Original Research

Investigating Environmental Health Studies Using Geographical Information Systems: Cancer Case Study

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Abstract

Geographical information systems (GIS) have been extensively used to research public health issues in recent years. Cancer is one of the most important health issues around the world. In this study, a standard, effective and efficient GIS-based decision support system is established to ensure taking necessary measures for cancer cases, providing assistance to reveal the relationship between environmental health and geographical location, which may lead to cancer, keeping cancer cases under control, and places being recorded where the patients diagnosed with cancer dwell, together with their geographical locations. This system was fulfilled in the city of Sivas (Turkey).

As a result of investigating, the cancer cases occurred between 2007 and 2010, The average of the cancer incidence rates for these years were calculated for both males and females and the curve equations representing them were estimated with a high coefficient of determination (R^2=0.99). Whereas the coefficient of determination (R^2) that expresses the strength of the relationship between the variables in the equation is 0.991 for females, this coefficient for males is 0.998. These equations almost represent existing data used to calculate the cancer incidence rates of the standardized age groups of males and females between 2007 and 2010.

Keywords: cancer, environmental health, GIS

Introduction

GIS has been widely used to map disease rates, understand relationships between environmental risk factors and disease, and determine accessibility to and utilization of health care services provided by professionals and public health administrators, including policy makers, statisticians, and regional, and district medical officers [1, 2]. The use of GIS covers significant topics such as disease mapping, epidemiological queries, health services analyses and planning, environmental health and justice analyses, exposure modeling, risk assessments, disease diffusion and clustering studies, health disparities research, and investigations of many other public health issues for the community [3]. In addition, it has great potential for the management of chronic diseases such as cancer and the analyses of clinical and administrative health care data [4]. Therefore, many researchers have been implementing health research by means of GIS [5-14].

Since health is a geographical phenomenon and various factors attributing to health diagnostics and planning are connected to geographical location, GIS for health studies serves as a significant tool. Applications such as:

- helping decision makers visualize patterns of disease and disparity
- geographical distribution and variation of diseases

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- analyses of spatial and temporal trends
- identifying gaps in immunizations
- mapping populations at risk and stratifying risk factors
- documenting health care needs of a community and assessing resource allocations
- forecasting epidemics
- planning and targeting interventions
- monitoring diseases and interventions over time
- managing patient care environments, materials, supplies, and human resources
- monitoring the utilization of health centers
- route health workers, equipment, and supplies to service locations
- publishing health information using maps are performed for public health by GIS [1, 2].

GIS can be used to determine the environmental risk factors, to reveal the existing health situation, to cope with health problems, and to analyze and map geographical distributions of populations under risk [8, 9].

Cancer is one of the most significant health problems all over the world and in Turkey. Environmental factors, notably nutrition and smoking, are known to be involved in more than half of cancer cases. Furthermore, cancer is a disease whose frequency increases depending on various factors. The most important issue in controlling cancer disease is the accurate cancer registry in a country. Unless accurate statistical data are attained, it is impossible to know which cancer has what significance and to make strategic plans, above all in relation to realistic human resources [15].

This study suggests revealing the current status of cancer and health care studies, to establish a GIS-based infrastructure in these studies, to conduct studies in an effective, quick, easy, and productive way, and to use the system, which is established as a decision support system in studies to be performed for eliminating or reducing the risks derived from cancer. Thus, contributions to social health can be made by evaluating the cancer cases in a certain settlement area using this system and producing the relevant statistical results.

Methodology

In this study, a GIS-based decision support system is constituted to record residences of people diagnosed with cancer together with their geographical locations, to reveal the relationship of these cancer diseases to geographical locations, to keep these diseases under control, and to support taking necessary measures for the risks of disease. This system is recommended so that it could also be applied in other administrative units in accordance with specified objectives (Fig. 1).

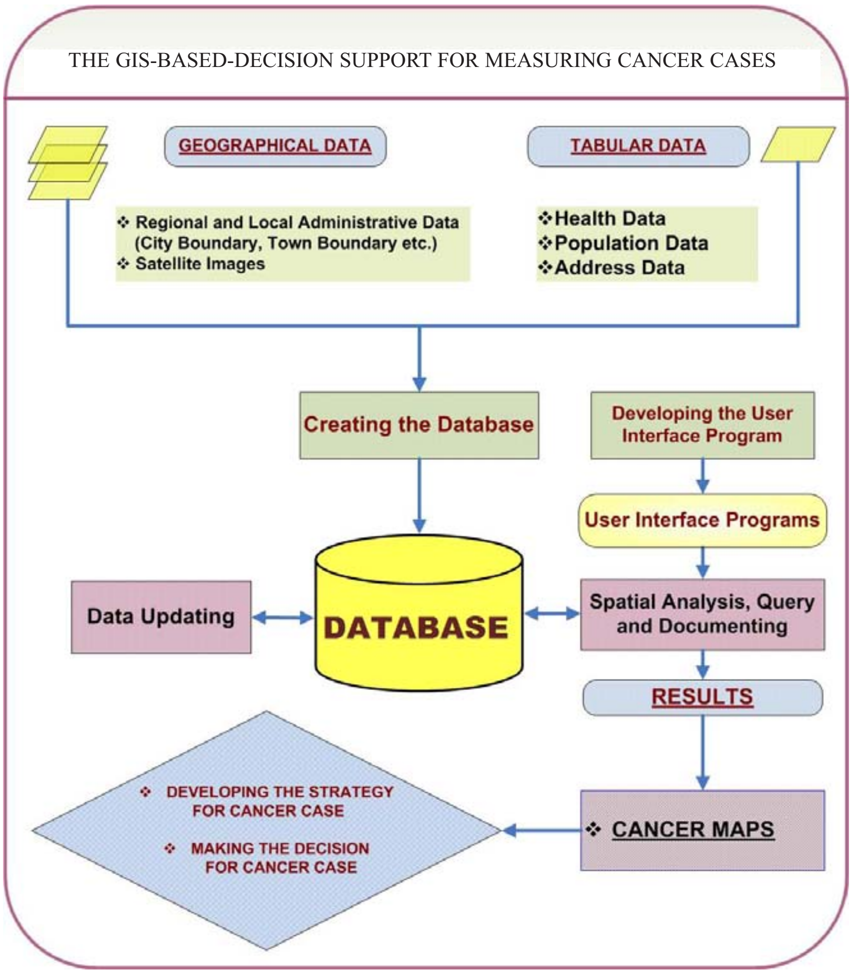


Fig. 1. The GIS-based decision support system for developing a cancer case strategy.

Taking notice of several standards is extremely important in establishing an effective and productive GIS-based health information system. Thus, the catalogue of International Classification of Diseases (ICD)-10, one of the WHO standards valid all over the world, was used for the database classification of diseases. Besides, malign neoplasms (cancer cases), which are most widely recorded in Turkey, were considered within the scope of this study.

In the study, ESRI ArcGIS 9.3, one of the most popular GIS software, was used. Relevant user-interface programs can be developed by this software. A user-interface program provides interaction between the user and the computer. Although many processes are needed for complex spatial analysis and queries in GIS software, these processes can be executed by pressing a button in developed user-interface programs. Thus, GIS software can easily be used widely by many users [16].

Many queries and analyses were implemented by the developed user interface programs within the scope of this study. Various statistical evaluations were revealed as a result of these studies.

Application in the City of Sivas, Turkey

The Study Area

The City of Sivas with its surface area of 28.488 km^2 is the second largest city of Turkey in terms of covered land. The City of Sivas, with its total number of 17 towns and 1,245 villages, also including the city center, is one of the important administrative units in Turkey (Fig. 2). As of 2010, its population is 642,224, whereas population of the town of Sivas Center is 354,913 [17].

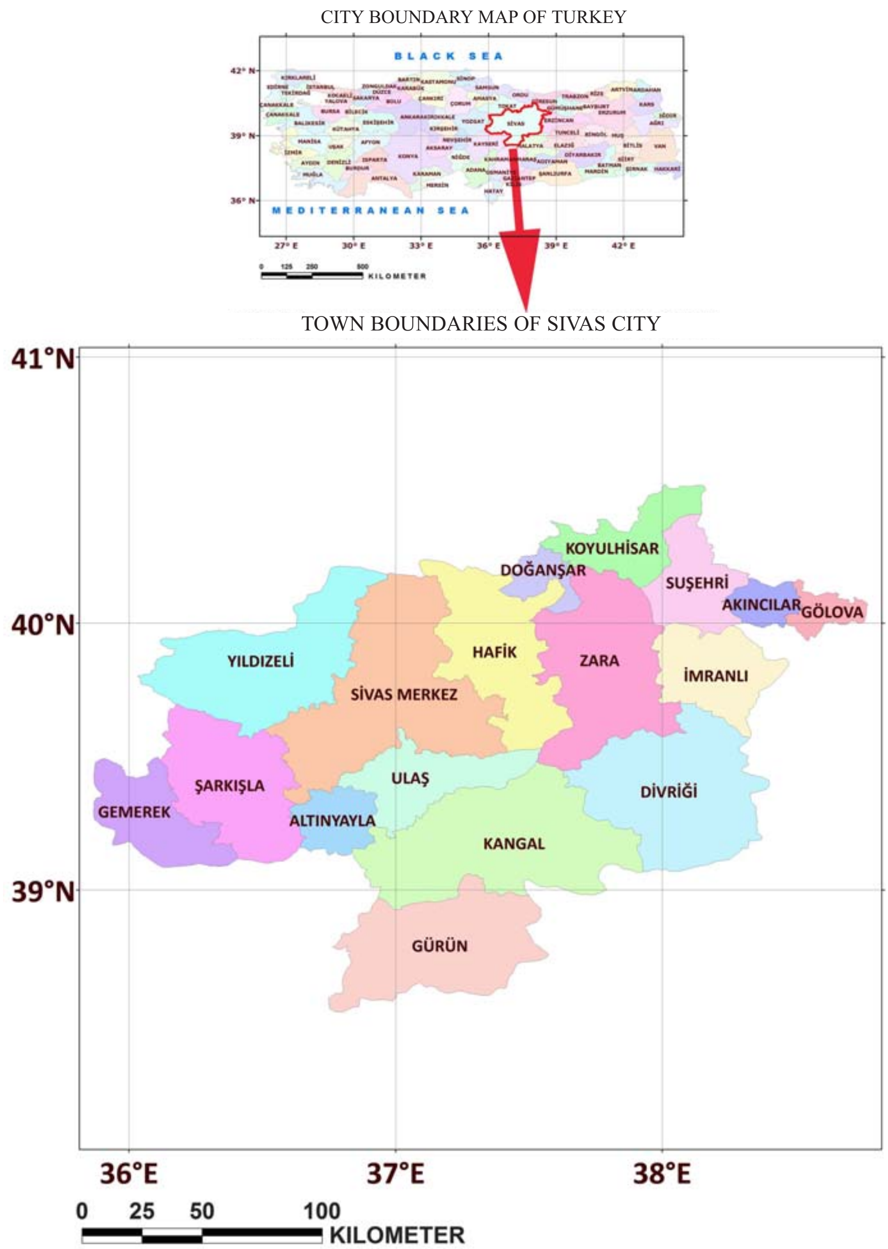


Fig. 2. The study area.

Table 1. Geographical/non-geographical layers designed and its attributes for the created system.

Geographical / Tabular Layers (Type)	Attributes
City Boundary (Polygon)	City ID, City Traffic Code, City Name, Current Population, Town Number, Geographical Region Name, Area
Town Boundary (Polygon)	Town ID, City ID, Town Name, Village Number, District Number, Area
Patient With Cancer (Standalonetable)	Patient Identity Number, Diagnose Year, Sex, Age, Age Group, Diagnose Code, Definite Diagnose Name, Cancer Type, City Name, Town Name, Village Name, District Name, Explanation
Town Cancer Case (Standalonetable)	City ID, Town ID, Year, Total Population, Male Population, Female Population, Incidence Rate, Number in Bladder Cancer, Number in Breast Cancer, Number in Colon and Rectal Cancer, Number in Endometrial Cancer, Number in Kidney Cancer, Number in Leukemia Cancer, Number in Lung Cancer, Number in Melanoma Cancer, Number in Lymphoma Cancer, Number Pancreatic in Cancer, Number in Prostate Cancer, Number in Thyroid Cancer, Number in Stomach Cancer, Number in Larynx Cancer, Number in Mesothelioma Cancer, Number in Other Cancer, Number in Total Cancer, Explanation
Town Cancer Incidence Rate (Standalonetable)	City ID, Town ID, Year, Age Group, Female in Cancer, Male in Cancer, Female Population, Male Population, Total Population, Total Cancer Case, Cancer Incidence Rate for Male, Cancer Incidence Rate for Female, Explanation

Location is one of the important determinants of cancer cases. There are asbestos minerals within the provincial border of Sivas. As is known, every type of asbestos causes cancer. The GIS-based system established for this purpose is extremely important in supporting public health protection.

Data Used

Proper information regarding yearly population and cancer records are important to the utmost degree while calculating cancer incidence rates. In Turkey, access to proper population records for every year at the level of city, town, sub-town, village, and quarter is available on a regular basis as the result of studies by the Turkish Statistical Institute (TurkStat) and the General Directorate of Civil Registration and Nationality (GDCRN), which have been carried out since 2007. On the other hand, Sivas Provincial Directorate of Health collects cancer data from the relevant health care institutions and hospitals, and is in charge of in compliance with ICD-10 standards.

In this study, population information for Sivas obtained from TurkStat at the level of town 2007-10, and data (3472 Cancer Registry in the towns of Sivas City) for cancer cases acquired from Sivas Provincial Directorate of Health and kept under record according to ICD-10 standards between years of 2007-10 were used. Additionally, data demonstrating provincial borders of Turkey and town borders of the city of Sivas were used as geographical data.

Geographical Layers Designed and User-Interface Programs Developed

Attributes of geographical/non-geographical data were designed as objectives of this study (Table 1).

On the other hand, several user-interface programs (again, for the objective of this study) were developed. These developed user-interface program functions as follows:

When the “Update the Diagnosis” button is pressed, a window pops up, where cancer case information for patients can be entered. After entering necessary information, cancer record information is added into the designed database by pressing the “Add to Database” button (Fig. 3).

When the “Statistical Query” button is pressed, it is possible to perform several statistical queries by considering cancer incidence rate or total cancer cases along with year criteria. When the “Find the Town in Maximum/ Minimum Cancer Case” button is pressed, the town where maximum/minimum cancer cases occurred is automatically searched and selected on the map in line with specified criteria, including the name of this determined town, how many cancer cases occurred therein, cancer incidence rates for that respective year, and the total population of that town are delivered to the users by a message box. On the other hand, when queried according to the diagnosis type (when the button “Find the Town in Maximum/Minimum Cancer Case” is pressed), the town in which the specified cancer type occurred maximally/minimally is automatically searched and selected on the map, and name of this determined town, the total number of cancer cases therein, the number of cancer cases of selected type, cancer incidence rates for that respective year, and the total population of that selected town are delivered to the users by a message box (Fig. 4).

When the “Query City” button is pressed, a window querying the city geographically pops up. As the city to be queried is determined via combobox, that city is selected on the map and information related to that city is automatically displayed on the screen (Fig. 5a). When the “Query the

Diagnosis According to Towns" button is pressed, a query in four towns (determined by the user) of the previously queried city can be performed considering the year criteria. As the result, percentage distribution of cancer types occurred and cancer incidence rates in these towns for that relevant year are automatically displayed on the screen (Fig. 5b). "Query The Diagnosis Distribution," a query in a town (determined by the user) of the previously queried city, can be performed considering the year criteria. At the end of this query, the number of males, females, and total people diagnosed with cancer, the statistical distribution of these patients by age group and cancer types are full-automatically queried and displayed on the screen (Fig. 5c).

When the "Query Town" button is pressed, a window querying the town geographically pops up. As the town to be queried is determined via combobox, that town is selected on the map and information related to that town is automatically displayed on the screen (Fig. 6a). When the button "Query Diagnosis in the Town" is pressed, the percentage distribution of cancer types in the previously queried town in four different years (determined by the user) and cancer incidence rates in this town in four years are queried automatically and displayed on the screen (Fig. 6b).

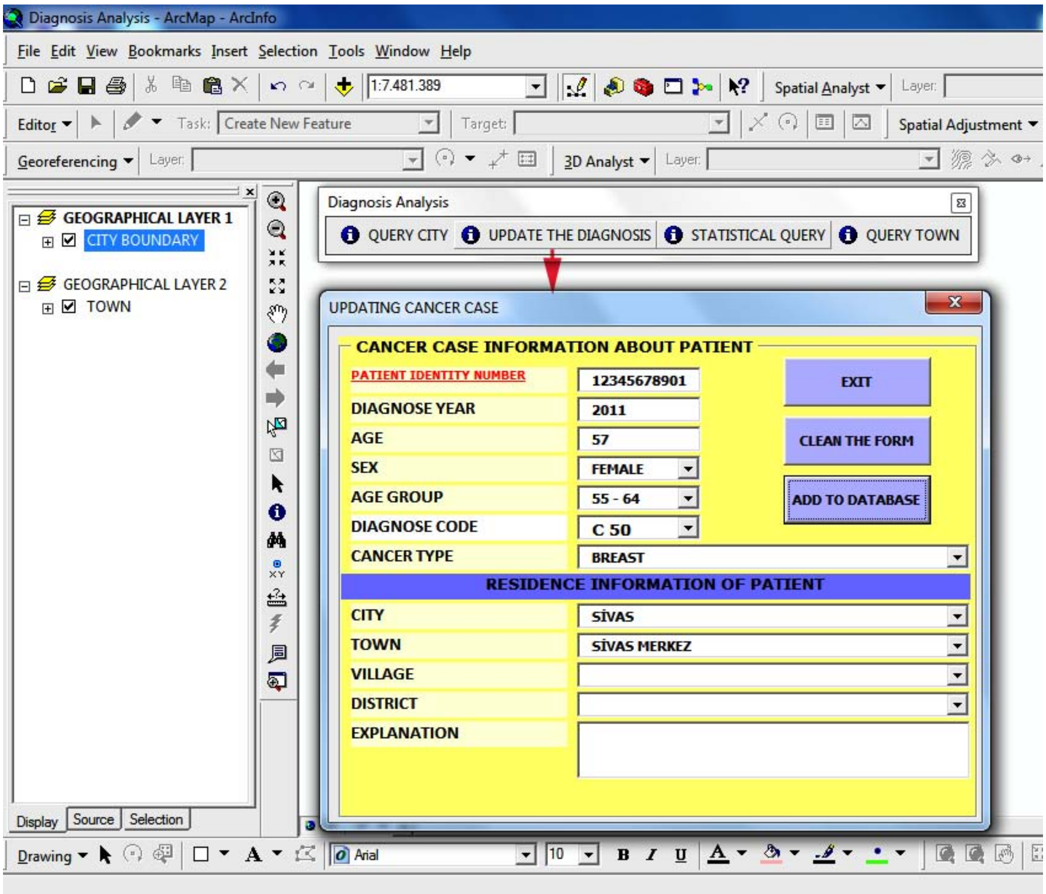


Fig. 3. User interface program developed for updating cancer case (Update the Diagnosis).

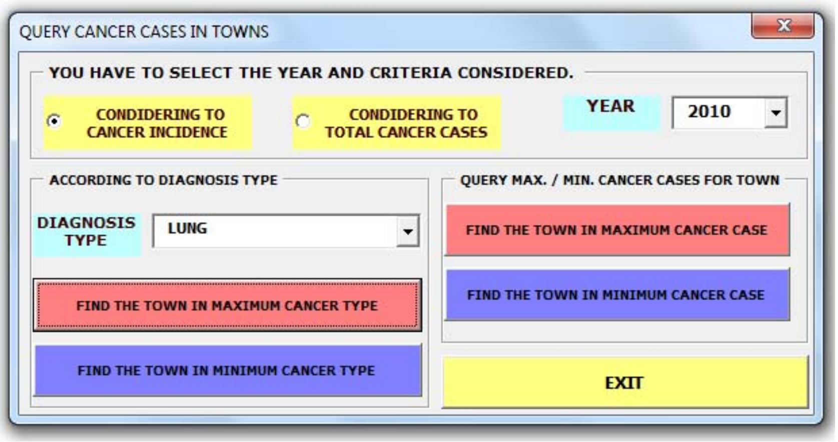


Fig. 4. User interface program developed for statistical query of cancer cases in towns (Statistical Query).

Results and Discussions

Several remarkable results were recorded by the GIS-based information system established within the scope of this study. When the total cancer incidence rate of the City of Sivas was considered, it is noted that it is above the world average in 2007; however, it remains under this average level in the years 2008, 2009, and 2010.

On the other hand, when the total cancer incidence rates between 2007 and 2010 are queried and analyzed for the towns by using this system, it is seen that Sivas Center, Hafik, and Yıldızeli towns are in the top three. The town with the highest cancer incidence rate for 2007, 2008, and 2009 is Sivas Center, whereas for 2010 it is the town of Hafik (Fig. 7). In this study, age-group and gender has been taken into consideration while calculating the cancer incidence rate and it has been standardized for the city of Sivas (all towns).

The town of Sivas Center is the town with the highest population in the study area. By the year 2010, its population (including villages) is 354,913. As a result of the queries and analyses carried out, it has been determined that in 2007, 2008, and 2010 the highest cancer incidence rate for males was between the ages of 65-74 whereas in 2009 it is between the ages of 55-64. The highest cancer incidence rate for females was between the ages of 35-44 in 2007, whereas in 2008 this was 45-54 and in 2009 between 65-74, whereas in 2010 between the ages of 55-64. It has been determined that during 2007 and 2008 females got cancer more than males (until the 45-54 age group), whereas after this age group males got cancer more than females. Whereas during 2009 and 2010, females caught cancer more in the 35-44 age group, after which the rate of getting cancer for males became higher. Furthermore, when the cancer incidence rates are classified according to age-group and gender for the years 2007-08, 2008-09, and 2009-10, a correlation of at least 94% is found between the cancer incidence rates of males, whereas there is a correlation of at least 93% for females. This puts forth that the cancer cases that occurred at the town of Sivas Center changed almost in the same rate for both males and females (Fig. 8).

As a result of the queries and analyses made, even though the town of Hafik has a low population it was ranked as second in point of cancer incidence rate in 2007, as third in 2008 and 2009, and as first in 2010. Therefore, it should be investigated whether there are risk factors that cause cancer in this town or not. Whereas the highest cancer incidence rate for males during 2007, 2008, and 2009 was between the ages of 55-64, it was between the ages of 65-74 in 2010. Whereas the highest cancer incidence rate for females in 2007, 2008, and 2009 was between the ages of 55-64, in 2010 this interval was 45-54. It has been determined that during 2007 and 2008 males got cancer more than females in all age groups. It is observed that in 2009 females got cancer more than males up to the 45-54 age group, whereas males got cancer more after this age group.

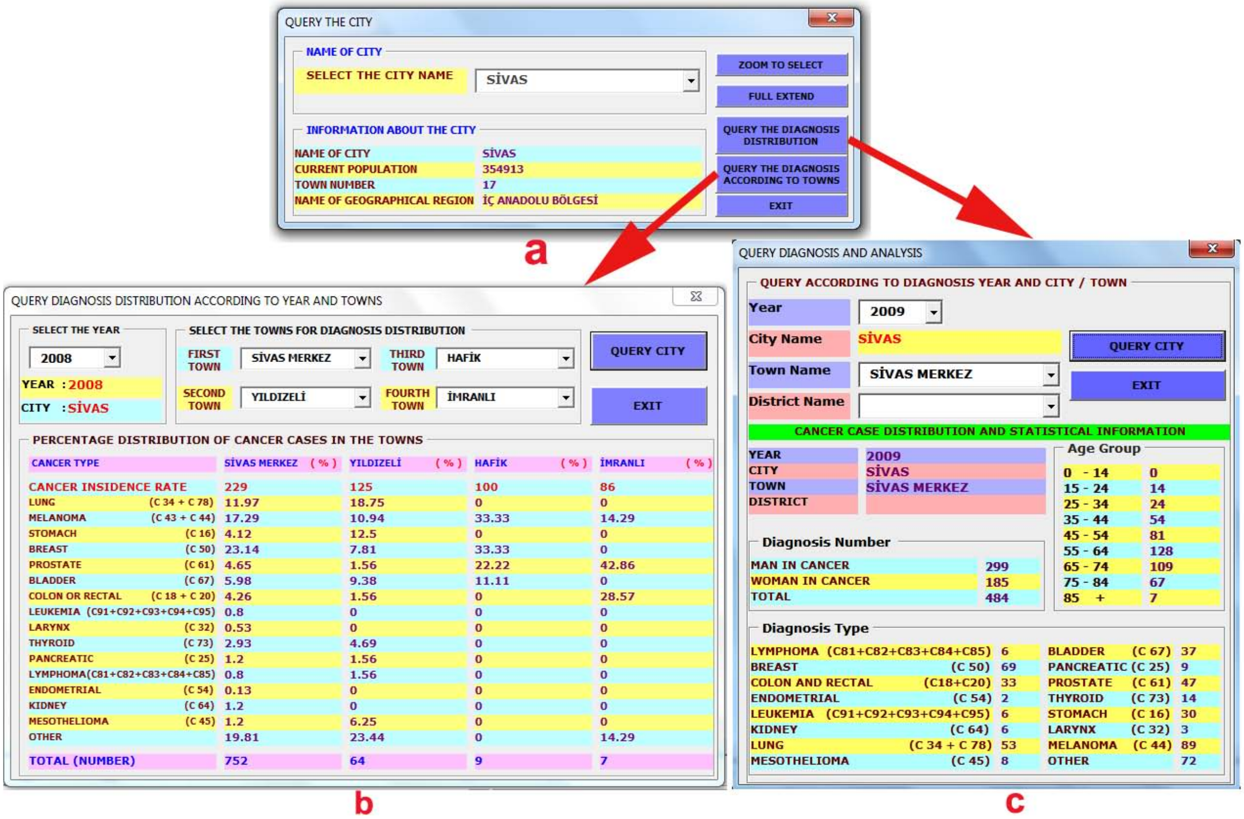
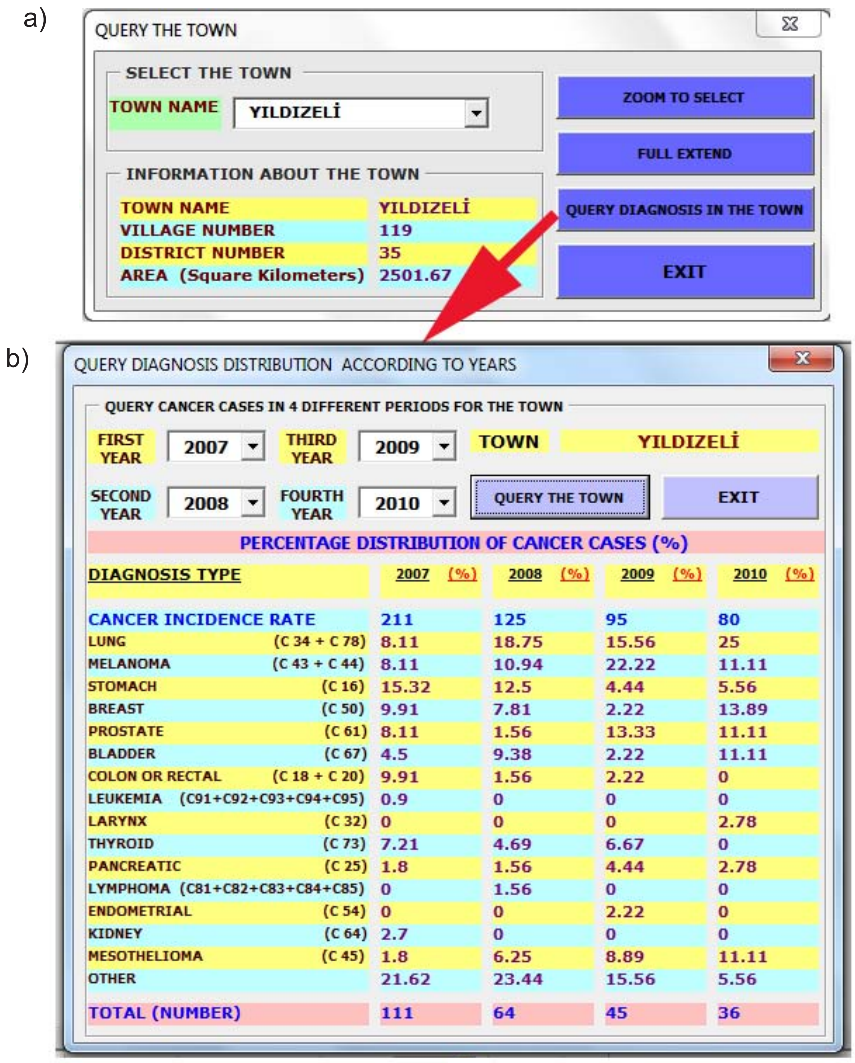


Fig. 5. User interface program developed for statistical distribution of diagnosis, query, and analysis of cancer cases in the city (Query City).

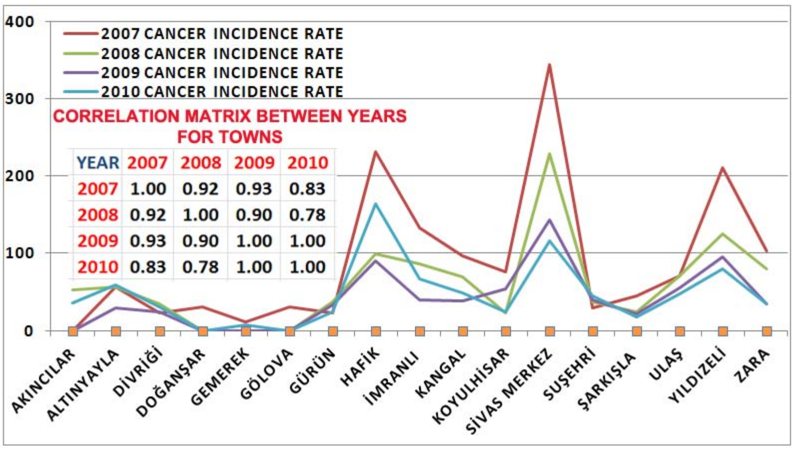
Whereas in 2010 females got cancer more than males up to the age group of 55-64, the cancer incidence rate was higher for males after this age group. On the other hand, the most common types of cancer that occurred in the town during 2007 and 2010 were lung, breast, melanoma, and prostate.

The town of Yıldızeli, one of the towns with higher cancer incidence rates, is ranked in the third place in 2007, in the second place in 2008 and 2009, and in the third place in 2010. The highest cancer incidence rate for males in 2007, 2008, and 2009 was seen in the age group of 65-74, whereas in 2010 it was the 55-64 age group. In 2007 and 2009 the



DIAGNOSIS TYPE		2007 (%)	2008 (%)	2009 (%)	2010 (%)
CANCER INCIDENCE RATE		211	125	95	80
LUNG	(C 34 + C 78)	8.11	18.75	15.56	25
MELANOMA	(C 43 + C 44)	8.11	10.94	22.22	11.11
STOMACH	(C 16)	15.32	12.5	4.44	5.56
BREAST	(C 50)	9.91	7.81	2.22	13.89
PROSTATE	(C 61)	8.11	1.56	13.33	11.11
BLADDER	(C 67)	4.5	9.38	2.22	11.11
COLON OR RECTAL	(C 18 + C 20)	9.91	1.56	2.22	0
LEUKEMIA	(C91+C92+C93+C94+C95)	0.9	0	0	0
LARYNX	(C 32)	0	0	0	2.78
THYROID	(C 73)	7.21	4.69	6.67	0
PANCREATIC	(C 25)	1.8	1.56	4.44	2.78
LYMPHOMA	(C81+C82+C83+C84+C85)	0	1.56	0	0
ENDOMETRIAL	(C 54)	0	0	2.22	0
KIDNEY	(C 64)	2.7	0	0	0
MESOTHELIOMA	(C 45)	1.8	6.25	8.89	11.11
OTHER		21.62	23.44	15.56	5.56
TOTAL (NUMBER)		111	64	45	36

Fig. 6. User interface program developed for query diagnosis distribution according to years (Query Town).



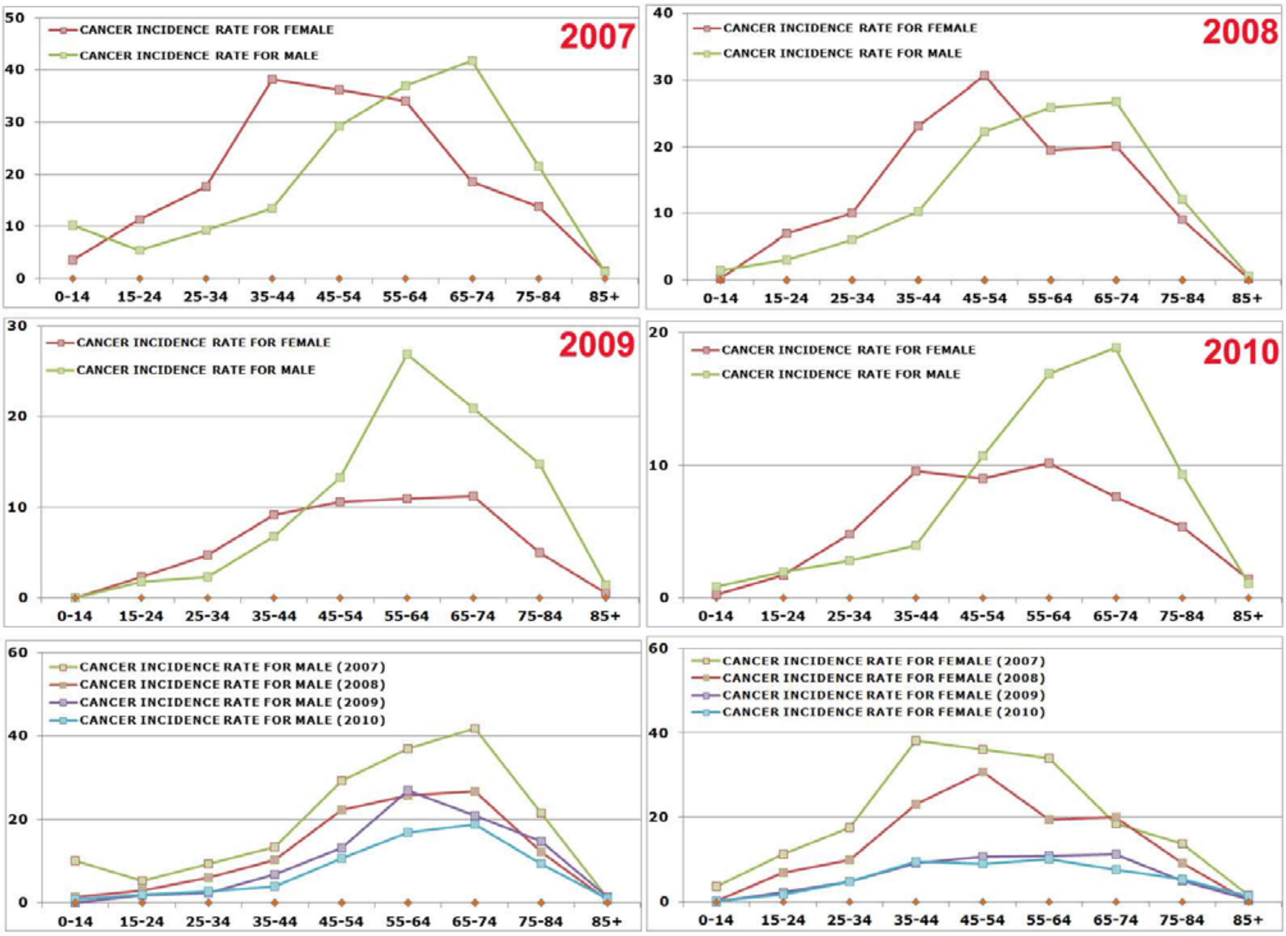
YEAR	2007	2008	2009	2010
2007	1.00	0.92	0.93	0.83
2008	0.92	1.00	0.90	0.78
2009	0.93	0.90	1.00	1.00
2010	0.83	0.78	1.00	1.00

Fig. 7. Cancer incidence rates for Sivas city.

highest cancer incidence rate for females was in the 55-64 group, whereas in 2008 and 2010 it was in the 65-74 age group. It has been determined that in 2007 females got cancer more than males for age groups up to 55-64. Whereas after this age group males get cancer more than females. It is observed that in 2008 females get cancer more than males for age groups up to 35-44, whereas after this age group males get cancer more than females. In 2009 cancer was seen more in females between the ages of 15-34, males between the ages of 35-54, females between the ages of 55-64, males between the ages of 65-84, and females after the age of 85. Whereas in 2010 the cancer incidence rate was the same for both males and females between the ages of 0-25, it was seen more in females after this age group. Lung, stomach, melanoma, prostate, breast, and bladder are the most frequently seen cancer types in this town. On the other hand, mesothelioma is observed most in this town. Asbestos minerals have been determined within the borders of Yıldızeli during the studies carried out by the Health Administration of the City of Sivas. It is thought that mesothelioma and lung cancer cases might be caused by these minerals.

The same things stated for the town of Sivas Center is also valid for the city of Sivas (including all towns). When the cancer incidence rates for the periods of 2007-08, 2008-09, and 2009-10 are considered, a correlation of at least 95% between males and a correlation of at least 93% between females was determined (Fig. 9). This puts forth the fact that cancer cases during these periods change almost in the same manner in the city of Sivas as well. However, all cancer types that have occurred during 2007 and 2010 in the city of Sivas (including all towns) were queried and analyzed. As a result of this analysis, it is observed that the most frequent cancer types are melanoma, breast, lung, and prostate. When the recorded cancer types and their numbers are taken into account, a correlation of at least 91% is observed for the periods of 2007-08, 2008-09, and 2009-10 (Fig. 10).

After age groups and genders were standardized for the city of Sivas (including all towns), the mean cancer incidence rates for both males and females were calculated for 2007, 2008, 2009, and 2010. These calculated values are expressed by sixth-degree polynomial equations. Whereas the coefficient of determination (R^2) that expresses the strength of the



CORRELATION MATRIX BETWEEN YEARS FOR MALE

YEAR	2007	2008	2009	2010
2007	1.00	0.98	0.94	0.98
2008	0.98	1.00	0.94	0.97
2009	0.94	0.94	1.00	0.97
2010	0.98	0.97	0.97	1.00

CORRELATION MATRIX BETWEEN YEARS FOR FEMALE

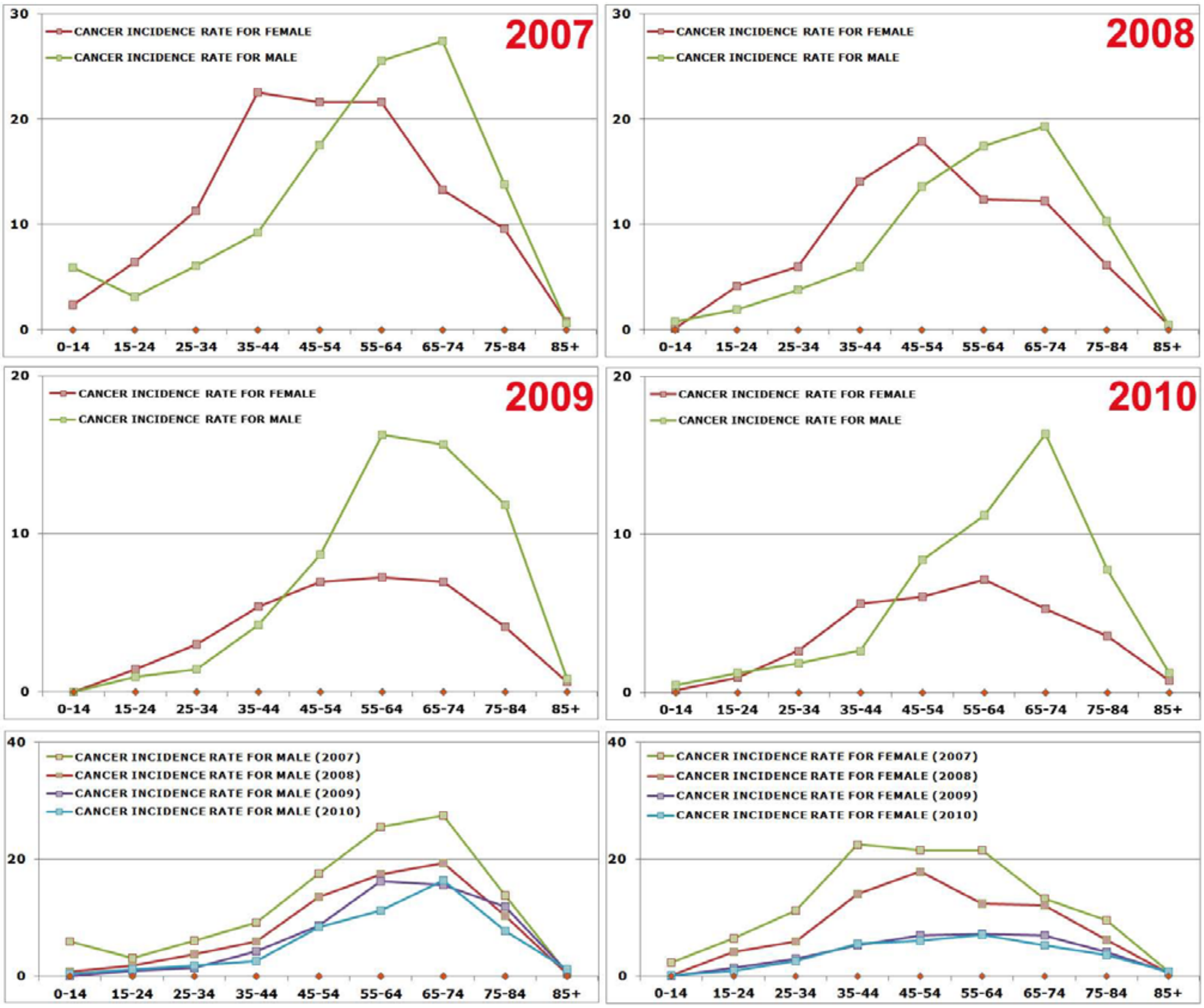
YEAR	2007	2008	2009	2010
2007	1.00	0.93	0.87	0.94
2008	0.93	1.00	0.93	0.92
2009	0.87	0.93	1.00	0.96
2010	0.94	0.92	0.96	1.00

Fig. 8. Male and female cancer incidence rates in the town of Sivas Center between 2007 and 2010.

relationship between the variables in the equation is 0.991 for females, this coefficient for males is 0.998. These equations almost represent existing data used to calculate the cancer incidence rates of the standardized age groups of males and females between 2007 and 2010. Accordingly the highest cancer incidence rate between 2007 and 2010 for females is observed in the age group of 45-54, for males it is observed in the age group of 65-74. Females got cancer more than males in age groups of up to 45-54, whereas after this age group males got cancer more than females (Fig. 11).

Due to the fact that thematic maps are a visual interaction tool, they are highly significant to present spatial data. The most important criteria in interpreting cancer cases are rates of cancer incidence. In this regard, cancer incidence rate maps for the towns of the city of Sivas were produced for both males and females between 2007 and 2010 (Figs. 12 and 13).

According to the latest scientific research related to cancer cases, people get cancer on account of different causes. Environmental factors are some of them. Various cancer types can be precluded in the case of controlling of these factors. As is known, people get cancer because of some radioelements such as cadmium, uranium, arsenic, nickel, and asbestos within soil, water, and air (environmental factors). At the same time, this event is based on geographical location. In particular, lung cancer is one of the most common cancer types in the world. In the created system, several queries and analyses were performed for determining the lung cancer distributions in the city of Sivas between 2007 and 2010. Afterward, these results were presented by means of the thematic map (Fig. 14). This map shows that it is in the top in point of lung cancer incidence in 2009 and 2010, although population of the town of Hafik is in the top twelfth among 17 towns in this period. Therefore, a detailed



CORRELATION MATRIX BETWEEN YEARS FOR MALE

YEAR	2007	2008	2009	2010
2007	1.00	0.99	0.95	0.96
2008	0.99	1.00	0.96	0.97
2009	0.95	0.96	1.00	0.95
2010	0.96	0.97	0.95	1.00

CORRELATION MATRIX BETWEEN YEARS FOR FEMALE

YEAR	2007	2008	2009	2010
2007	1.00	0.95	0.89	0.94
2008	0.95	1.00	0.93	0.93
2009	0.89	0.93	1.00	0.98
2010	0.94	0.93	0.98	1.00

Fig. 9. Cancer incidence rates for male and female in the city of Sivas (all towns) between 2007 and 2010.

investigation should be carried out as to determine if there might be any environmental factors within the soil, water or air of the town that could lead to cancer.

Conclusions

Cancer is one of the most important health issues around the world. Thus, studies carried out for preventing the public health from cancer are extremely important. In this study, a GIS-based information system was established to take necessary measures in geographical locations with cancer risk, to contribute to preventing the public health, and to support the decision of institutions responsible for health care. As a result, the cancer cases that occurred at the city of Sivas and its towns between 2007 and 2010 were examined in detail and various statistical information was revealed.

Within this scope, the cancer cases that occurred between 2007 and 2010 were standardized, keeping in mind age group and gender. The average of the cancer incidence rates for these years were calculated for both males and females and the curve equations representing them were estimated with a high coefficient of determination (R^2=0.99). Thus, the cancer incidence rates for both males and females in the desired age group can be calculated easily by using these equations. One of the most significant factors in the development of cancer is geographical factors. Revealing the relationship between these factors and cancer cases will contribute to taking necessary measures against cancer. Although mesothelioma is quite rarely recorded around the world, in Turkey it is determined to be far above the world average. With the assistance of a GIS-based information system established within the scope of this study, it is automatically identified that cases of mesothelioma and lung cancer are quite higher in the town of Yıldızeli as the result of the query accomplished by pressing a single button. Several studies conducted by the Sivas Provincial Directorate of Health do also confirm this result. On the other hand, although the town of Hafik has lower population, it is regarded as one of the towns with highest lung cancer incidences and cancer incidence rates. In this town, a detailed study should be performed as to determine if there might be any environmental factors (radioelements such as cadmium, uranium, arsenic, nickel and asbestos within soil, water, and air) that could lead to cancer.

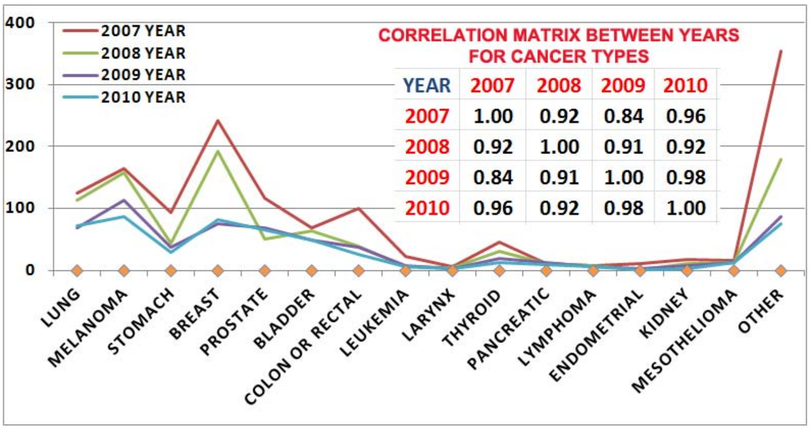
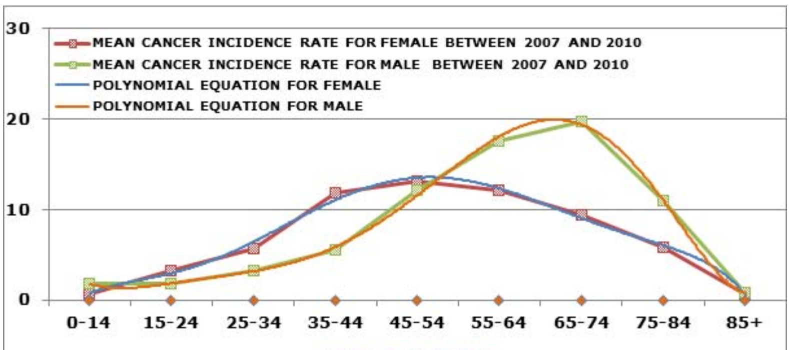


Fig. 10. Distributions of cancer types in the city of Sivas (all towns) between 2007 and 2010.



For Female

$$y = -0.005x^6 + 0.1456x^5 - 1.6173x^4 + 8.4323x^3 - 21.139x^2 + 26.687x - 11.793$$

$$R^2 = 0.991$$

For Male

$$y = 0.0075x^6 - 0.2034x^5 + 2.0655x^4 - 10.059x^3 + 25.419x^2 - 30.963x + 15.534$$

$$R^2 = 0.998$$

Fig. 11. The curve equation estimated for determining male/female cancer incidence rates in the city of Sivas between 2007 and 2010.

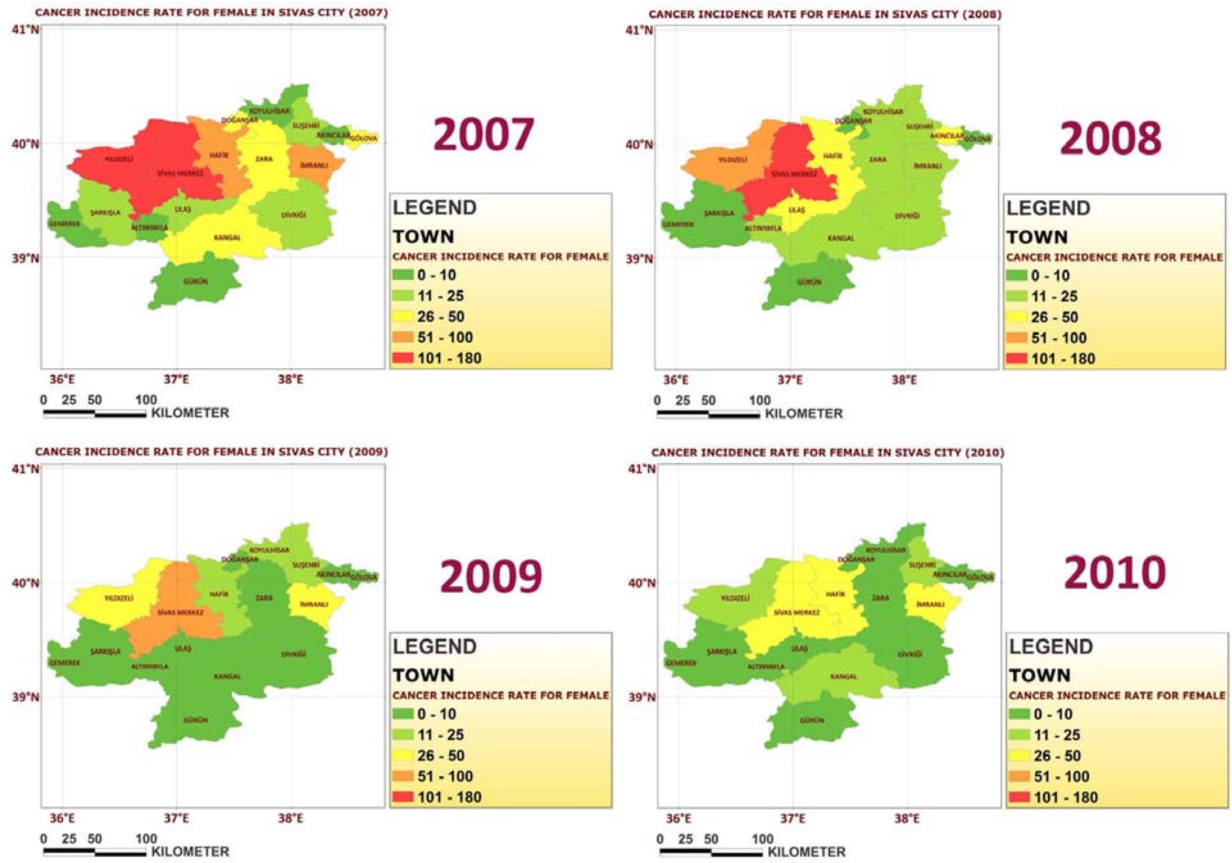


Fig. 12. Cancer incidence rate maps for females in the city of Sivas (all towns) between 2007 and 2010.

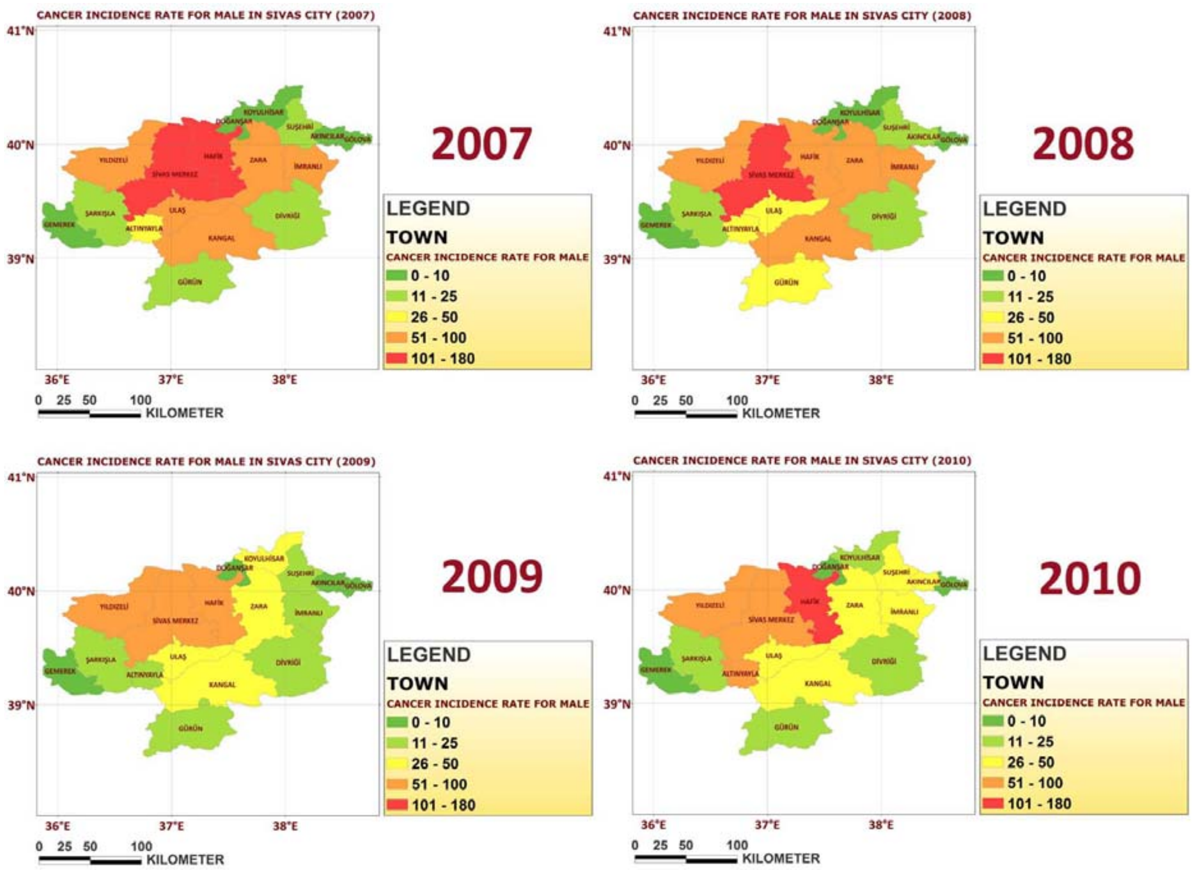


Fig. 13. Cancer incidence rate maps for males in the city of Sivas (all towns) between 2007 and 2010.

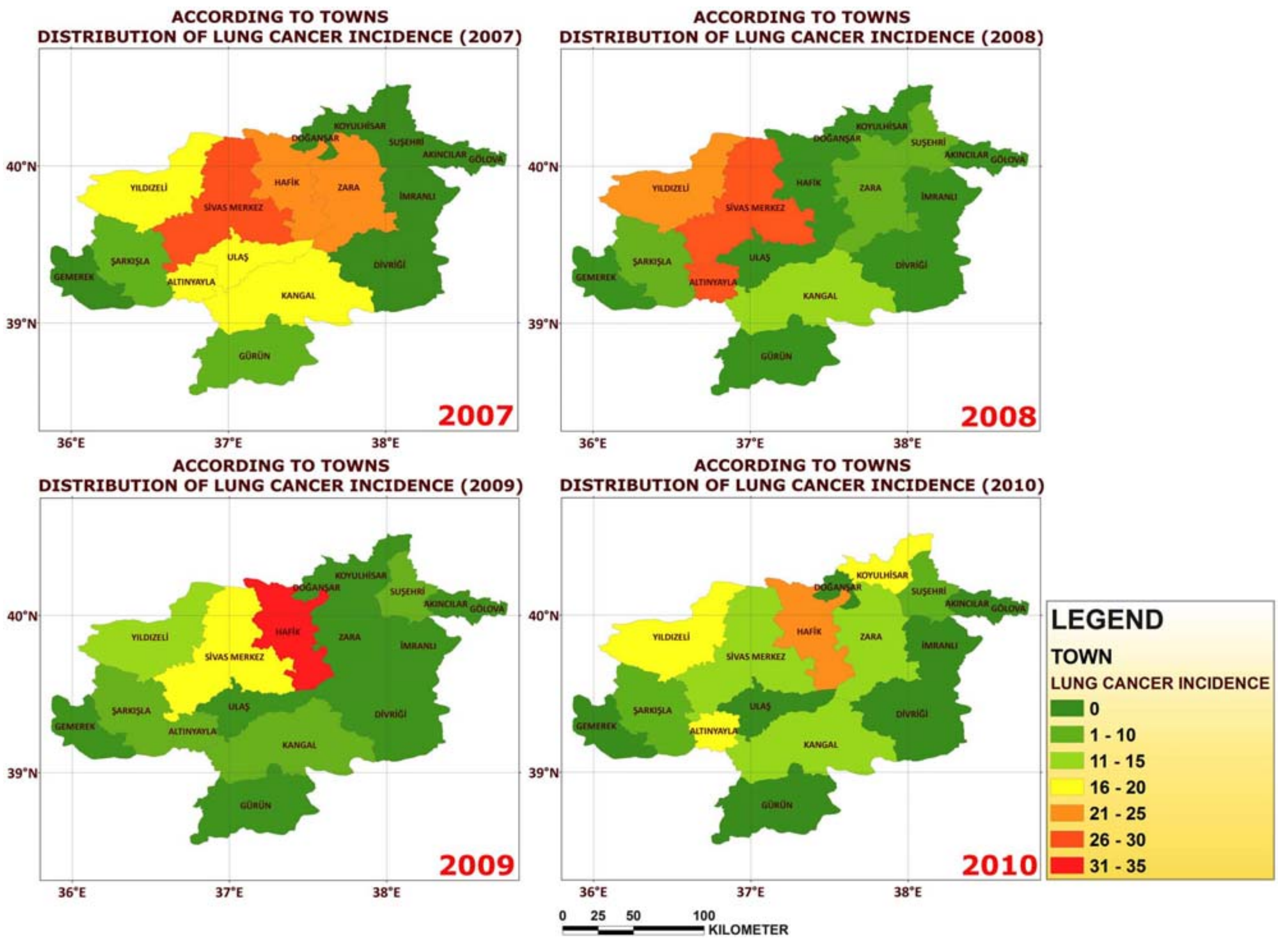


Fig. 14. Lung cancer incidence maps in the city of Sivas (all towns) between 2007 and 2010.

As could be understood from these results, the established system makes a major contribution to the studies for taking cancer cases under control, which occurred in a specific geographical location.

The most significant criteria in assessing cancer control is the cancer incidence rate. With the system established within the framework of this study, cancer incidence rate and cancer cases are presented clearly. Thematic maps are a visual interaction tool. Additionally, several maps can be produced for specific diseases and other health events. Again, through the system recommended within the scope of this study, it is possible to produce cancer incidence rate maps, common cancer case maps, and other maps. Considering these maps, studies for the prevention of public health can be conducted.

It is extremely important that data of diagnosis recorded by the authorities are collected in a proper, standardized, and systematized way. Establishing the necessary legal and technical infrastructure for this purpose should be ensured by the authorized institutions. Because the more proper and standard the data are, the more proper and consistent the obtained results will be. A GIS-based health information system established within this framework will play a major role in the prevention of public health against cancer and other diseases by making a significant contribution to decision makers.

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