the parks with water leakage problems also providing the *Aede's* habitat. The other possible habitats include, in-house flower pots, playgrounds and empty plot lots.

5. Conclusions

The DF cases last for 6 months for the Rawalpindi-Islamabad and 3 to 4 months for Swat. DF occurrence is highly dependent on temperature, rainfall and humidity. DF occurrence and emergence has been noted early in Swat as compared to Rawalpindi-Islamabad. Environmental variables are highly dynamic and depend upon local weather conditions [38]. These variables like temperature, rainfall and humidity are beyond the direct control of humans; however, they can be regulated by controlling activities like changes in land-cover, construction activities, fuel consumption, *etc.* which cause an increase in temperature. Urbanization, hydrology, LULC, HDI, house types, urbanization types and indoor-outdoor breeding sites form a complex structure which helps and promotes DF occurrences and transmission. Poor living standards of people, bad hygienic conditions and poor education are the major social covariant, which can help and promote DF occurrence and transmission. Many variables can be managed and controlled to eradicate the Dengue habitat. The identified habitats (variables) are graveyards, playgrounds, empty plots, parks and indoor flower pots which have been proven as potential breeding sites for *Aedes*. The DF cases have been observed shortly after rainfall, (a gap of one week). This indicates that *Aede's* breeding sites are natural containers and not domestic containers. The graveyards and parks in highly urbanized areas should be monitored and maintained properly during the months of July, August, September, October and November. These are critical months in which Dengue emergence and transmission occurs. The old graves should be repaired and managed properly; trees with open barks should be eliminated to reduce the *Aede's* habitat. In the future, graveyards should be planned and designed outside urban areas. The design of graves should also be changed. The present design provides the space for stagnant water storage. The outdoor areas should be clean, particularly around empty plots in urban areas. The survey results suggest that most of the cases are happing in houses which have an empty plot next to them. Indoor flower pots should be monitored and cleaned on a daily basis to destroy the *Aede's* habitat. Construction activities in monsoon season also provide the potential habitat for *Aedes* mosquitos. The Threat Index Map (TIM) should be used by govt. bodies to control and monitor highly prone areas. Data should be collected and managed with geographic reference of location (Latitude, Longitude). This would help to locate the affected areas quickly with the help of online mapping applications.

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