World Journal of Biology Pharmacy and Health Sciences
eISSN: 2582-5542
Cross Ref DOI: 10.30574/wjbphs
Journal homepage: https://wjbphs.com/

(RESEARCH ARTICLE)

Check for updates

A study on spatial distribution of infectious diseases based on a normal Q-Q plot and GIS

Thi-Quynh Nguyen [1,*], Thi-Tuyet-Mai Nguyen [2] and Thi-Bich-Thuy Luong [1]

[1] *Faculty of Nursing, East Asia University of Technology, Hanoi, Vietnam.*

[2] *Faculty of Pharmacy, East Asia University of Technology, Hanoi, Vietnam.*

World Journal of Biology Pharmacy and Health Sciences, 2023, 16(03), 138–146

Publication history: Received on 09 November 2023; revised on 18 December 2023; accepted on 20 December 2023

Article DOI: https://doi.org/10.30574/wjbphs.2023.16.3.0510

Abstract

Background: Distribution of infectiousdisease location based on Geographic Information System (GIS) is considered as an infrastructure in the field of health in formation managment and also known as a fundamental issue in the field of new technologies in police medicine. The aim of this article is to carry out a study on spatial distribution of infectious diseases based on a normal Q-Q plot and GIS. Case studies from hand, foot, mouth diseases (HFMD) and dengue hemorrhagic fever (DHF) will be illustrated in Ho Chi Minh city (Vietnam).

Methods: The normal Q-Q plot was firstly constructed to study the distribution of HFMD and DHF cases and HFMD and DHF incidence. A GIS was then employed to map the spatial distribution of the HFMD and DHF incidence. Finally, the study results in Ho Chi Minh city was discussed and concluded.

Results: It was found that (i) the observed values from HFMD/DHF cases were mostly not on the expected straight line of the normal distribution in the normal Q-Q plot (ii) The high HFMD/DHF infection rate were mainly concentrated in the center of the city. The highest infection rate area was found in District 1, followed by districts District 5, District 3, District 11 and District 11. Whereas, districts having low HFMD/DHF infection rates included District 9, Nha Be, Cu Chi and Can Gio.

Conclusions: Findings in this study indicated that the combination of a normal Q-Q plot and a GIS is an effective tool to monitor and control the various infectious diseases.

Keywords: Spatial distribution; Geographic Information System; Normal Q-Q plot; Hand; foot; Mouth diseases; Dengue hemorrhagic fever; Ho Chi Minh City; Vietnam.

1. Introduction

An infection process is the interaction of a pathogenic microorganism with a macro organism under certain environmental and social conditions (1). Microorganisms causing infectious diseases parasites on host and persist due to continuous reproduction of new generation which change their properties in accordance with evolution of the environment conditions. Human activities are the most potent factors driving disease emergence. Main factors are social, economic, political, climatic, technologic, environmental factors, shape, disease patterns and influence emergence (1). A recent study has shown that travel is a potent force in the emergence of disease. Migration of humans has been the pathway for disseminating infectious diseases throughout recorded history and will continue to shape the emergence, frequency, and spread of infections in geographic areas and populations (2). It is therefore, understanding and responding to disease emergence require a global perspective, conceptually and geographically.

* Corresponding author: Thi-Quynh Nguyen

In this ever increasingly complex world, it is no surprise that the problems that face public health researches are becoming more and more intricate to solve. A cross-disciplinary approach may be one of the ways to discover new methods. Recently, GIS has emerged as an important component of many projects in public health and epidemiology (1,3,4). Epidemiologists have traditionally used maps when analyzing associations between location (5), environment (6), and disease (7). GIS has been used in the surveillance and monitoring of vector-borne diseases, water-borne diseases, in environmental health, analysis of disease policy and planning, health situation in an area, generation and analysis of research hypotheses, identification of high-risk health groups, planning and programming of activities, and monitoring and evaluation of interventions. GIS enabled researchers to locate high prevalence areas and populations at risk, identify areas in need of resources, and make decisions on resource allocation. Good epidemiology science and good geographic information science go hand in hand. Many development agencies and government institutions are exploring Health GIS in India (8). However, the sheer size of our country, varied life styles, climatic zones and environmental conditions make it all the more important for India to have a health GIS.

Studies on the geographical distribution of diseases can be categorized into three main classes: disease mapping, disease clustering and ecological analysis (9). GIS-based disease mapping depends on identifying a number of aspects, the most important of which are locations of disease occurrence, patterns of disease spread, environmental risk factors that lead to disease spread and socio-economic data, in order to analyze spatial relationships within the affected area (10). Hand, foot, and mouth diseases is primarily transmitted via the fecal-oral route, respiratory droplets, contact with blister fluid of infected individuals, or general close contact with infected individuals (11–14). Most cases of HFMD are mild and patients are able to recover quickly; however, there are some severe cases and even some deaths (15). The HFMD disease was generally mild and lasted less than a week in most cases, characterized by fever, a blister-like rash on the hands and feet, and oral ulcers caused by ruptured blisters in the mouth (16). HFMD outbreaks have been reported worldwide, and Western Pacific countries have reported outbreaks of HFMD many times over the last decade (17–20). In Asia, HFMD is a threat to public health; in Singapore (21,22), Malaysia (22,23), Japan (24) and Vietnam (25–27). It has been reported many times, with large numbers of cases 20-25. Therefore, HFMD has become a significant concern for public health throughout the Asia-Pacific region and beyond (28). Apart from HFMD, dengue is also the leading cause of human arboviral disease worldwide. With the help of GISs, several studieshave mapped the regional clustering patterns of dengue cases and examined the relationships between these patterns and pertinent entomological parameters (29–31) and environmental conditions (32), and have determined the dengue and vector distributions' spatial-temporal diffusion patterns (31,33).

The objective of this study was to employ a normal Q-Q plot and a Geographic Information System (GIS) to study on spatial distribution of infectious diseases, HFMD and DHF in Ho Chi Minh city (Vietnam). The normal Q-Q plot was firstly constructed to study the distribution of HFMD and DHF cases and HFMD and DHF incidence. A GIS was then employed to map the spatial distribution of the HFMD and DHF incidence. Finally, the study results was discussed and concluded.

2. Study areas and materials

In Vietnam, dengue hemorrhagic fever is still a dangerously developing arboviral illness. DHF is endemic in Vietnam, with an estimated 1.6 million cases occurring annually in urban and periurban areas (34). Previous studies have shown that all four DENV serotypes had circulated in Vietnam at some point, with DENV-1 and DENV-2 being the most often detected serotypes, as is normal in hyperendemic nations (35). Until 2018, Ho Chi Minh City and the surrounding areas were dominated by the DENV-1 subtype (36). Ho Chi Minh City was in a significant DENV outbreak in 2022; the Ho Chi Minh Centre for Disease Control reported 78,561 cases of dengue there between January 1 and December 11 (37). It was reported in a study, during 2005, 764 children were brought to a large children's hospital in Ho Chi Minh City, Vietnam, with a diagnosis of hand, foot, and mouth disease (38). In this study, to study on spatial distribution of infectious diseases (HFMD and DHF) based on a normal Q-Q plot and GIS, datasets of HFMD and DHF cases in 2023 were collected from the Center for Disease Control of Ho Chi Minh City (HCDC) .

2.1. Methods

2.1.1. The normal Q-Q plot

The normal Q-Q plot, or quantile-quantile plot, is a graphical tool to help us assess if a set of data plausibly came from some theoretical distribution such as a normal or exponential. A normal Q-Q plot is a scatterplot created by plotting two sets of quantiles against one another. If both sets of quantiles came from the same distribution, the points forming a line that's roughly straight. A normal Q-Q plot compares the distribution of two sets of data. In most cases, a probability plot will be most useful. A probability plot compares the distribution of a data set with a theoretical distribution.

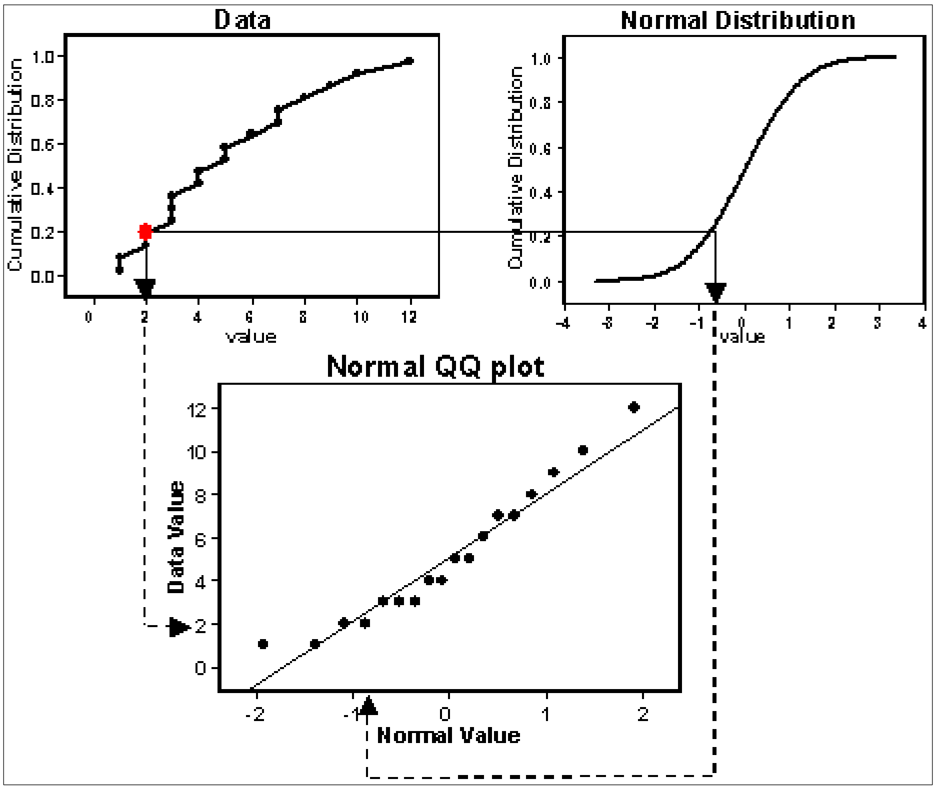


Figure 1 Normal Q-Q plot example

To construct the normal Q-Q plot the data values are firstly ordered and cumulative distribution values are calculated as (i-0.5)/n for the ith ordered value out of n total values (this gives the proportion of the data that falls below a certain value). A cumulative distribution graph is produced by plotting the ordered data versus the cumulative distribution values (Figure 1). The same process is done for a standard normal distribution (a Gaussian distribution with a mean of 0 and a standard deviation of 1, shown in Figure 1). Once these two cumulative distribution graphs have been generated, data values corresponding to specific quantiles are paired and plotted in a Q-Q plot as shown in Figure 1.

Points on the normal Q-Q plot provide an indication of univariate normality of the dataset. If the data is normally distributed, the points will fall on the 45-degree reference line. If the data is not normally distributed, the points will deviate from the reference line. The quantile values of the standard normal distribution are plotted on the x-axis in the normal Q-Q plot, and the corresponding quantile values of the dataset are plotted on the y-axis. It can be seen that the points fall close to the 45-degree reference line.

2.1.2. Geographic Information System (GIS)

A GIS contains four types of information and computer files: geographic, map, attribute, and data-point files. In general, modeling involves the integration of GIS with standard statistical and health science methods. Spatial interaction models analyze and predict the movements of people, information, and goods from place to place. By accurately modeling these movements, it is possible to identify areas most at risk for disease transmission and thus target intervention efforts (1). Spatial diffusion models analyze and predict the spread of phenomena over space and time and have been widely used in understanding spatial diffusion of diseases. By incorporating a temporal dimension, these models can predict how diseases spread, spatially and temporally, from infected to susceptible people in an area. Spatial variation in health related data is well known, and its study is a fundamental aspect of epidemiology. Representation and identification of spatial patterns play an important role in the formulation of public health policies. GIS is an effective tool to monitor and control the various infectious diseases. A number of papers discuss the applications of GIS in controlling, monitoring, and surveillance of infectious diseases (9,32).

One of the most fundamental steps in map creation is the transformation of information from the surface of a globe onto a flat map. Mapmakers have developed and used hundreds of different map projections over the past 2,000 years, yet there is no perfect choice because every map projection uniquely alters some aspect of space during the transformation process (39). Detailed information about the type, amount, and distribution of distortion is essential for choosing the best projection for a particular map or data set.

In Geographic Information System, a map projection is any of a broad set of transformations employed to represent the curved two-dimensional surface of a globe on a plane (40). In a map projection, coordinates, often expressed as latitude and longitude, of locations from the surface of the globe are transformed to coordinates on a plane (41,42). Projection is a necessary step in creating a two-dimensional map and is one of the essential elements of cartography. All projections of a sphere on a plane necessarily distort the surface in some way and to some extent (43).

The Universal Transverse Mercator (UTM) is a map projection system for assigning coordinates to locations on the surface of the Earth. Like the traditional method of latitude and longitude, it is a horizontal position representation, which means it ignores altitude and treats the earth surface as a perfect ellipsoid. However, it differs from global latitude/longitude in that it divides earth into 60 zones and projects each to the plane as a basis for its coordinates. Specifying a location means specifying the zone and the x, y coordinate in that plane. The projection from spheroid to a UTM zone is some parameterization[disambiguation needed] of the transverse Mercator projection. The parameters vary by nation or region or mapping system. Most zones in UTM span 6 degrees of longitude, and each has a designated central meridian. The scale factor at the central meridian is specified to be 0.9996 of true scale for most UTM systems in use (44,45).

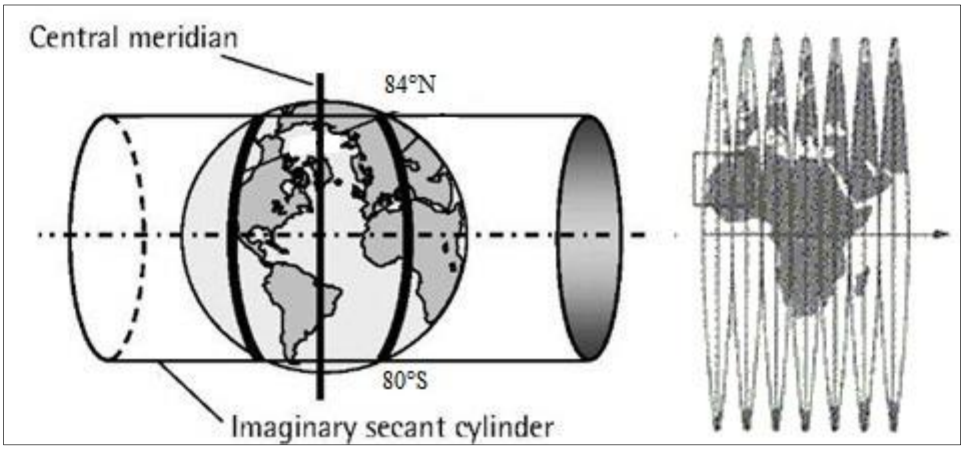


Figure 2 The UTM projection in a GIS

The WGS 84 spatial reference system describes Earth as an oblate spheroid along north-south axis with an equatorial radius of α = 6378.137 km and an inverse flattening of 1/f = 289.257223564. Let's take a point of latitude φ and of longitude φ and compute its UTM coordinates as well as point scale factor k and meridian convergence γ using a reference meridian of longitude λ_0. By convention, in the northern hemisphere $N_0 = 0$ km and in the southern hemisphere $N_0 = 10000$ km. By convention also $k_0 = 0.9966$ and $E_0 = 500$ km. The following formulas will be used to change from latitude, longitude (φ, λ) to UTM coordinates (E, N).

$$E = E_0 + k_0 A\left(\eta' + \sum_{j-1}^{3} \alpha_j \cos(2j\xi')\sinh(2j\eta')\right) \quad (1)$$

$$N = E_0 + k_0 A\left(\xi' + \sum_{j-1}^{3} \alpha_j \cos(2j\xi')\sinh(2j\eta')\right) \quad (2)$$

$$k = \frac{k_0 A}{\alpha}\sqrt{\left\{1 + \left(\frac{1-n}{1+n}tan\varphi\right)^2\right\}\frac{\sigma^2 + \tau^2}{t^2 + cos^2(\lambda - \lambda_0)}} \quad (3)$$

$$\gamma = tan^{-1}\left(\frac{\tau\sqrt{1+(t)^2} + \sigma t tan(\lambda - \lambda_0)}{\sigma\sqrt{1+(t)^2} + \tau t tan(\lambda - \lambda_0)}\right) \quad (4)$$

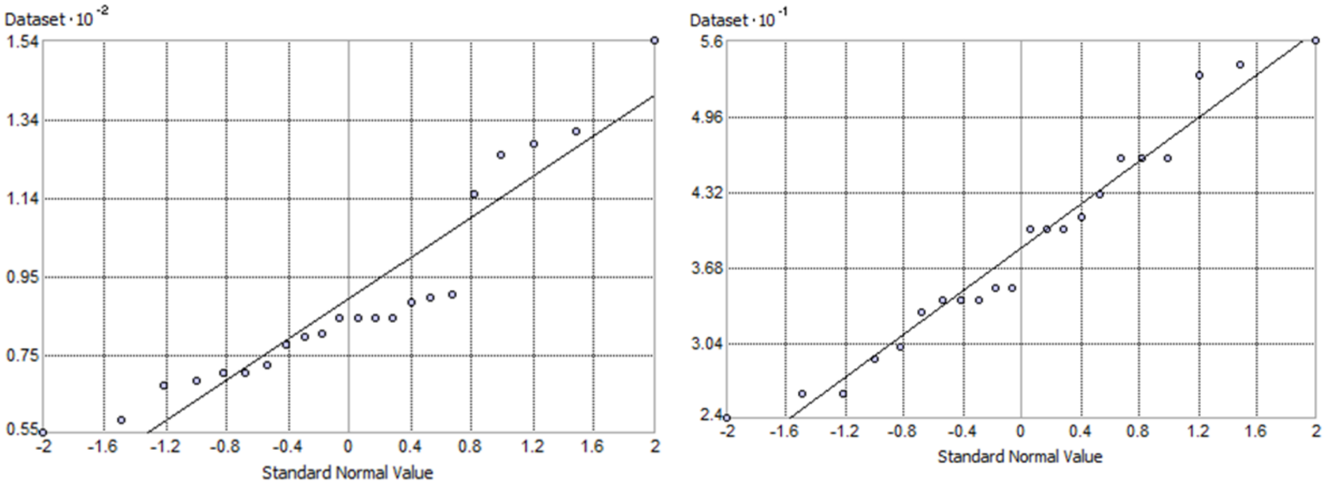
where: E is Easting, N is Northing, k is the Scale Factor, and γ is the grid convergence.

3. Results and discussion

3.1. Analysis of distribution of HFMD and DHF cases and incidence

Regarding DHF infections, it was reported that districts with the number of infections greater than 100 cases include District 1 (154 cases), Binh Chanh (131 cases), District 8 (128 cases), Binh Thanh (125 cases) and Nha Be (115 cases). Districts with an average number of infections ranging from 80 to 90 cases include District 5 (90 cases), District 6 (89 cases), Cu Chi (88 cases), District 2, District 9, Tan Binh and Thu Duc (94 cases) and District 3 (80 cases). Districts having a low number of HFMD cases (less than 70 cases) included District 7 and District 10 (70 cases), Hoc Mon (68 cases), Can Gio (67 cases), District 4 (58 cases) and Go Vap (55 cases). Regarding DHF infections, statistics showed that districts having a large number of infections (over 40 cases) included District 8 (56 cases), Binh Chanh (54 cases), District 6 (53 cases), District 2, District 9, Thu Duc (46 cases), District 1 (43 cases) and District 11 (41 cases). Districts having an average number of DHF cases ranging from 30 to 40 cases include District 10, Tan Binh, Hoc Mon (40 cases), District 3 and Nha Be (35 cases), District 5, District 12 and Binh Thanh (34 cases), District 7 (33 cases) and Cu Chi (30 cases). Districts having a low number of DHF cases (less than 30 cases) include District 4 (29 cases), Go Vap and Phu Nhuan (26 cases) and Can Gio (24 cases).

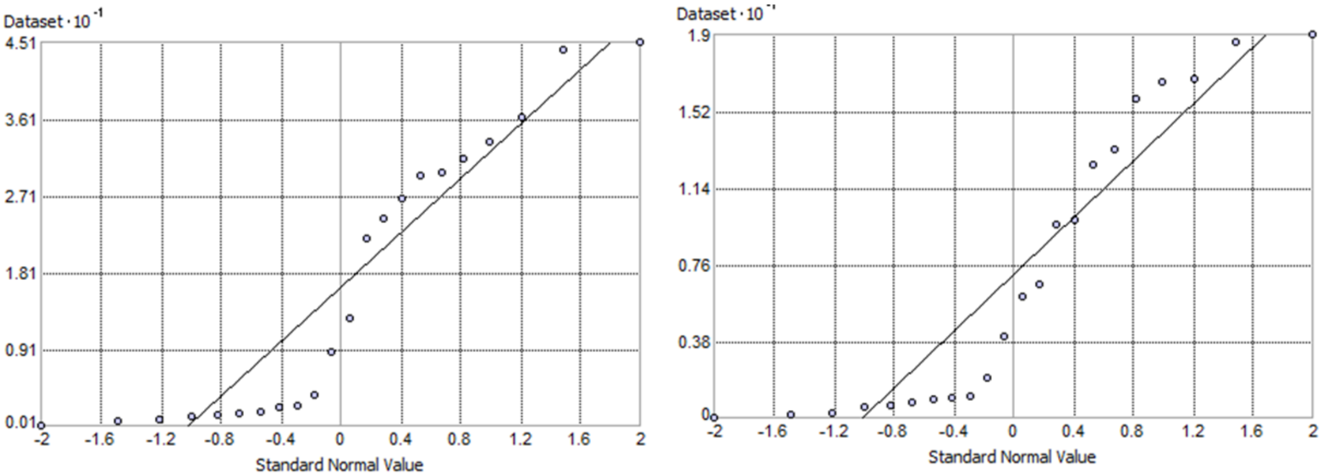
The normal Q-Q plot in Figure 3-a presents the distribution of HFMD cases. Data from Figure 3 illustrate that the observed values from HFMD cases were mostly not on the expected straight line of the normal distribution. This proves that the data on HFMD cases does not follow the normal distribution. However, compared with the observed values obtained by HFMD cases, the observed values of DHF cases tended to concentrate on the expected straight line of the normal distribution. This proves that the data is normally distributed.



(a) Hand, Foot, Mouth Diseases (b) Dengue Hemorrhagic Fever

Figure 3 Normal Q-Q plots of HFMD and DHF cases in Ho Chi Minh city.

The normal Q-Q plots in Figure 4 illustrate the distribution of HFMD (Figure 4-a) and DHF (Figure 4-b) infection rates. The data in Figures 4-a and 4-b both demonstrate that the observed values of the HFMD and DHF infection rates were mostly not on the expected straight line of the normal distribution presenting that the variable of HFMD cases was not normally distributed.



(a) Incidence of Hand, Foot, Mouth Diseases (b) Incidence of Dengue Hemorrhagic Fever

Figure 4 Normal Q-Q plots of HFMD and DHF incidence in Ho Chi Minh city.

3.2. Analysis of spatial distribution of HFMD and DHF incidence

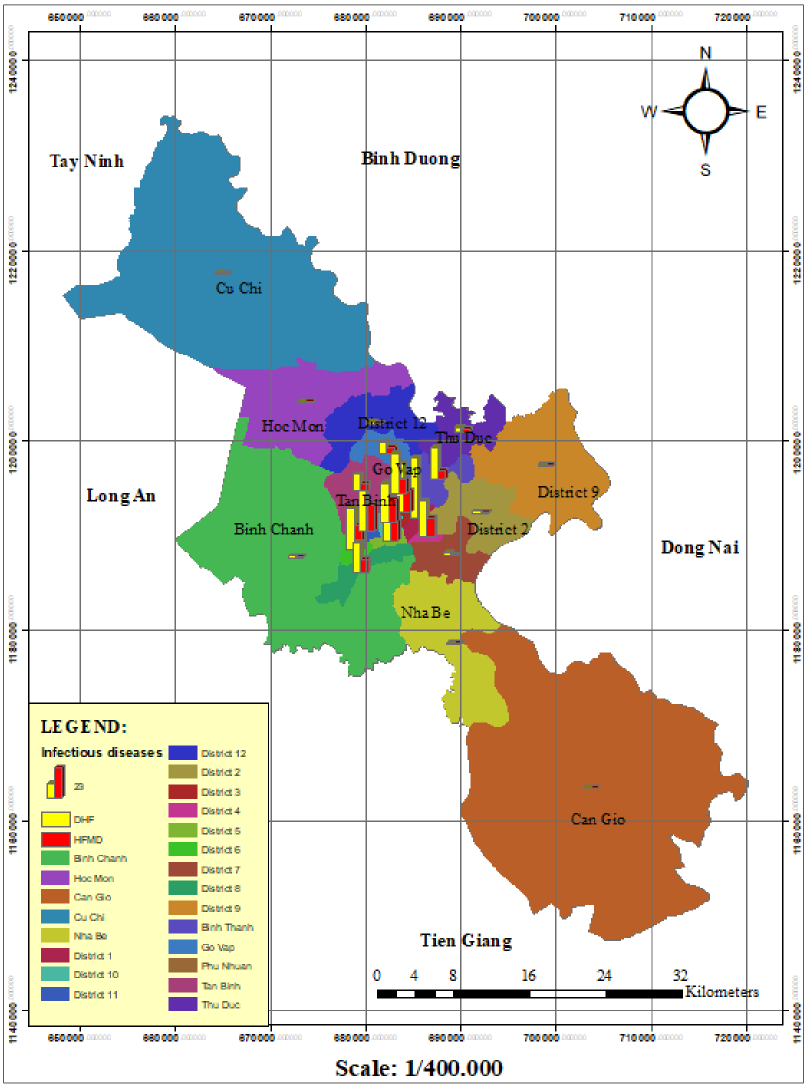


Figure 5 Map of HFMD and DHF incidence in Ho Chi Minh city

The map shown in Figure 5 illustrate the spatial distribution of two infectious diseases, HFMD and DHF, which were collected in Ho Chi Minh City. The data in Figure 5 demonstrate that high DHF infection rates were mainly concentrated in the center of the city. Specifically, these areas of high infection rates were concentrated in the central districts of the city in order from highest to lowest as follows. The highest DHF infection rate were found in District 1 (45,054), followed by districts such as District 5 (44,163), District 3 (36,170), District 11 (33,408) and District 11 (33,408). Data from the map shown in Figure 5 illustrate that high infection rates were mainly concentrated in the central districts of the city. In contrast, districts having low HFMD infection rates appeared mainly in suburban districts in the north, south, east, and west districts of the city. Districts having low DHF infection rates include District 9 (1.0962), Nha Be (0.7188), Cu Chi (0.5130) and Can Gio (0.0556).

Similar to those obtained when using the variable of DHF infection rates, data in Figure 5 also illustrate that a high proportion of HFMD cases occured mainly in the urban districts in the center of the city. Specifically, they were concentrated in the central districts of the city in order from highest to lowest as follows. The area of the highest DHF infection rate were found in District 1 (12,5801), followed by districts such as District 5 (16,6838), District 3 (15,8245), District 11 (19,024) and District 11 (18,6406). Districts having low HFMD infection rates were mainly in suburban districts such as District 9 (0.6003), Nha Be (0.21875), Cu Chi (0.1749) and Can Gio (0.01992).

4. Conclusion

The purpuse of this study is to perform a study on spatial distribution of infectious diseases based on a normal Q-Q plot and GIS. Case studies from hand, foot, mouth diseases (HFMD) and dengue hemorrhagic fever (DHF) will be illustrated in Ho Chi Minh city (Vietnam). The normal Q-Q plot was firstly constructed to study the distribution of HFMD and DHF cases and HFMD and DHF incidence. A GIS was then employed to map the spatial distribution of the HFMD and DHF incidence. Finally, the study results in Ho Chi Minh city was discussed and concluded. It was found that, firstly, the observed values from HFMD/DHF cases were mostly not on the expected straight line of the normal distribution in the normal Q-Q plot. Secondly, The high HFMD/DHF infection rate were mainly concentrated in the center of the city. The highest infection rate area was found in District 1, followed by districts District 5, District 3, District 11 and District 11. Whereas, districts having low HFMD/DHF infection rates included District 9, Nha Be, Cu Chi and Can Gio. It can be concluded that the study results indicated the combination of a normal Q-Q plot and a GIS is an effective tool to monitor and control the various infectious diseases.

Compliance with ethical standards

Acknowledgments

The authors are grateful to Center for Disease Control of Ho Chi Minh City (HCDC) for providing the datasets of hand, foot, mouth diseases and dengue hemorrhagic fever.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Gupta R, Jay D, Jain R. Geographic information systems for the study and control of infectious diseases. In: Map India Conference. 2003.

[2] Wilson ME. Travel and the emergence of infectious diseases. Emerg Infect Dis. 1995;1(2):39.

[3] Barnes S, Peck A. Mapping the future of health care: GIS applications in health care analysis. Geogr Inf Syst. 1994;4:31–3.

[4] Carrat F, Valleron A-J. Epidemiologic mapping using the “kriging” method: application to an influenza-like epidemic in France. Am J Epidemiol. 1992;135(11):1293–300.

[5] Brownstein JS, Cassa CA, Kohane IS, Mandl KD. An unsupervised classification method for inferring original case locations from low-resolution disease maps. Int J Health Geogr. 2006;5(1):1–7.

[6] Tainio M, Andersen ZJ, Nieuwenhuijsen MJ, Hu L, De Nazelle A, An R, et al. Air pollution, physical activity and health: A mapping review of the evidence. Environ Int. 2021;147:105954.

[7] Altshuler D, Daly MJ, Lander ES. Genetic mapping in human disease. Science (80-). 2008;322(5903):881–8.

[8] Kumar A, Gupta I, Brandt J, Kumar R, Dikshit AK, Patil RS. Air quality mapping using GIS and economic evaluation of health impact for Mumbai City, India. J Air Waste Manage Assoc. 2016;66(5):470–81.

[9] Murad A, Khashoggi BF. Using GIS for disease mapping and clustering in Jeddah, Saudi Arabia. ISPRS Int J Geo-Information. 2020;9(5):328.

[10] Nicol J. Geographic information systems within the national health service: the scope for implementation. Plan Outlook. 1991;34(1):37–42.

[11] Ho M, Chen E-R, Hsu K-H, Twu S-J, Chen K-T, Tsai S-F, et al. An epidemic of enterovirus 71 infection in Taiwan. N Engl J Med. 1999;341(13):929–35.

[12] Liu MY, Liu W, Luo J, Liu Y, Zhu Y, Berman H, et al. Characterization of an outbreak of hand, foot, and mouth disease in Nanchang, China in 2010. PLoS One. 2011;6(9):e25287.

[13] Qi ZHU, YuanTao HAO, JiaQi MA, ShiCheng YU, Yu W. Surveillance of hand, foot, and mouth disease in mainland China (2008–2009). Biomed Environ Sci. 2011;24(4):349–56.

[14] Deng T, Huang Y, Yu S, Gu J, Huang C, Xiao G, et al. Spatial-temporal clusters and risk factors of hand, foot, and mouth disease at the district level in Guangdong Province, China. PLoS One. 2013;8(2):e56943.

[15] Pérez-Vélez CM, Anderson MS, Robinson CC, McFarland EJ, Nix WA, Pallansch MA, et al. Outbreak of neurologic enterovirus type 71 disease: a diagnostic challenge. Clin Infect Dis. 2007;45(8):950–7.

[16] Alsop J, Flewett TH, Foster JR. "Hand-foot-and-mouth disease" in Birmingham in 1959. Br Med J. 1960;2(5214):1708.

[17] Ang LW, Koh BK, Chan KP, Chua LT, James L, Goh KT. Epidemiology and control of hand, foot and mouth disease in Singapore. Ann Acad Med Singapore. 2009;38(2):106–12.

[18] Chatproedprai S, Theanboonlers A, Korkong S, Thongmee C, Wananukul S, Poovorawan Y. Clinical and molecular characterization of hand-foot-and-mouth disease in Thailand, 2008–2009. Jpn J Infect Dis. 2010;63(4):229–33.

[19] Bo Y-C, Song C, Wang J-F, Li X-W. Using an autologistic regression model to identify spatial risk factors and spatial risk patterns of hand, foot and mouth disease (HFMD) in Mainland China. BMC Public Health. 2014;14(1):1–13.

[20] Österback R, Vuorinen T, Linna M, Susi P, Hyypiä T, Waris M. Coxsackievirus A6 and hand, foot, and mouth disease, Finland. Emerg Infect Dis. 2009;15(9):1485.

[21] Shah VA, Chong CY, Chan KP, Ng W, Ling AE. Clinical characteristics of an outbreak of hand, foot and mouth disease in Singapore. Ann Acad Med Singapore. 2003;32(3):381–7.

[22] McMinn P, Lindsay K, Perera D, Chan HM, Chan KP, Cardosa MJ. Phylogenetic analysis of enterovirus 71 strains isolated during linked epidemics in Malaysia, Singapore, and Western Australia. J Virol. 2001;75(16):7732–8.

[23] AbuBakar S, Chee H-Y, Al-Kobaisi MF, Xiaoshan J, Chua KB, Lam SK. Identification of enterovirus 71 isolates from an outbreak of hand, foot and mouth disease (HFMD) with fatal cases of encephalomyelitis in Malaysia. Virus Res. 1999;61(1):1–9.

[24] Onozuka D, Hashizume M. The influence of temperature and humidity on the incidence of hand, foot, and mouth disease in Japan. Sci Total Environ. 2011;410:119–25.

[25] Nhan LNT, Khanh TH, Hong NTT, Van HMT, Nhu LNT, Ny NTH, et al. Clinical, etiological and epidemiological investigations of hand, foot and mouth disease in southern Vietnam during 2015–2018. PLoS Negl Trop Dis. 2020;14(8):e0008544.

[26] Nguyen NTB, Pham H V, Hoang CQ, Nguyen TM, Nguyen LT, Phan HC, et al. Epidemiological and clinical characteristics of children who died from hand, foot and mouth disease in Vietnam, 2011. BMC Infect Dis. 2014;14:1–7.

[27] Anh NT, Van HMT, Hong NTT, Thanh TT, Hang VTT, Ny NTH, et al. Emerging coxsackievirus A6 causing hand, foot and mouth disease, Vietnam. Emerg Infect Dis. 2018;24(4):654.

[28] Zhu P, Ji W, Li D, Li Z, Chen Y, Dai B, et al. Current status of hand-foot-and-mouth disease. J Biomed Sci. 2023;30(1):15.

[29] Ali M, Wagatsuma Y, Emch M, Breiman RF. Use of a geographic information system for defining spatial risk for dengue transmission in Bangladesh: role for Aedes albopictus in an urban outbreak. Am J Trop Med Hyg. 2003;69(6):634–40.

[30] Tran A, Deparis X, Dussart P, Morvan J, Rabarison P, Remy F, et al. Dengue spatial and temporal patterns, French Guiana, 2001. Emerg Infect Dis. 2004;10(4):615.

[31] Morrison AC, Getis A, Santiago M, Rigau-Perez JG, Reiter P. Exploratory space-time analysis of reported dengue cases during an outbreak in Florida, Puerto Rico, 1991-1992. Am J Trop Med Hyg. 1998;58(3):287–98.

[32] Bohra A, Andrianasolo H. Application of GIS in Modeling Dengue Risk Based on Sociocultural Data: Case of Jalore, Rajasthan, India. 2001;

[33] Ungchusak K, Burke DS. Travelling waves in the occurrence of dengue hemorrhagic fever in thailand. Nature. 2004;427:344347Cushing.

[34] Cattarino L, Rodriguez-Barraquer I, Imai N, Cummings DAT, Ferguson NM. Mapping global variation in dengue transmission intensity. Sci Transl Med. 2020;12(528):eaax4144.

[35] Ty Hang VT, Holmes EC, Veasna D, Quy NT, Tinh Hien T, Quail M, et al. Emergence of the Asian 1 genotype of dengue virus serotype 2 in viet nam: in vivo fitness advantage and lineage replacement in South-East Asia. PLoS Negl Trop Dis. 2010;4(7):e757.

[36] Tran VT, Inward RPD, Gutierrez B, Nguyen NM, Rajendiran I, Thanh PN, et al. Cryptic transmission and re-emergence of Cosmopolitan genotype of Dengue Virus Serotype 2 within Ho Chi Minh City and Southern Vietnam. medRxiv. 2023;2004–23.

[37] HCDC. Hand, foot, mouth and dengue fever epidemic situation updated until September 11, 2022 [Internet]. 2022. Available from: https://hcdc.vn/tinh-hinh-dich-benh-tay-chan-mieng-sot-xuat-huyet-cap-nhat-den-ngay-1192022-81472dae343782d142f3940ac20491df.html

[38] Van Tu P, Thao NTT, Perera D, Truong KH, Tien NTK, Thuong TC, et al. Epidemiologic and virologic investigation of hand, foot, and mouth disease, southern Vietnam, 2005. Emerg Infect Dis. 2007;13(11):1733.

[39] Mulcahy KA, Clarke KC. Symbolization of map projection distortion: a review. Cartogr Geogr Inf Sci. 2001;28(3):167–82.

[40] Lambert JH. Notes and comments on the composition of terrestrial and celestial maps. In: Mathematical Geography in the Eighteenth Century: Euler, Lagrange and Lambert. Springer; 2022. p. 367–422.

[41] Snyder JP, Voxland PM. An album of map projections. US Government Printing Office; 1989.

[42] Ghaderpour E. Some equal-area, conformal and conventional map projections: A tutorial review. J Appl Geod. 2016;10(3):197–209.

[43] Monmonier M. How to lie with maps. University of Chicago Press; 2018.

[44] Snyder JP. Map projections--A working manual. Vol. 1395. US Government Printing Office; 1987.

[45] Contributors P. PROJ coordinate transformation software library. Open Source Geospatial Found Beaverton, OR, USA. 2018;