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GEOSTATISTICAL ANALYSIS OF APRICOT SHOT HOLE DISEASE AND INFLUENCE FACTORS IN DISTRICT NAGAR, GILGIT-BALTISTAN, PAKISTAN

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ABSTRACT

Apricot (*Prunus armeniaca* L.*)* is the most common, high-income generative fruit and consequently plays an important part in the region's socio-economic growth. However, apricots are susceptible to several diseases and pests that cause lower yields and significant financial losses, including apricot shot hole disease brought on by *Wilsonomyces carpophilus*, a polyphagous fungus, creates a serious threat to stone fruits, particularly the apricot tree. The current study used descriptive statistics and geostatistical approaches to evaluate the geographical distribution of the apricot shot hole disease (5 valleys, 30 orchards, and 480 apricot trees) in the district Nagar, Gilgit-Baltistan, Pakistan. From each apricot tree, 150 apricot fruits, a total of 72,000, were randomly selected to assess the incidence, disease index, and severity. Results revealed that the disease is spatially distributed within the study area, varying within valleys and orchards. The range of disease prevalence was 50.0-67.70%, incidence 56.97-64.01%, index 32.49-40.56% and mean severity 0.21-0.24%. Geostatistical techniques were used to predict the spatial dependency class. Results revealed that disease prevalence had a nugget/sill ratio of 0.915, inferring weak spatial dependence, whereas incidence, disease index, and severity inferred moderate spatial dependence with nugget/sill ratios of 0.479, 0.628, and 0.393, respectively. Moreover, the spherical semivariogram model, trend analysis graph, and GIS maps indicate the region's spatial distribution of apricot shot hole disease. This information linked to metrological data (temperature, precipitation, and relative humidity) seemingly favored the apricot shot hole disease development during the growing period. Evaluation of geostatistical mapping strategies in monitoring spatial distributions of apricot shot hole disease in a field setting will improve the decision support for disease management, selection of resistant variety, and improve sanitation condition of apricot orchards. Continuous climate and pest monitoring are essential for creating an efficient disease warning system for farmers and other organizations involved in agriculture to prevent future plant epidemics.

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INTRODUCTION

Apricot (*Prunus armeniaca. L*) is the most popular fruit of Gilgit-Baltistan (GB) and is grown in all ten districts of the area. More than 2.72 million apricot trees on 6,370 hectares yield annual production of 107,737 tons (Agriculture Staristics, 2017). It has a major share of agricultural income, thus playing a significant role in the region's socio-economic development. A large segment of small and medium-sized farmers in mountainous areas rely on apricot that is well adapted to the edaphoclimatic conditions.

The apricot has been utilized in medications as a treatment for numerous illnesses (Gilani *et al.*, 2010). Its bark is applied topically to relax inflamed skin. Infections in the vagina are treated with kernel paste. Apricot oil is used in cosmetics to shield the skin from ultraviolet rays and as a laxative and expectorant. Apricot pulp-based baby meals are a healthy source of iron, phosphorus, and calcium. Oil cake can be used as organic manure and edible seed oil. It is also reportedly used for cough, constipation, and asthma (Ghasemnezhad *et al.*, 2010). In Pakistan, apricots are primarily grown in GB, Khyber Pakhtunkhwa (KPK), Balochistan, Upper Punjab, and Kashmir (Ullah *et al.*, 2017; Bibi *et al.*, 2017). Numerous diseases, such as Bacterial Canker, Bacterial Spot, Peach Scab, Phytophthora Root, Crown Rot, Collar Rot, Brown Rot, Shot Hole Disease, etc., affect apricot trees.

Among these, the apricot shot hole degrades fruit's quality and lowers its market worth. In Gilgit-Baltistan, the disease is widespread and the biggest challenge for underprivileged apricot growers. *Wilsonomyces carpophilus* is a recognized pathogen that causes shot hole disease (Williams-Woodward, 1998; Hashmi and Shafiullah, 2003). According to Väcäroju *et al.* (2008), the fungus was discovered initially on peach trees in France in 1843. It was then discovered throughout Africa, Asia, Europe, North, Central, and South Americas, Australia, and Oceania. The disease can cause damage anytime during extended wet weather, but it is most dangerous in spring's very cool and wet circumstances (Evans *et al.*, 2008). The fungus that causes shot hole disease may cause spots on fruit and leaves in the spring and destroy buds in the winter. A leaf falling could happen in the spring if there is a severe infestation. Fruit lesions are typically grouped on the upper edges of the fruit and are light brown with dark purple margins. Fruit spots can be very noticeable, and when fruits ripen, they may turn scabby and flake off, leaving roughened regions underneath. Leaf spots fall out (shot hole) (Tovar-Pedraza *et al.*, 2013). *W. carpophilus* overwinters as hyphae and conidia inside the scales of infected buds and on the cankers on twigs. Conidia begin germinating in the early spring when favorable environmental circumstances are favorable (Highberg and Ogawa, 1986). No published data is available regarding the spatial distribution of shot hole disease in the apricot orchard of Gilgit-Baltistan, especially District Nagar. Therefore, the prime objective of the current study is to highlight the actual status and spatial distribution of apricot shot holes in different valleys of district Nagar by using geographical information system (GIS).

MATERIAL AND METHODS

Study Site

The present research on the spatial distribution of apricot shot hole disease and climate scenarios was carried out in District Nagar, Gilgit-Baltistan, Pakistan. The district of Nagar is situated in a semiarid mountain valley in the western part of the Karakoram, bordering Gilgit to the south and Hunza to the north. Its coordinates are 36.28N, and 74.58E. Nagar served as an agrarian "microstate" or princedom for many years, ruled by an autocrat (tham) and a small local elite. (Figure 1).

Apricot Shot Hole Disease Distribution

Five apricot-growing valleys (V_1: Chalt; V_2: Jafarabad; V_3: Minapin; V_4: Shayar; and V_5: Asqurdas in District Nagar, Gilgit-Baltistan, were selected to assess the spatial distribution of apricot shot holes disease. From each of these valleys, six apricot fruit orchards, sixteen apricot fruit trees, and 150 fruits were randomly selected to record information about disease prevalence, incidence, disease index, and mean severity as well described by Youssefi and Hajian (2014); Humayun *et al.* (2020).

$$\mathrm{A.Sh.P} = \frac{\mathrm{N.I.O}}{\mathrm{T.N.O}} \times 100$$

(A.Sh.P: Apricot shot hole prevalence; N.I.O; Number of infected orchards; T.N.O: Total number of orchards)

The incidence was calculated based on the number of infected fruits in the sample population.

$$\mathrm{A.Sh.I} = \frac{\mathrm{N.I.F}}{\mathrm{T.N.F}} \times 100$$

A.Sh.I: Apricot shot hole incidence; N.I.F; Number of infected fruits; T.N.O: Total number of fruits).

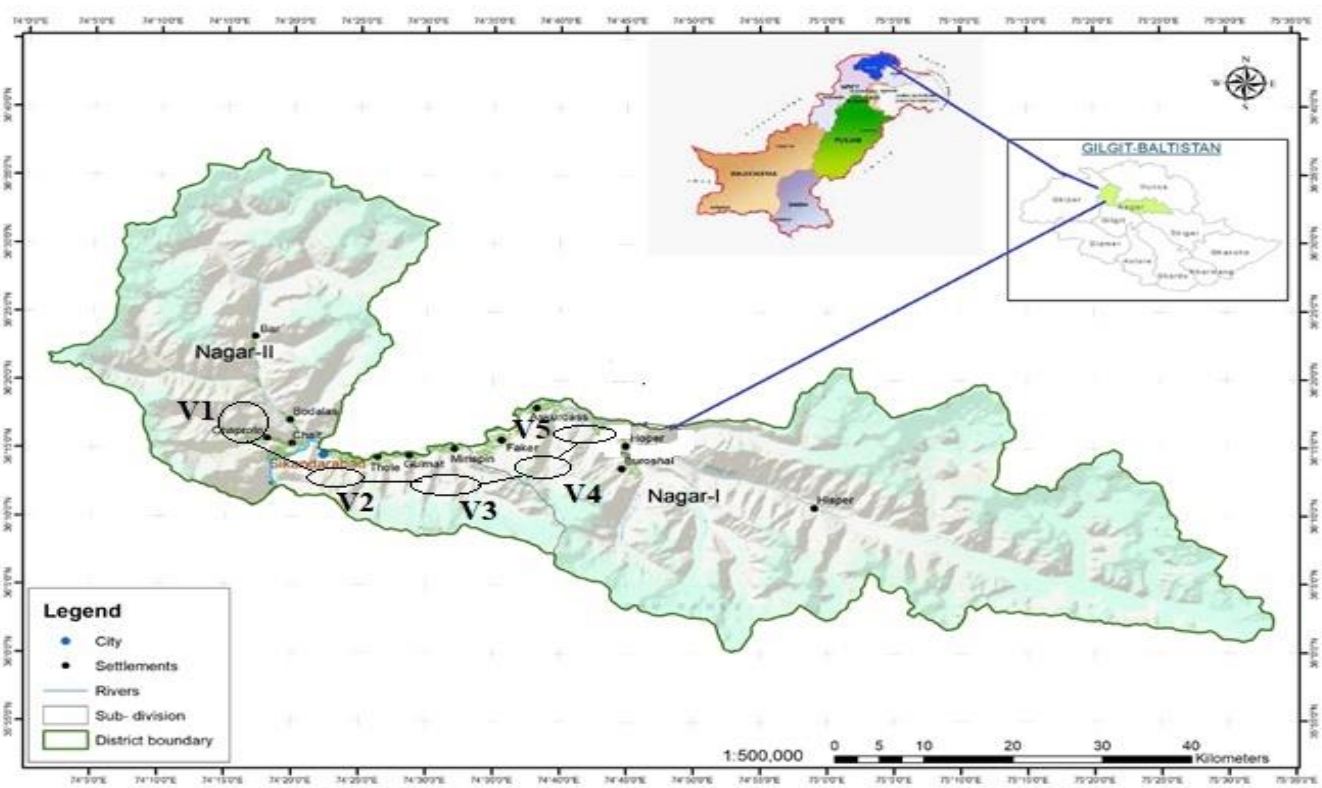

Figure 1. Map of study district and research valleys.

The disease index was calculated by using a 0-5 rating by combining disease incidence by formula;

$$D.I\ (\%) = \frac{N1(0) + N2(1) + N3(2) + N4(3) + N5(4) + N6(5)}{T.N.F\ X\ D.G(5)}\ x\ 100$$

Where: N_1= No. of fruit having a disease "0"; N_2= No. of fruit with disease rating "1"; N_3= No. of fruit with disease rating "2"; N_4= No. of fruit with disease rating "3"; N_5= No. of plants with disease rating "4"; N_6= No. of fruit with disease rating "5"; T.N.F= Total No. of fruits in a sample; D.G: Disease grade.

Where, the mean severity was calculated by disease index % divided by the total number of apricot fruits.

$$M.S = \frac{D.I\ \%}{T.N.F}$$

(M.S: Mean severity; D.I: Disease index; T.N.F: Total number of fruits)

Geographic Information System

A database of districts comprised of X and Y coordinates in the study valleys was created after the shapefile of the District was opened in GIS software (ArcGIS 10.7). Three fields, X, Y, and Z were opened in the projects. In X-field, X-coordinate, Y-field, and Y-coordinate were selected, whereas disease data was placed in the Z-field. Arc view spatial analyst "Interpolate grid option" was selected. On the output "grid specification dialogue," the output grid extends chosen the same as the District Nagar, and the interpolation method employed was inverse distance weight (IDW) (Jamshidi and Salahi, 2012; Cohen *et al.*, 2022).

$$Z(x_0) = \frac{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}}$$

Where, $Z(x_0)$ is the interpolated value, n represents the total number of sample data values, x_i is the ith data value, h_{ij} is the separation distance between interpolated value and the sample data value, and β denotes the weighting power. A semivariogram function can characterize the disease variable's spatial distribution, and its function's calculation can be expressed based on the following equation (Davis *et al.*, 2022; Balanagouda *et al.*, 2021; Hussain *et al.*, 2021).

$$r(h) = \frac{1}{2N(h) \sum_{i=1}^{N(h)} [Z(Xi) - Z(xi + h)]^2}$$

Where r(h) is the semivariogram function, h is the spatial distance of the sample points, called the step size, N(h) is

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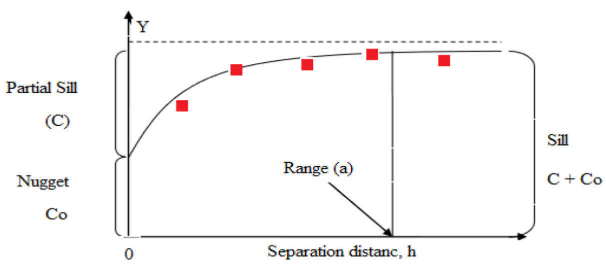
the number of samples with the separation distance h, Z(xi) and Z (xi +h) are the measured value of the regionalized variable Z(xi) at the spatial positions xi and xi + h, respectively. Suppose h is the abscissa, the function graph drawn with r(h) as the ordinate is called the semivariogram function graph. The fitting of the r(h) coordinate value can be used to obtain the corresponding theoretical model and the model parameters. The characteristics of spatial variability can be obtained by analyzing the model parameters. The aspherical model was used in this study, and the model is as.

0, h=0

$$r(h) = \{C_0 + C\left(\frac{3h}{2a} - \frac{h^3}{2a^3}\right), 0 \le h \le a$$

C_0+ C, h> a

$$\text{Spherical} = \gamma(h) = \left\{ C_0 + C\left(\frac{3h}{2ac} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right) \quad \begin{matrix} 0 \le h < a \\ h \ge a, \end{matrix} \right.$$



Spatial dependence (SDP %) will be calculated as described by (Biondi *et al.*, 1994; Hussain *et al.*, 2021), is given by the expression:

$$\text{SDP Spherical\%} = \frac{C1}{C0 + C1} \text{ x } 100$$

For the spherical semivariogram: SDP Spherical (%); ≤25% strong spatial dependence; 25% < SPD (%) ≤ 75% moderate spatial dependence and ≥75% weak spatial dependence.

Climate data were obtained from the research paper of Khan *et al.* (2020) titled Climate of the Gilgit-Baltistan Province and online during the growing of apricot.

Geostatistical Analysis

Arc GIS software 120.7 were used for spatial analysis, semivariogram, trend analysis, and GIS disease maps (Hussain *et al.*, 2016; Mascolo *et al.*, 2014).

RESULTS

Apricot Shot Hole Disease Distribution

Valley-wise, none of them was disease-free; however, the disease is spatially distributed, varying within valleys, orchards, and even with individual apricot trees. The prevalence, incidence, disease index, and mean severity of apricot shot hole disease in the study area are depicted in Figure 2. Valley (V4: Shayar) had the highest mean disease prevalence of 67.7 %. In the remaining valleys, the mean disease prevalence ranged from 50 to 67.7 %. The apricot shot hole was the most common in ORC2 and ORC6 of V1 and V4 (87.5%) and the least common in ORC5 of V5 (31.25%). V5 (Asqurdas) had the lowest mean disease incidence of 56.97 %, and V4 had the highest at 64.01% (Shayar). ORC1 of V2 had the highest disease incidence rate of 68.59% in individual orchards. The disease index and mean severity of apricot fruit differed significantly between valleys and orchards. The survey results indicated that the mean disease index and severity on fruits varied from 32.49 to 40.56% and 0.21 to 0.24%, respectively, across the different valleys. ORC5 of V3 had the highest disease index (54.41 %), followed by ORC5 of V5 (29.22 %). Similarly, the lowest mean severity was 0.21% in V2, and the highest was 0.24 in V3.

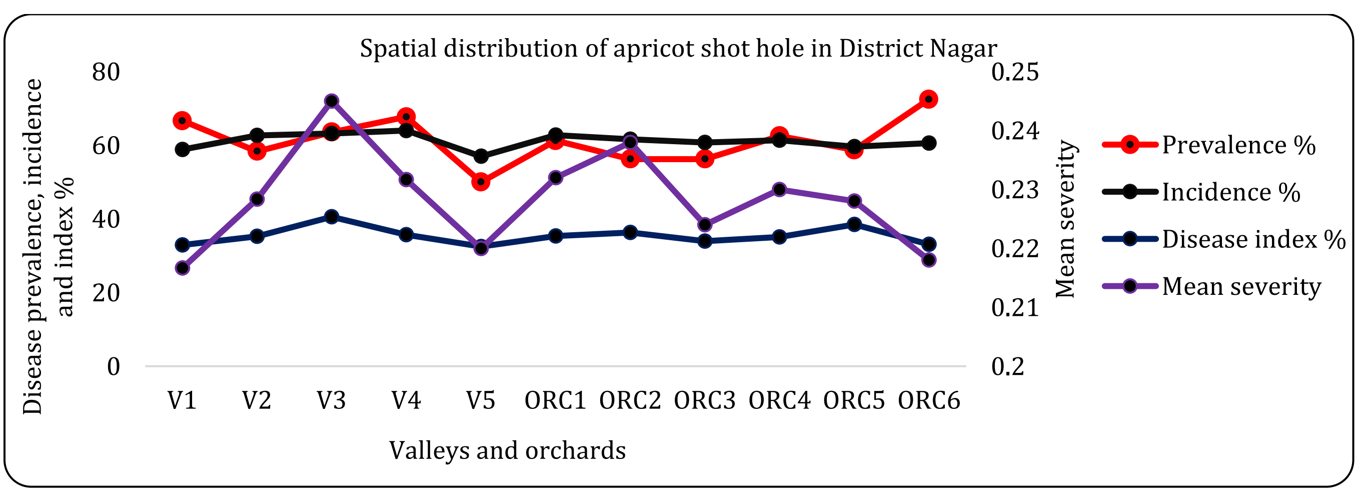


Figure 2. Spatial distribution of apricot shot hole disease in District Nagar.

Geostatistical Analysis of Apricot Shot Hole Disease Distribution

Differential spatial dependence level of measured disease parameters and geostatistical analysis shows the main characteristics of the semivariogram model and geospatial parameters (Table 1). The nugget-to-sill variance ratio indicates the degree of spatial correlation, with values ranging from 25% to 75% indicating strong, moderate, and weak spatial correlation, respectively. The nugget/sill ratios for disease prevalence, incidence, disease index, and mean severity were 0.915, 0.479, 0.628, and 0.393, indicating weak to moderate spatial dependence, respectively. This means that spatial variation can explain 91.5%, 47.9%, 62.8%, and 39.3% of the total variation, while the remaining 8.5%, 52.1%, 37.2 %, and 60.7% are attributable to unexplained sources of variation. The spatial distribution of maps of apricot shot hole prevalence, incidence, disease index, and mean severity can be expressed in Figures 4-5. Disease prevalence ranged between 31.25 and 87.49%, indicating a high prevalence and spatially distributed alkaline soil. The district's highest prevalence was observed in the southern and eastern parts. Disease incidence ran from 49.47 to 68.58 % (Figure 3a-b). The highest disease incidence was observed in the district's central areas while lower on the western side (Figure 4a-d). Disease index and severity were spatially distributed in the study area. However, they were higher in the eastern part of the field than in the western part, according to GIS maps of the variables (Figures 5a-b. According to the semivariogram, shot hole disease has a higher prevalence ratio, followed by disease index, mean severity, and incidence). Except for incidence, the trend analysis graph of disease parameters was higher to low than high from north to south and low to high then low from west to east of the district. From west to east, the incidence trend was high to low rather than low to high except for incidence and prevalence outlier.

Table 1. Geostatistical parameters for apricot shot hole disease in District Nagar.

Shot Disease	Model	Range	N (C_0)	PS (C)	S (C_0+C)	N/S ratio	SDI %	Class
Prevalence	Spherical	51049.95	0.915	0.084	0.999	0.915	91.5	W
Incidence	Spherical	13007.89	0.739	0.802	1.54	0.479	47.9	M
Disease Index	Spherical	32946.83	0.698	0.421	1.11	0.628	62.8	M
Mean Severity	Spherical	16304.85	0.507	0.788	1.29	0.393	39.3	M

N: nugget; PS: partial sill; Sill; N/S ratio = [N/ (N+PS)]

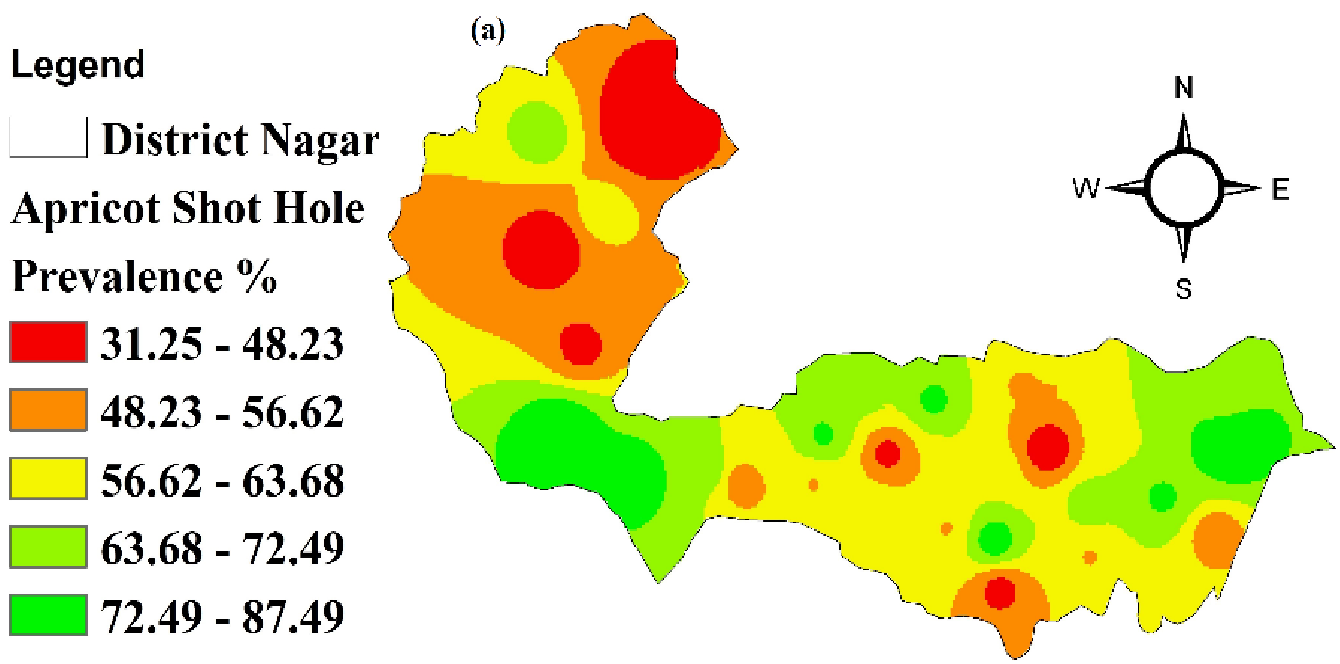


Figure 3(a). Spatial distribution map of apricot shot hole; disease prevalence.

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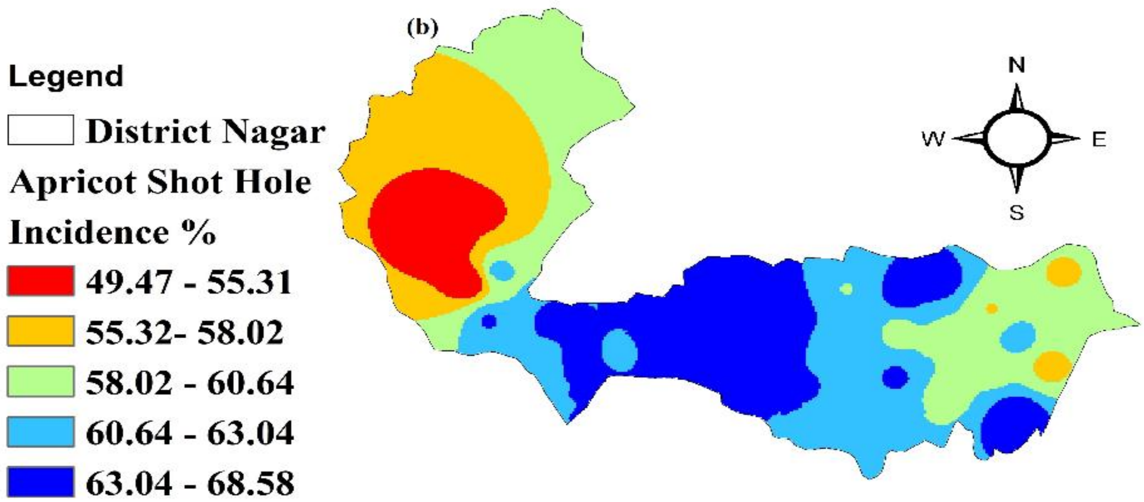


Figure 3(b). Spatial distribution map of apricot shot hole; incidence.

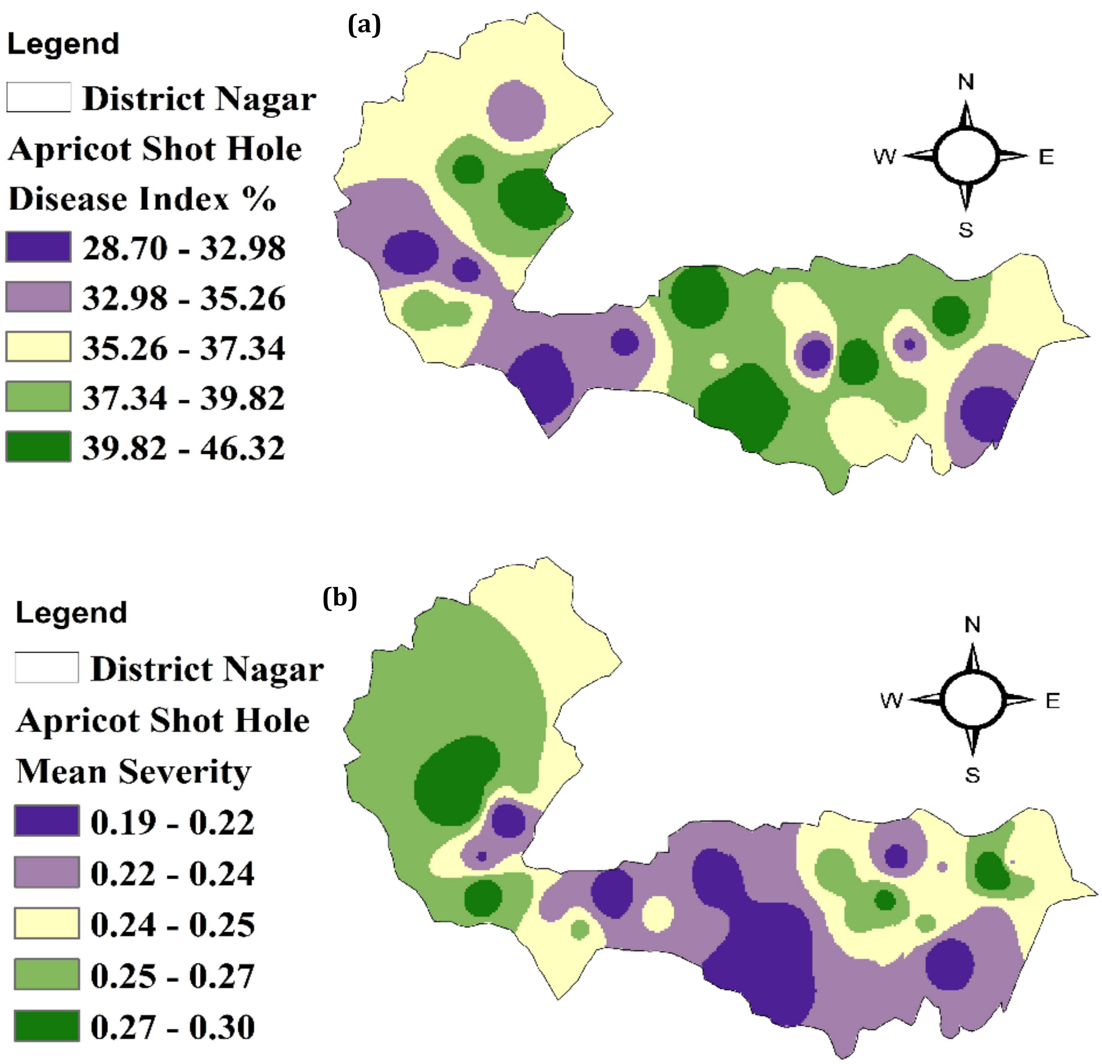
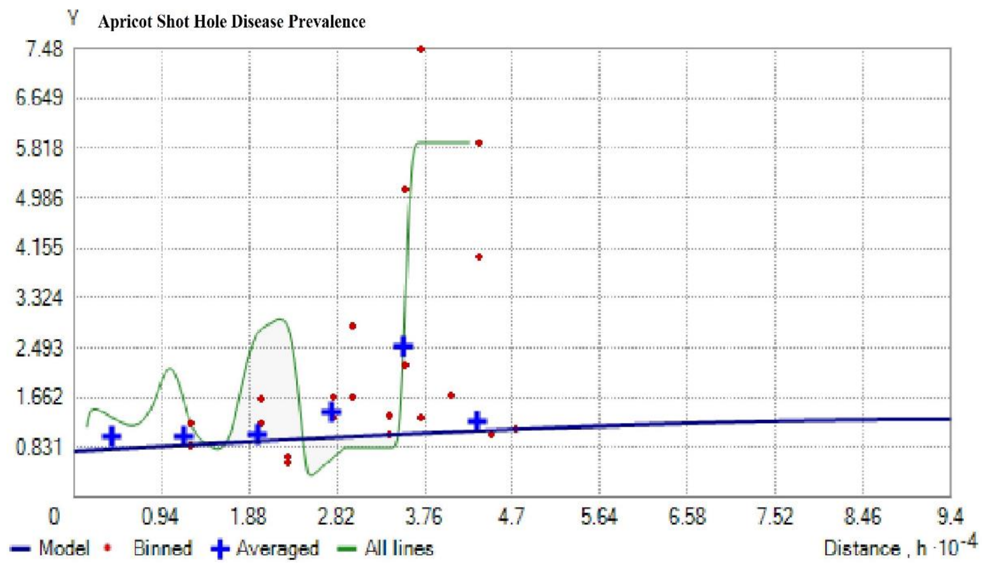


Figure 4. Spatial distribution map of apricot shot hole a) disease index and b) incidence mean severity.

(c)



(d)

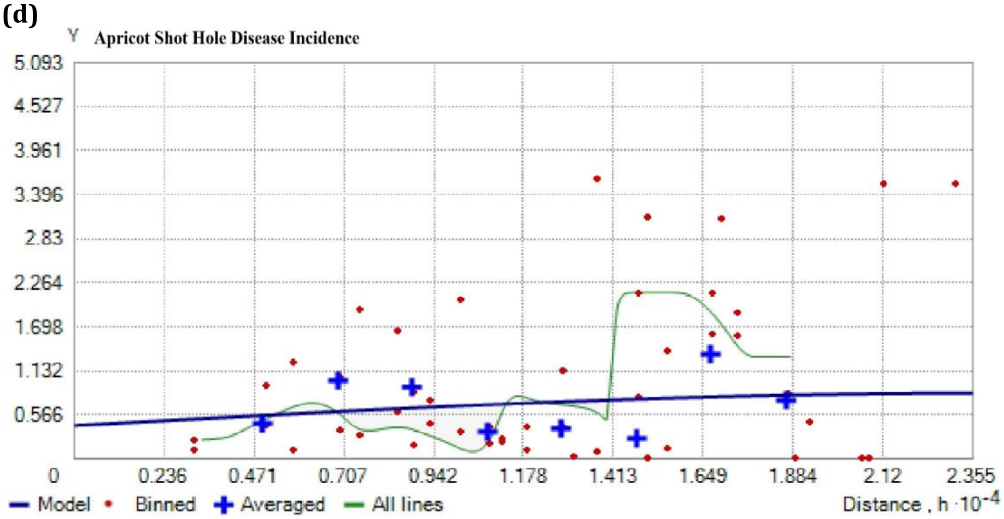


Figure 4. Semivariogram model, to predict apricot shot; c) disease prevalence and (d) incidence.

(a)

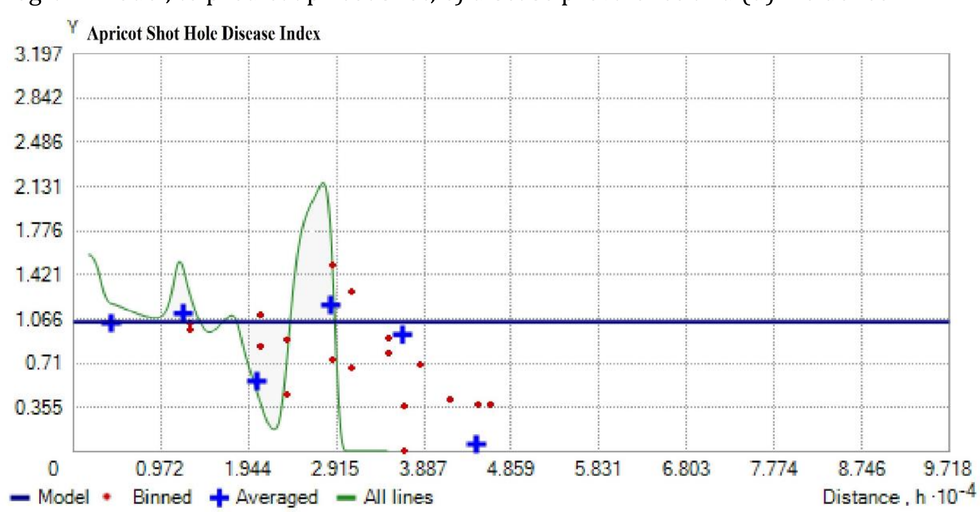


Figure 5(a). Semivariogram model, to predict apricot shot hole; disease index.

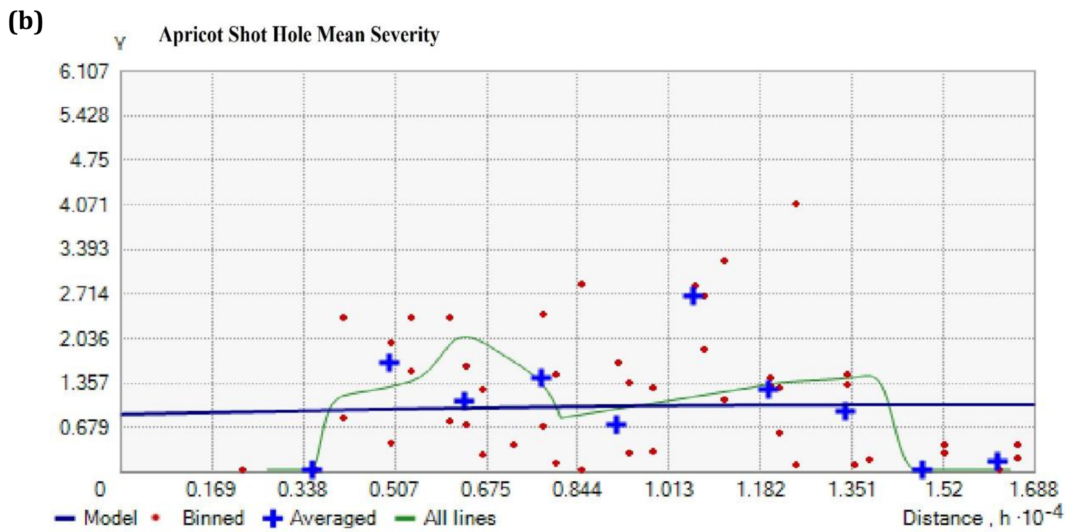
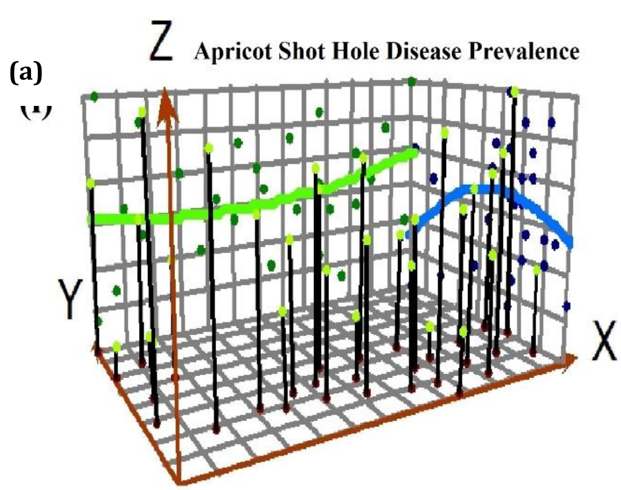


Figure 5(b). Semivariogram model, to predict apricot shot hole; mean severity.

The incidence of shot holes followed a U-shaped pattern from south to north and east to west, indicating a high to low and then high trend in disease incidence. The southern portion of the study area had the highest value, while the eastern and western portions had the lowest. To reduce the impacts of total trends on the local semi-variant analysis process and more accurately simulate short-range random variation, trend surface analysis was performed to obtain the trends of apricot shot hole disease. Based on the ID Winter polation, the trend analyses of disease, including prevalence, incidence, disease index, and mean severity in the study area, were carried out in Figure 6-7. Each point represents the attribute value of a sample. These points were then projected onto the EW SN orthogonal plane, and the best fit line was made through the projection point. The X-axis represents the east direction, the Y-axis represents the true north direction, and the Z-axis indicates the magnitude of the measured value of each sample. The green curve indicates the change of the trend effect of the east-west trend, and the blue curve is the change of the trend effect of the south-north direction. Disease prevalence trend was low to high then low from east to west and high to slightly low then high south-north direction while similar trend from east to west in disease incidence and low to very high then low trend was observed south-north direction (Figure 6). Apricot shot hole disease index and mean severity trend as depicted in Figure 7.



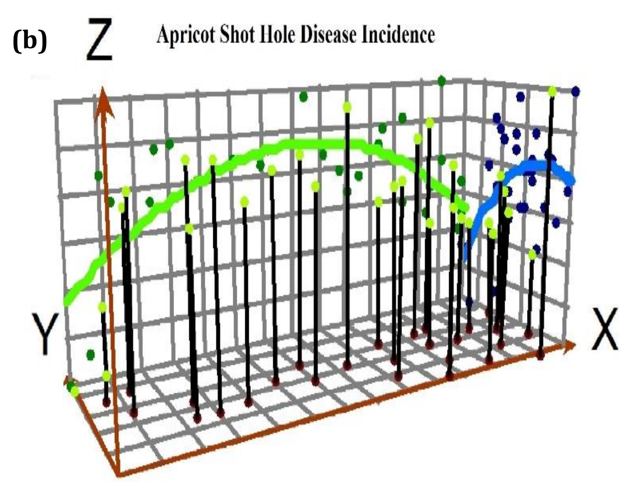


Figure 6. Trend analysis of the spatial distribution of apricot shot hole; a) disease prevalence and (b) incidence.

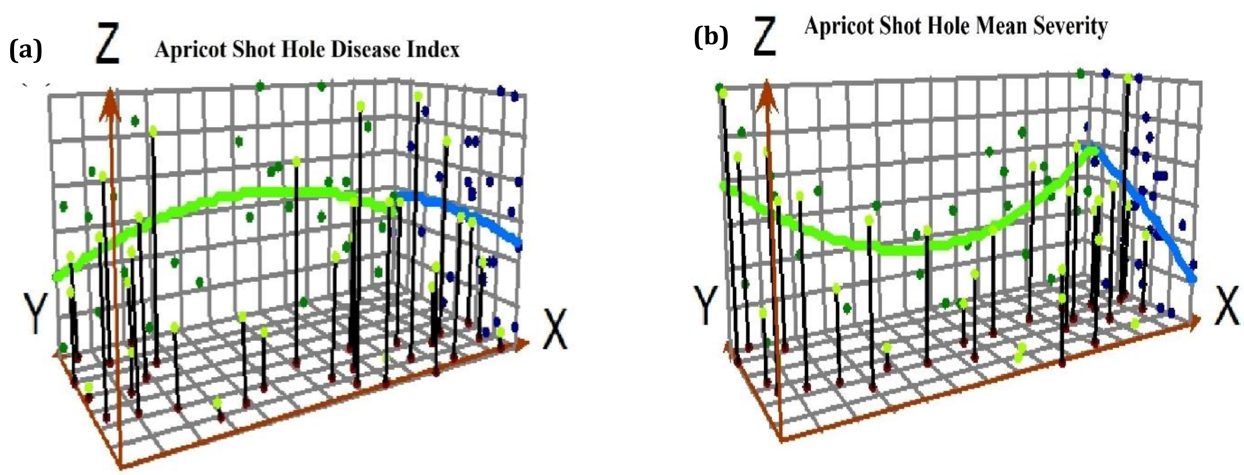


Figure 7. Trend analysis of the spatial distribution of apricot shot hole; a) disease index and (b) severity.

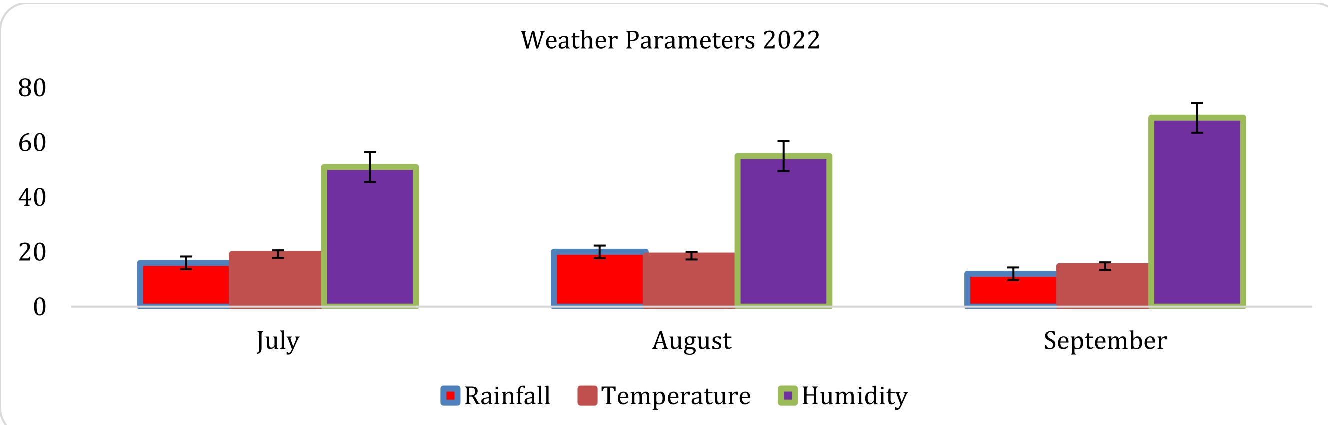


Figure 8. Monthly average weather parameters.

DISCUSSION

Prunus species are susceptible to insects, pests, and diseases, so the loss of apricots and apricot products is increasing rapidly, which can lead to qualitative and quantitative losses and the socio-economics of those who depend on them. A source of income that can affect development and livelihood. However, apricot shot hole disease (*Wilsonomyces carpophilus*) is the most devastating pathogen in the world, especially in Gilgit-Baltistan (Hashmi and Shafiullah, 2003). In Gilgit-Baltistan, the actual state and spatial distribution of apricot shothole disease have not yet been determined. The results show that shotholes are spread throughout the district with uneven distributions, even in valleys and orchards. As discussed, the coefficient of variation values was used to interpret the variability of the disease in the field (Pimentel-Gomes and Garcia, 2002). Current research reveals the prevalence of a wide range of diseases, from low to medium to very high, in all valleys. Shot hole disease index and average severity were measured in the same low to medium and high range. High CV is the first sign of data heterogeneity (Cerri and Magalhães, 2012). Disease variability in the field may be related to new pathogen strains, culture methods, hostages, the presence of each pathogen inoculum, and environmental conditions. Many factors affect severe shothole pollution, including temperature, precipitation, humidity, and wind.GB accounts for 114,286 tonnes of apricot production, the greatest of any region in Pakistan (The Nation, 2017).

Shot hole disease, which primarily results in early defoliation, lowers the plant's flowering, and may cause fruit quantity losses, is responsible for wasting fruits during several cycles from the plant's flowering to post-harvest stages (Han *et al.*, 2021). Similar to the pathogen that causes shot hole disease, this infection weakens the leaves of plants and results in severe defoliation, which lowers photosynthetic activity in plants and affects the production of fruit (Ivanová *et al.*, 2012; Han *et al.*, 2021; Teviotdale *et al.*, 1997). Temperature, rainfall, evapotranspiration, precipitation, and wind are the main elements that influence and aid in the development of the shot hole fungus, *W. carpophilus,* in the portions of apricot plants such as branches, leaves, flowers, twigs, and fruits. A similar study of the prevalence of shot hole disease in the state of Mexico was conducted by Tovar-Pedraza *et al.* (2013), and their findings revealed that 75-80% of apricot trees in Mexico orchards are found to be shot hole disease infected.

The disease symptoms were observed throughout the district and valleys, and they may be nearly 60-80% in all valleys and vary in orchards. Climatic factors such as temperature significantly affect fungal disease development, conidia, and spores formation at 5-25 ℃ (Ivanová *et al.*, 2012; Verma and Singh, 2010). The average temperature in the Nagar district of Gilgit-Baltistan, Pakistan, which was noted as an average of 15-25 ℃ during the production year, was suitable for the disease development. However, the average rainfall was noted as 25mm. Average humidity during the study was 60% in the Nagar district, which is suitable for the disease development and separation from plant to plant and location to location; similar relations were discussed by (Bubici *et al.*, 2010; Thomidis and Exadaktylou, 2013). The critical factors that promote the transfer of spores from diseased plant parts to healthy plant sections even from plant to plant and location to location occur with the influence of wind, rain, irrigation water, and other cultural practices from shot hole development to separation (Cao *et al.*, 2013; Uddin and Stevenson, 1998).

They also discussed the wetness period or duration and type of irrigation which helps increment humidity and causes shot hole spores separation. So, it is pretty challenging to control the shot hole disease in advanced stages. Adopting suitable nursery management techniques, such as plant-to-plant spacing, adequate training, pruning, and timely irrigation of plants, can prevent diseases and separation. Frequent watering of plants raises humidity levels, which causes the growth of shot holes. Therefore, cutting-edge applications and nursery management strategies may aid in preventing the growth and separation of shot hole disease.

CONCLUSION

According to the data, the occurrence of shot hole disease in five examined valleys of the Nagar district and its severity is dispersed throughout the valleys and varies from orchard to orchard. Weather data and cultural customs support the disease with the highest mean severity and index. Several GIS software programs integrate spatial analytic capabilities like geostatistics for producing distributional maps. As a result of the extensive usage of GIS-based studies, geostatistical methods are expected to become increasingly common in practical contexts and at various sizes, making it easier to build successful local and regional disease and pest management programs.

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DATA AVAILABILITY

The data supporting this study's findings are available on request from the corresponding author.

ETHICAL STATEMENT

This study did not engage in any human or animal testing.

AUTHOR CONTRUBUTIONS

All the authors have contributed equally to the research and compiling the data as well as editing the manuscript.

CONFLICT OF INTEREST

The authors have not declared any conflict of interest.

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