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ABSTRACT

Global studies suggest that cataract, like any other disease, is associated with environmental factors. To identify and establish such association, we need the spatio-temporal disease distribution pattern and geo-spatial analysis of soil, considered for the first time as one of the key factors as it describes the combined effect of all the local conditions. The objective of this study was to determine and map the cataract disease clusters and pattern (in terms of locations, seasons, and gender) and explore their associations with the local environmental factor (soil and clay minerals), and occupation of the people exposed to such environment (agriculture). A poisson probability model that performs space-time analysis of the disease data and determines the spatio-temporal disease clusters using Satscan program was followed. GIS maps of the local environmental factors (soil map) were overlaid on these cluster maps to determine the environmental correlates. To observe for presence of clay minerals having potential to carry harmful organic compounds in these clusters, X-ray diffraction (XRD) technique was used. Six clusters of 48 vulnerable villages across four Hoblis were observed. Summers were most affected season, and rural women practicing agriculture were at higher risks. Regions with the presence of clay minerals like "Smectite" and " Kaolinite " had higher prevalence of the disease. Geo-Spatial analysis of cataract distribution and the regional environmental data revealed an interesting pattern—regions having presence of clay minerals "Smectite" and "Kaolinite" had higher prevalence of cataract.

Keywords Cataract clusters, Disease surveillance, Environment, Epidemiology, Geo-spatial scan.

INTRODUCTION

Background

Pavagada had the highest Cataract incidence rate of 14.63% in 2012-13, and 24.14% in 2017-18. Since historically Pavagada has higher prevalence rate, we chose this for our analysis. The occurrence of a disease depends on a combination of local factors and extent of the exposures the population is subjected to (Praveen *et al*. 2010). Like any other diseases, cataract also is geographically scattered (Vashist *et al*. 2011)

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varies between gender (Sreekanth 2017), populations (Murthy *et al*. 2005 and Malik Sahai 2005), occupations (Rozanova *et al*. 2009, Sinha *et al*. 2009) and environmental and biological conditions (Lim *et al*. 2012). Despite this heterogeneity, it is observed that rural population (Xiao-Guang *et al*. 2017) especially women are the most vulnerable. Therefore, analysis of the spatial components and the disease incidence becomes important to determine their trend.

Study area

General characteristics of the district

Tumakuru district in Karnataka is situated about 70 kms to the North-West of Bangalore.

Pavagada taluk has four hoblis namely, Nagalamadike (NAG) that lies in the east and has 25 villages, Nidagal (NID) in the west with 30 villages, YN Hoskote (YNH) in the north with 31 villages and Pavagada (PAV) in the south with 37 villages. These hoblis form the basis for our analysis.The details of the study area are shown in Table 1.

Objective and aim

The purpose of this study is:

To detect the disease clusters and identify vulnerable locations, seasons, and gender by using a statistical tool, SatScan.

Map, analyze and interpret the spread of disease across the taluk using Arc-GIS.

Overlay the disease distribution map with the regional environment related maps to observe if any pattern exists in relation to the environmental factors.

Characterization of soil samples for their structural and textural properties by X-ray diffraction (XRD) approach as presence of clay minerals like "Smectite" and " Kaolinite " have potential of carrying harmful organic compounds used in agriculture.

To provide direction for further studies on the disease distribution and its association with local geographical and environmental factors in other regions.

MATERIALS AND METHODS

Data

Cataract disease of Pavagada taluk in Tumkur district of Karnataka in India was obtained from the office of Director, "Karnataka State Health and Family Welfare Society (Blindness Control Division)" working under National Health Mission (NHM), for the period April 2018 to November 2018.

Demographic, which is the data about the male and female population at the Hobli and village level was obtained from the Karnataka District Census Handbook 2011, published by the "census.org" (Directorate of Census Operations, 2011), a Central Government organization, and is available on their website. The gender-wise workforce data of the taluk was also obtained from this source.

Environmental such as soil is considered as a key factor for this study as it strongly represents the local environment. The intricacies of the formation, distribution and characterization of soil depend local

Table 1. Population data.

Hobli	Total population	Area sq km	Geoarea in Hectare	House holds	Male population	Female population	Total cataract cases	Male cataract cases	Female cataract cases
NAG	30708	295	29486	7409	15698	15010	108	47	61
NID	47041	244	24404	10507	23620	23421	138	47	91
PAV	52611	294	29435	12918	26377	26234	225	85	140
YNH	61960	308	30786	14054	31336	30624	155	58	97
Total affected villages	1,92,320			43,718	97,031	95,289	626	237	389

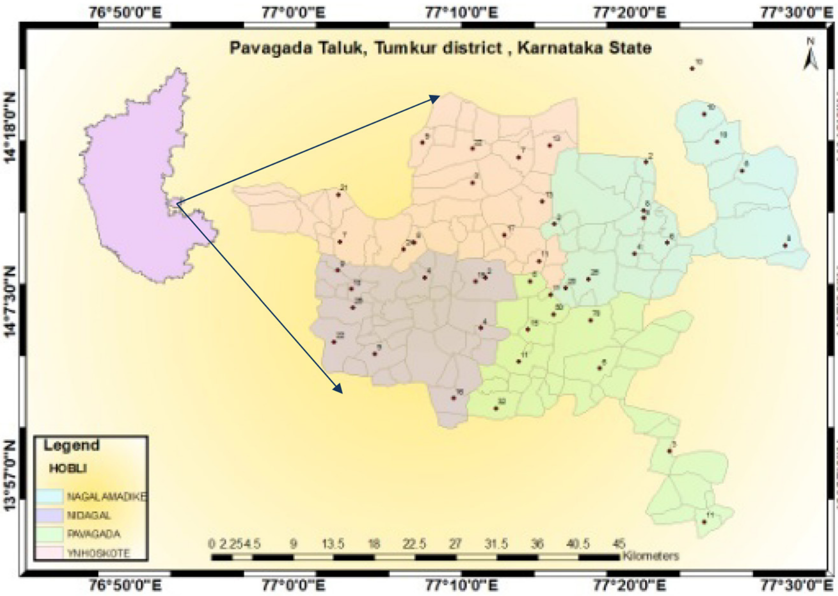

Fig. 1. Cataract distribution in dtudy area.

parent rock material, topography of the area, altitude, drainage conditions, degree of erosion, the slope of the land and importantly, the process of weathering based on local conditions. When these factors are the same, the type of soil is the same across regions. When the conditions change, the soil type also changes. Therefore, the soil data becomes essential to describe the combined effect of all the local factors mentioned above. Moreover, the characterization and definition of soils are globally standardized, making it a significant factor for comparative studies.

Soil for Pavagada taluk, Tumakuru district of Karnataka, was obtained from the reports published on the website of the Ministry of Agriculture and Farmers Welfare, Government of India and from the National Bureau of Soil Survey and Land Use Planning, (Indian Council for Agricultural Research), Nagpur, India.

Clay mineral for the soil samples of the study area were determined by subjecting the soil particles for a thorough characterization of their structural and textural properties by X-ray diffraction (XRD) approach conducted at the XRD unit of National Center of Excellence in Geological Research of Geological Survey of India, Bangalore.

Methodology for summarizing disease data

Spatial analysis was done hobli and gram panchayat-wise for the study period. Monthly occurrence of the disease was analyzed. Maps were created in Arc-GIS for the number of cataract cases incident in each village and hobli. The distribution of the disease in the region is shown in Fig. 1. Preliminary analysis of the cataract disease data across the four hoblis of the study area is shown in Table 2. YNH had the highest disease prevalence at 24.76%, followed by NID and NAG at 22.04% and 17.25% respectively. YNH had the highest affected male population. The prevalence of the disease in females was high, with 24.94% in YNH, followed by 22.39% and 15.68% in NID and NAG respectively.

Spatial files were digitized using topo sheet data obtained from Geological Society of India by using Arc-GIS software. Soil maps were developed for the study area for overlaying on the disease cluster map.

Space-time analysis uses spatial scan to detect the disease clusters and also performs tests for significance. Several software packages like SatScan, ClusterSeer, GeoSurvellience, and R software environment that uses Surveillance package, are common

Table 2. Summarized cataract data.

Hobli	Total population	Male population	Female population	Total cataract cases	% Cases	Male cataract cases	% Male cases	Female cataract cases	% Female cases
NAG	30708	15698	15010	108	17	47	20	61	16
NID	47041	23620	23421	138	22	47	20	91	23
PAV	52611	26377	26234	225	36	85	36	140	36
YNH	61960	31336	30624	155	25	58	24	97	25
Total affected villages	1,92,320	97,031	95,289	626		237		389	

for the Spatial, Temporal and Space-Time Scan Statistic analysis. For our study, we used SatScan version 10.0.2. Space-time scan statistics, introduced by Martin Kulldorff (Kulldorff 1997), performs spatial surveillance of diseases, to detect disease clusters and evaluate their statistical significance. The statistic is defined by a cylindrical window that represents a possible cluster where the base corresponds the spatial and the height corresponds the time and moves in space and time covering the entire study region. Overlapping cylinders of different shapes and sizes are obtained. Satscan creates a sampling of the study area with circles to cover 50 % of the population in the selected area. Actual and expected number of cases are obtained for the circles and likelihood value is calculated. For each window the scan statistics tests the null hypothesis against the alternative hypothesis that there is higher risk of cataract within a window compared to outside the window. After replicating the simulation several times under the null hypothesis of no cluster, the likelihood values are obtained and ranked for each replication and potential clusters having high likelihood ratio are detected.

The statistical significance is evaluated by using Monte Carlo hypothesis testing where more than 999 random datasets are generated under the null hypothesis to obtain the P-value. The maximum circle radius of cylindrical window was set at 3 km. For the cluster to be statistically significant, its p-value should be less than 0.05 when the null hypothesis is rejected and confirms the significance of disease cluster for the datasets.

Poisson probability model

The input files required for Poisson probability model run by the program are the case file, population file and Coordinate files. For discrete scan statistics separate data locations were specified for each individual village. For space-time trends analysis, it is necessary to have a time related to each case time. Therefore, we used month as time for cases. The population file had the population count for each village with date specified. These files were provided to SatScan in ASCII format. Multiple case files each representing different data sets with information about case counts for different seasons, gender and locations were created to be run in SatScan. Since Poisson probability model requires the relevant case file, coordinate file and the population file to be accompanied together for each of the above requirements, they were bundled appropriately to provide as input files for different requirements.

We obtained three datasets from the summarized data (refer the supplementary material):

A dataset consisting of villages, their population, disease data, time and locations along with all the environmental and geological co-variants to detect the cluster of vulnerable locations.

Similarly, three data subsets were used to detect the cluster of vulnerable locations for each of the seasons--Summer, Monsoon and Post Monsoon.

Two data subsets for determining the clusters to identify the vulnerable locations based on the gender in the study area.

Datasets

Datasets were generated for detecting the clusters for

Location, Seasons and Gender.

To obtain a disease cluster for the entire taluk for each of the above data sets, a case file, coordinate file and population file were generated. The case file and population files had information about the Location, Time, Case count and Population in addition to other covariate information pertaining to each village in the taluk. The Coordinate files had the Latitude and Longitude for each village in the taluk.

Output

SatScan detects the clusters for each dataset. The text output gives a summary of the analysis and the shape files output depicting the clusters are opened in Arc-GIS for visualization and interpretation.

RESULTS AND DISCUSSION

Cluster data analysis

The spatial scan statistic detects the location of clusters and evaluates their statistical significance. Analysis was conducted using the Discrete Poisson probability model in SatScan for period 01/01/2018 to 31/12/2018 for 113 locations with a population of 159517, averaged over time. The Cluster information obtained by running the program for different datasets are shown in Table 3.

Cluster data - place

A cluster is detected by Space-time discrete scan statistics was run for multiple villages with varied population size and disease counts. These clusters indicate that higher risk prevails in those villages listed in the cluster summary text. The number of villages listed are 48 for the taluk. The number of cases observed is 63 and expected cases are 20.34. The villages have a maximum likelihood ratio of 30.1 indicating that these villages have more cases than expected. The low p-value indicates the statistical significance of the method showing that its occurrence is not by chance. The relative risk of the villages inside the cluster area is 3.33 compared to other villages outside the cluster area.

The cluster map is generated in Arc-GIS as shown in Fig. 2A. The vulnerable areas in the taluk are located around the center extending from Kottur village in NID hobli in the west to Bugadur village in NAG hobli in the East, covering 18.78 kms radius. The most vulnerable Locations are marked in red as their relative risk are higher than other locations.

Table 3. Space-time analysis for identifying vulnerable place, season and gender.

	Place		Time		Person	
	total	SU	MO	PM	Male	Female
Affected villages	113	71	91	55	88	98
Population,averaged over time	159517	165803	169267	92614	62859	96658
Total cases	626	191	311	124	237	389
Annual cases / 100000	392.7	115.3	183.9	134	377.3	402.7
Clusters	1	1	1	1	1	1
Villages in cluster	48	27	48	21	42	41
Coordinates / radius in kms	18.78	12.68	45.35	16.72	87.5	18.78
Cluster population	74533	85454	104742	40720	34212	47960
Cluster cases	63	95	153	62	21	42
Expected cases	20.34	17.47	79.39	20.68	6.08	13.56
Annual cases / 100000	1216.4	626.8	354.3	401.7	1303.1	1247.5
Observed / expected	3.1	5.44	1.93	3	3.45	3.1
Relative risk	3.33	9.83	2.82	5	3.69	3.35
Log likelihood ratio	30.1	104.03	39.94	36.41	11.6	20.15
P-value	4.8E-09	1E-17	3.3E-13	1.4E-12	0.0068	5.8E-06

SU - Month of summer
MO - Month of monsoon
PM- Post monsoon month

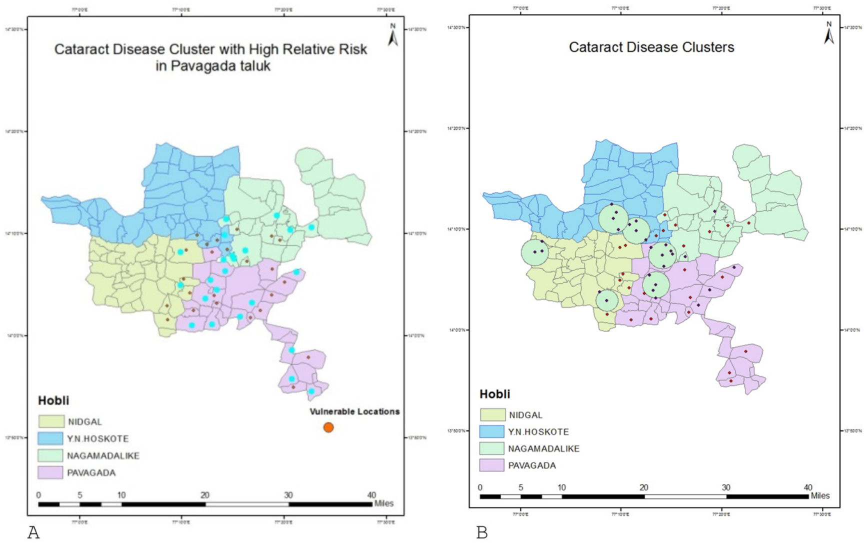

Fig. 2A. High risk cataract disease cluster in study area. **Fig. 2B.** Cataract disease cluster in study area for 3 kms circle.

To obtain more specific locations in the taluk, the Space-time discrete scan statistics was run for multiple villages were the radius this time was chosen as 3 kms. The output resulted in 13 clusters , out of which 6 clusters with high relative risk and significant p-value. The Fig. 2B shows the detected clusters. Table 4 shows Kondethimmanahalli and Chennakeshavapura gram panchayats of Nidagal hobli, Budibetta and Ponnasamudra gram pachayats of Y.N.Hoskote, Palavalli and Thirumani gram panchayats in Nagamadalike hobli are the most vulnerable regions in the taluk.

The local environmental and geological factors are required to be explored in this region for establishing an association with the disease. The soil-order in the region is “Alfisol” or “Inceptisol” which might have clay minerals such as “smectite” or “kaolinite” whose mineral structure has the potential to retain harmful organic compounds used in agriculture. When individuals are exposed to such soils, there could be a higher rate of cataract incidence in the region.

Cluster data - time

A cluster is detected by Space-time discrete scan statistics run for multiple villages with varied population size and disease counts for the different seasons – summer, monsoon, and post monsoon. These clusters indicate that higher risk prevails in those villages listed in the cluster summary text.

Summer

The cluster lists 71 villages in the taluk. The villages have a maximum likelihood ratio of 104.03 indicating that these villages have more cases than expected. The low p-value indicates the statistical significance of the method. The relative risk of the villages inside the cluster area is 9.83 compared to other villages outside the cluster area. The cluster map is generated in Arc-GIS as shown in Fig. 3A. The vulnerable location in the taluk covers 12.68 kms radius. The most vulnerable Locations are marked in red as their relative risk are higher than other locations. The agricultural activities such as land preparations are done during summer months before the monsoon sets in. Summer being hot, humid and dusty could be a potential carrier for harmful insecticides and pesticides in the atmosphere, used during agricultural activities.

Monsoon

The cluster lists 91 villages in the taluk. The villages have a maximum likelihood ratio of 39.94 indicating that these villages have more cases than expected.

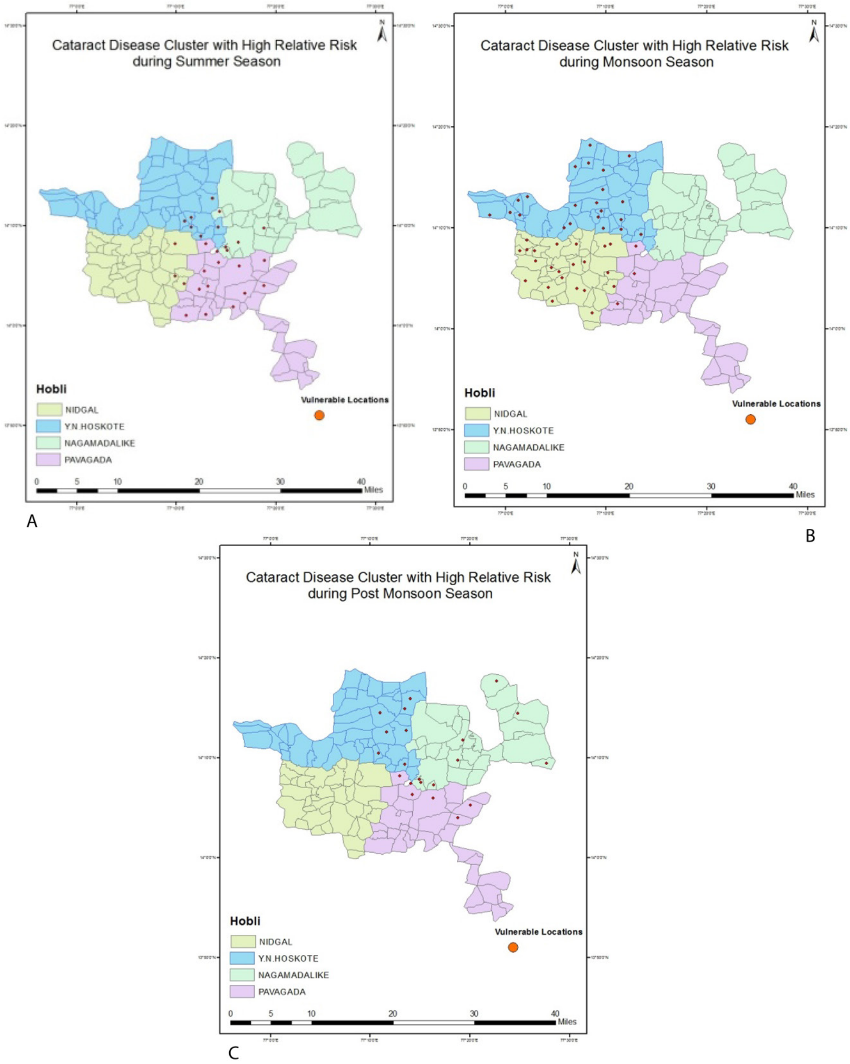

Fig. 3A. High risk cataract disease cluster during summer season. **Fig. 3B.** High risk cataract disease cluster during monsoon season. **Fig. 3C.** High risk cataract disease cluster during post monsoon season.

The low p-value indicates the statistical significance of the method. The relative risk of the villages inside the cluster area is 2.82 compared to other villages outside the cluster area. The cluster map is generated in Arc-GIS as shown in Fig. 3B. The vulnerable location in the taluk covers 43.35 kms radius. The most vulnerable Locations are marked in red as their relative risk are higher than other locations. Not many activities are performed in the agricultural fields during monsoon seasons thereby reducing the exposure of individuals to harmful organic compounds in atmosphere.

Post monsoon

The cluster lists 55 villages in the taluk. The villages have a maximum likelihood ratio of 36.41 indicating that these villages have more cases than expected. The low p-value indicates the statistical significance of the method. The relative risk of the villages inside the cluster area is 5 compared to other villages outside the cluster area. The cluster map is generated in Arc-GIS

Table 4. Spatial cluster -place (3 kms radius).

Cluster	Relative risk	P-value	Log likeli-hood ratio	Total cases	Season	Female = 1, Male = 0	Village name	Hobli	Soil order
1	2.25	0.0028	13.45	4	PM	1	Veerammanahalli	NAG	WBM
				14	MO	1	Thirumani, Intorayanahalli	NAG	I
				6	MO	1	Kadapalakere	PAV	A
				36	MO	1	Bommathanahalli,Neelam-manahalli,Dandenahalli	PAV	WBM
				11	MO	1	B. Achammanahalli	PAV	WBM
				1	MO	1	Kanikalabande	YNH	WBM
				72					
2	3.42	0.02	11.29	2	PM	1	Hariharapura	NID	A
				19	MO	1	Kilarlahalli,Pemmanahalli, Gollarahatti	PAV	A
3	4.48	0.044	10.02	6	MO	0	Yettinahalli	YNH	I
				3	SU	1	Budibetta	YNH	I
				2	SU	1	Komarlahalli	YNH	I
				4	MO	1	Talamaradahalli Aladamara-dhahatti	YNH	I
4	62.18	0.077	9.431	4	PM	1	Bommanagathihalli	NID	A

SU - Month of summer
MO - Month of monsoon
PM- Post monsoon month
NAG - Nagamadalike hobli
PAV- Pavagada hobli
NID - Nidagal hobli
YNH - Y.N.hoskote hobli
WBM - Water body mask type of soil
I - Inceptisol type of soil
A - Alfisol type of soil

as shown in Fig. 3C. The vulnerable location in the taluk covers 16.72 kms radius. The most vulnerable Locations are marked in red as their relative risk are higher than other locations. During this time the exposure of individuals to harmful insecticides and pesticides increase as they are involved in harvesting

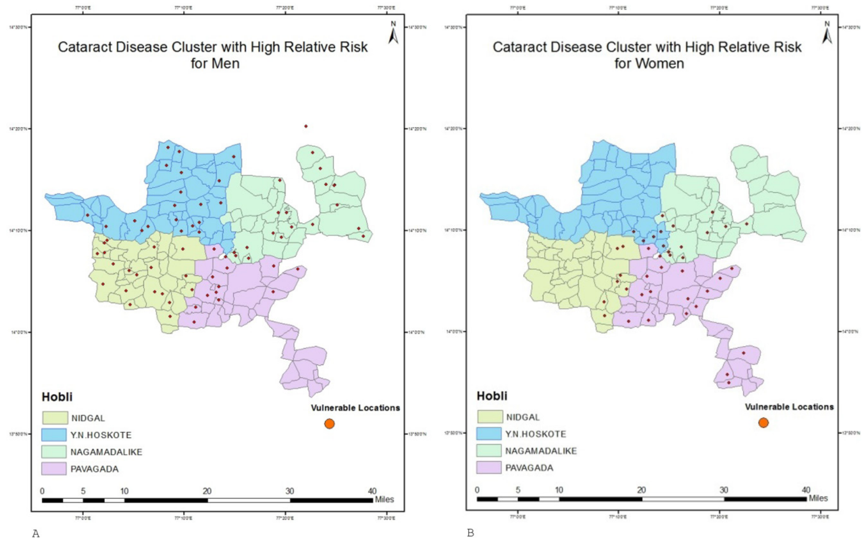

Fig. 4A. High risk cataract disease cluster for men. **Fig. 4B**. High risk cataract disease cluster for women.

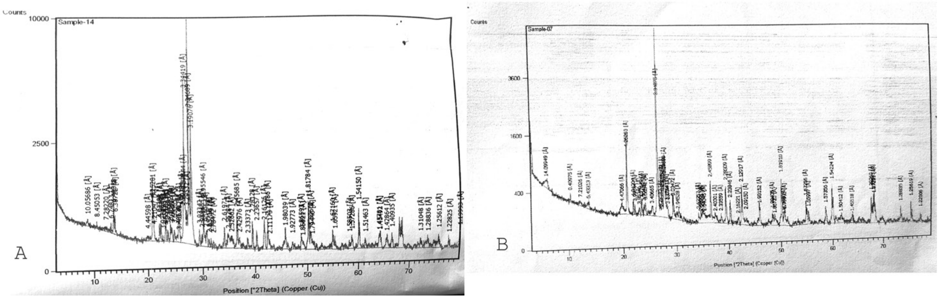

Fig. 5A. Diffractogram for clay mineral identification of soil sample - Kotagudda region. **5B.** Diffractogram for clay mineral identification of soil sample - Thirumala region.

and post harvesting activities.

Cluster data - gender

A cluster is detected by Space-time discrete scan statistics run for multiple villages with varied population size and disease counts for each gender. These clusters indicate that higher risk prevails in those villages listed in the cluster summary text.

Men

The cluster lists 88 villages for the taluk. The villages

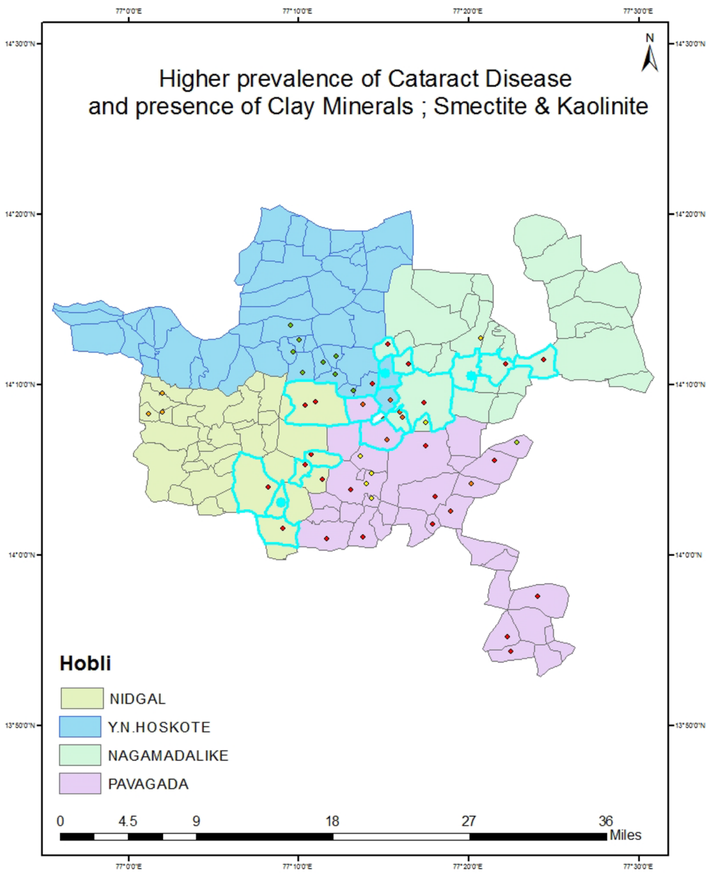

Fig. 6. Higher prevalence of cataract disease from Kotagudda to Tirumala region having presence of clay minerals : Smectite and kaolinite.

have a maximum likelihood ratio of 11.6 indicating that these villages have more cases than expected. The low p-value indicates the statistical significance of the method. The relative risk of the villages inside the cluster area is 3.69 compared to other villages outside the cluster area. The cluster map is generated in ArcGIS as shown in Fig. 4A . The vulnerable location in the taluk covers 87.5 kms radius. The most vulnerable Locations are marked in red as their relative risk are higher than other locations. Men with cataract are scattered across the taluk. These are age-related rather than exposure to environmental factors.

Women

The cluster lists 98 villages. The villages have a maximum likelihood ratio of 20.15 indicating that these villages have more cases than expected. The low p-value indicates the statistical significance of the method. The relative risk of the villages inside the cluster area is 3.35 compared to other villages outside the cluster area. The cluster map is generated in ArcGIS as shown in Fig. 4B. The vulnerable location in the taluk covers 18.78 kms radius. The most vulnerable Locations are marked in red as their relative risk are higher than other locations. The percentage of women affected by cataract is high compared to men. Those affected are predominantly located in regions that have major agricultural activities in the taluk and the radius of the cluster is around 19 kms in this region.

Environmental data analysis

XRD diffractograms of the initial soil particles and those of the particles after calcination as shown in Figs. 5A - 5B, at 950 °C , showed major peaks after heating. It was observed that the peak shifted from d spacing of 14 to d spacing at 10. Presence of peak at d spacing 1.54 in initial /unprocessed diffractogram confirmed the presence of trioctahedral smectite . The peak at d spacing 7 observed in initial / unprocessed diffractogram disappeared after heating, indicating the presence of Kaolinite. The XRD technique used to obtain information about the composition of soil particles revealed the presence of smectite and kaolinite from regions between Kotagudda in Nidgal hobli to Thirumani in Nagamangala hobli. The presence of the above clay minerals in the region and the higher prevalence of the Cataract diseases in those regions as shown in Fig. 6. Establishes the correlation of this environmental factor (presence of smectite and kaolinite in the soil) to the disease.

CONCLUSION

Using the SatScan space-time analysis, the study explored the distribution of cataract in Pavagada taluk. We were able to identify the clusters (48 villages) that had higher incidence of cataract disease. It was observed that the higher risks were during summers, and it was found that women were more vulnerable in these regions practicing agriculture. Geo-Spatial analysis of disease data established that the regions with presence of clay minerals like smectite and kaolinite had higher prevalence. The study gives scope to carry out similar studies in other regions to detect disease clusters and determine its association with the soil and clay minerals present in the region. This study will also be very useful for future studies on assessing the clay mineral structure and its potential to retain organic compounds used in agriculture which may contribute to higher incidence of disease in rural areas.

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