

Supplementary Table 1. Explanatory Variables Utilized for Feature Selection in Machine Learning Analysis of Thyroid Cancer Incidence in Iran

Variable	Data Source
Cancer-Related Variables	
V1: The Age-Standardized-rate of Thyroid Cancer incidence in the 100,000 Population	-
Sociodemographic Variables	
V2: The Mortality-rate in the 100,000 Population	NOCR
V3: The Cancer Mortality-rate in the 100,000 Population	NOCR
V4: Population-density	SCI
V5: Age Group Population-rate in %	SCI
V6: Elderly-rate in %	-
V7: Province-area in Km ²	SCI
V8: Household-density	SCI
V9: The Birth-rate in the 100,000 Population	NOCR
V10: The Marriage-rate-rate in the 100,000 Population	NOCR
V11: The Divorce-rate in the 100,000 Population	NOCR
V12: The Fertility-rate in 100,000 Women	SCI
V13: Urbanization-rate in %	SCI
V14: Economic Partnership-rate in %	SCI
V15: The Literacy-rate-rate in %	SCI
V16: Vehicle-density-rate in 100,000 Population	SCI
V17: Tamin-Insurance-rate in %	SCI
V18: Salamat Insurance-rate in %	SCI
V19: Ashayer Insurance-rate in %	SCI
V20: Graduate-density in 100,000	SCI
V21: Provincial-Education-rate in %	SCI
Healthcare Infrastructure Variables	
V22: Hospital-density in 100,000 Population	SCI
V23: Inpatient Bed Count-density in 100,000 Population	SCI
V24: Primary-Care-density in the 100,000 Population	SCI
V25: Nuclear-Medicine-density in the 100,000 Population	SCI
V26: The Physician-To-Population Ratio in the 100,000 Population	SCI
V27: Clinic-density in the 100,000 Population-rate in 100,000 Population	SCI
V28: Emergency Care Facilities-density-rate in the 100,000 Population	SCI
V29: Rehabilitation-center-density in the 100,000 Population	SCI
V30: Laboratory-availability-density in the 100,000 Population	SCI
V31: Pharmacy-density in the 100,000 Population	SCI
Environmental Variables	
V32: Urban-Gini-Index	SCI
V33: Rural Gini Index	SCI

V34: Elevation-in-Meter	SCI
V35: Maximum Temperature Average	SCI
V36: Minimum Temperature Average	SCI
V37: Temperature Average	SCI
V38: Minimum Low Temperature	SCI
V39: Maximum High Temperature	SCI
V40: Yearly-Precipitation	SCI
V41: Maximum Daily Precipitation	SCI
V42: Yearly-Precipitation-Average	SCI
V43: Maximum Average Relative Humidity	SCI
V44: Minimum Average Relative Humidity	SCI
V45: Days-with-Frost	SCI
V46: Days with Dust	SCI
V47: Sunshine-duration	SCI
V48: Maximum Wind Speed	SCI
Air Quality Variables	
V49: Carbon Monoxide (CO ₂)	APMS
V50: Ozone (O ₃ -1)	APMS
V51: Ozone (O ₃)	APMS
V52: Nitrogen Dioxide (NO ₂)	APMS
V53: Sulfur Dioxide (SO ₂)	APMS
V54: Particulate Matter of Size ≤10 Micron (PM ₁₀)	APMS
V55: Particulate Matter of Size ≤2.5 Micron (PM _{2.5})	APMS
V56: Air Quality Index (AQI)	APMS

National Office for Civil Registration (NOCR), Statistical Center of Iran (SCI), Air Pollution Monitoring System of Iran (APMS)

Supplementary Table 2. The Average Age-Standardized Incidence-rates (ASR) of Thyroid Cancer by Sex and Province in Iran (2014-2017)

Province	Entire Population	Female	Male
Alborz	1.66	5.03	1.65
Ardabil	2.14	6.76	1.81
Bushehr	3.47	11.89	2.59
Chaharmahal-and-Bakhtiari	5.48	16.33	5.87
East Azerbaijan	3.38	10.52	3.05
Fars	4.76	15.05	4.05
Gilan	3.96	13.04	2.76
Golestan	2.01	6.03	1.93
Hamedan	2.05	6.39	1.82
Hormozgan	1.68	5.19	1.51
Ilam	2.41	7.94	1.67
Isfahan	5.34	17.5	4.02
Kerman	2.93	9.63	2.19
Kermanshah	2.59	7.88	2.43
Khuzestan	1.45	4.48	1.3
Kohgiluyeh-and-BoyerAhmad	6.22	20.47	4.62
Kurdistan	1.3	4.13	1.1
Lorestan	1.6	4.77	1.66
Markazi	2.41	6.9	2.8
Mazandaran	2.76	9.13	1.98
North-Khorasan	1.58	4.75	1.55
Qazvin	2.14	6.61	1.97
Qom	6.08	19.91	4.65
Razavi-Khorasan	2.45	7.27	2.57
Semnan	1.21	3.44	1.41
Sistan-and-Baluchestan	1.56	4.54	1.67
South-Khorasan	1.86	5.44	2
Tehran	2.18	6.68	2.03
West-Azerbaijan	1.3	3.65	1.55
Yazd	9.17	32.07	5.58
Zanjan	1.47	4.67	1.27

Supplementary Table 3. Feature Rankings and Importance Scores from Random Forest Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Importance Score	Feature	Importance Score	Feature	Importance Score
1	PM ₁₀	0.083	Primary-Care	0.124	Laboratory-availability	0.134
2	Yearly-Precipitation	0.082	Max-Daily-Precipitation	0.1	Literacy-rate	0.07
3	Laboratory-availability	0.07	Vehicle-density	0.081	Pharmacy	0.052
4	Primary-Care	0.065	Laboratory-availability	0.066	Province-area	0.049
5	Urban-Gini-Index	0.064	Rehabilitation-center	0.053	Graduate-density	0.049

Supplementary Table 4. Feature Rankings and Importance Scores from XG-Boost Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Importance Score	Feature	Importance Score	Feature	Importance Score
1	Laboratory-availability	0.5	Laboratory-availability	0.33	Sunshine-duration	0.32
2	Sunshine-duration	0.205	Sunshine-duration	0.294	Laboratory-availability	0.201
3	Elevation-in-Meter	0.049	Nuclear-Medicine	0.082	CO ₂	0.077
4	Urbanization	0.04	Tamin-Insurance	0.045	Tamin-Insurance	0.052
5	Tamin-Insurance	0.031	Min-Low-Temperature	0.039	Ozone	0.034

Supplementary Table 5. Feature Rankings and Importance Scores from Cat-Boost Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Importance Score	Feature	Importance Score	Feature	Importance Score
1	Laboratory-availability	8.028	Sunshine-duration	10.181	Sunshine-duration	14.157
2	Province-area	5.748	Elevation-in-Meter	8.794	Elevation-in-Meter	8.166
3	Elevation-in-Meter	4.928	Tamin-Insurance	4.377	Laboratory-availability	6.43
4	Yearly-Precipitation	4.779	Max-High-Temperature	4.04	Literacy-rate	4.187
5	Mortality-rate	4.708	Laboratory-availability	4.031	Physician	3.725

Supplementary Table 6. Feature Rankings and Importance Scores from LASSO Regression Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Coefficients	Feature	Coefficients	Feature	Coefficients
1	Laboratory-availability	0.515	Tamin-Insurance	3.557	Laboratory-availability	0.429
2	Marriage-rate	-0.274	Graduate-density	-3.104	Days-with-Frost	0.244
3	PM ₁₀	0.203	Primary-Care	1.927	Graduate-density	-0.239
4	Provincial-Education-rate	-0.089	Laboratory-availability	1.855	Nuclear-Medicine	0.122
5	Vehicle-density	0.078	Provincial-Education-rate	-1.616	Vehicle-density	0.122

Supplementary Table 7. Feature Rankings and Importance Scores from Ridge Regression Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Coefficients	Feature	Coefficients	Feature	Coefficients
1	Laboratory-availability	0.284	Tamin-Insurance	4.033	Laboratory-availability	0.189
2	PM ₁₀	0.221	Graduate-density	-3.254	Days-with-Frost	0.112
3	Provincial-Education-rate	-0.204	Yearly-Precipitation-Average	2.54	Graduate-density	-0.11
4	Vehicle-density	0.169	Max-Average-Relative-Humidity	-2.248	Vehicle-density	0.104
5	Max-Average-Relative-Humidity	-0.153	Primary-Care	2.146	Max-High-Temperature	-0.102

Supplementary Table 8. Feature Rankings and Importance Scores from Stepwise Regression Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Coefficients	Feature	Coefficients	Feature	Coefficients
1	Vehicle-density	0.505	Laboratory-availability	1.792	Laboratory-availability	0.648
2	Provincial-Education-rate	-0.639	Mortality-rate	-1.573	Graduate-density	-0.388
3	Laboratory-availability	0.867	Provincial-Education-rate	-2.01	Marriage-rate	-0.393
4	Graduate-density	-0.317	Vehicle-density	2.715	Days-with-Frost	0.351
5	Marriage-rate	-0.588	Max-High-Temperature	-1.659		

Supplementary Table 9. Feature Rankings and Importance Scores from OLS Regression Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Coefficients	Feature	Coefficients	Feature	Coefficients
1	Provincial-Education-rate	1.169	Tamin-Insurance	4.532	Literacy-rate	0.517
2	Graduate-density	0.777	Graduate-density	-3.531	Days-with-Frost	0.502
3	Max-Average-Relative-Humidity	0.75	Yearly-Precipitation-Average	2.82	Provincial-Education-rate	-0.4
4	Vehicle-density	0.718	Max-Average-Relative-Humidity	-2.47	Graduate-density	-0.383
5	Yearly-Precipitation	0.602	Primary-Care	2.3	Laboratory-availability	0.373

Supplementary Table 10. Feature Rankings and Importance Scores from Elastic-Net Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Coefficients	Feature	Coefficients	Feature	Coefficients
1	Laboratory-availability	0.468	Graduate-density	-1.754	Laboratory-availability	0.357
2	Graduate-density	-0.347	Laboratory-availability	1.7098	Graduate-density	-0.245
3	Provincial-Education-rate	-0.292	Tamin-Insurance	1.42	Days-with-Frost	0.201
4	PM ₁₀	0.246	Provincial-Education-rate	-1.003	Max-High-Temperature	0.1401
5	Vehicle-density	0.242	Max-Average-Relative-Humidity	-0.915	Literacy-rate	0.139

Supplementary Table 11. Feature Rankings and Importance Scores from Recursive Feature Elimination (RFE) Analysis of Thyroid Cancer Risk Factors in Iran, Stratified by Sex

Feature Rank	Total		Females		Males	
	Feature	Coefficients	Feature	Coefficients	Feature	Coefficients
1	Province-area	0.357	Laboratory-availability	2.856	Province-area	0.239
2	Laboratory-availability	0.666	Nuclear-Medicine	1.555	Laboratory-availability	0.732
3	Yearly-Precipitation	0.31	Primary-Care	1.726	Rehabilitation-center	0.207
4	Tamin-Insurance	0.735	Tamin-Insurance	1.507	Graduate-density	-0.284
5	Graduate-density	-0.652	Graduate-density	-2.719	Days-with-Frost	0.308

Supplementary Table 12. SHAP Validation Results Using Random Forest for Thyroid Cancer Age-Standardized Incidence-rates in Entire Population Iran

Feature Name	Mean Impact	STD Impact	ABS Mean Impact
Sunshine-duration	-0.029	0.396	0.325
Yearly-Precipitation	0.092	0.52	0.257
Marriage-rate	0.032	0.201	0.168
Elevation-in-Meter	-0.042	0.29	0.153
Provincial-Education-rate	-0.012	0.167	0.144
PM ₁₀	0.001	0.143	0.138
Laboratory-availability	0.012	0.165	0.121
Vehicle-density	0.036	0.225	0.091
Urbanization	-0.027	0.089	0.08
Mortality-rate	-0.028	0.075	0.06
Graduate-density	0.003	0.071	0.047
Max-Average-Relative-Humidity	0.001	0.075	0.046
Tamin-Insurance	0.001	0.059	0.033
Urban-Gini-Index	-0.017	0.03	0.03
Primary-Care	0.008	0.035	0.029
Province-area	-0.002	0.042	0.022

Supplementary Table 13. SHAP Validation Results Using XG-Boost for Thyroid Cancer Age-Standardized Incidence-rates in Entire Population Iran

Feature Name	Mean Impact	STD Impact	ABS Mean Impact
Marriage-rate	0.004	0.48	0.415
Sunshine-duration	-0.09	0.479	0.407
Yearly-Precipitation	0.169	1.205	0.358
Laboratory-availability	0.058	0.417	0.306
PM ₁₀	-0.007	0.2	0.177
Provincial-Education-rate	-0.062	0.15	0.128
Mortality-rate	-0.059	0.166	0.124
Elevation-in-Meter	-0.028	0.158	0.088
Urbanization	-0.024	0.104	0.079
Graduate-density	-0.017	0.123	0.068
Vehicle-density	0.014	0.073	0.058
Primary-Care	-0.004	0.056	0.042
Province-area	-0.005	0.048	0.038
Urban-Gini-Index	-0.026	0.031	0.029
Tamin-Insurance	0	0.031	0.026
Max-Average-Relative-Humidity	-0.004	0.022	0.017

Supplementary Table 14. SHAP Validation Results Using Cat-Boost for Thyroid Cancer Age-Standardized Incidence-rates in Entire Population Iran

Feature Name	Mean Impact	STD Impact	ABS Mean Impact
Urbanization	-0.032	0.269	0.239
Marriage-rate	0.06	0.285	0.233
Sunshine-duration	-0.018	0.27	0.227
Yearly-Precipitation	0.051	0.359	0.194
Graduate-density	-0.04	0.261	0.165
Elevation-in-Meter	-0.025	0.209	0.128
Laboratory-availability	-0.022	0.136	0.113
PM ₁₀	0.013	0.114	0.092
Max-Average-Relative-Humidity	0.015	0.176	0.091
Vehicle-density	0.022	0.178	0.088
Mortality-rate	-0.019	0.114	0.082
Provincial-Education-rate	-0.02	0.084	0.074
Tamin-Insurance	0.002	0.088	0.063
Province-area	-0.008	0.069	0.053
Primary-Care	0.014	0.08	0.045
Urban-Gini-Index	-0.016	0.043	0.034

Supplementary Table 15. SHAP Validation Results Using Random Forest for Thyroid Cancer Age-Standardized Incidence-rates in Females Iran

Feature Name	Mean Impact	STD Impact	ABS Mean Impact
Sunshine-duration	0.112	1.612	1.351
Tamin-Insurance	0.459	1.436	0.714
Elevation-in-Meter	0.112	1.119	0.553
Max-Daily-Precipitation	0.053	0.6	0.531
Nuclear-Medicine	0.061	0.43	0.384
Provincial-Education-rate	-0.004	0.466	0.376
Laboratory-availability	-0.057	0.481	0.35
Vehicle-density	-0.059	0.339	0.305
Min-Low-Temperature	0.016	0.284	0.252
Max-High-Temperature	0.072	0.259	0.189
Graduate-density	0.082	0.204	0.177
Rehabilitation-center	0.048	0.217	0.149
Yearly-Precipitation-Average	0.078	0.219	0.136
Max-Average-Relative-Humidity	-0.046	0.145	0.123
Mortality-rate	-0.002	0.155	0.115
Primary-Care	-0.013	0.14	0.1

Supplementary Table 16. SHAP Validation Results Using XG-Boost for Thyroid Cancer Age-Standardized Incidence-rates in Females Iran

Feature Name	Mean Impact	STD Impact	ABS Mean Impact
Sunshine-duration	-0.047	1.956	1.741
Tamin-Insurance	0.576	2.409	1.354
Laboratory-availability	-0.29	0.877	0.69
Max-Daily-Precipitation	-0.211	0.587	0.545
Min-Low-Temperature	-0.013	0.562	0.492
Graduate-density	0.162	0.466	0.414
Nuclear-Medicine	0.072	0.381	0.36
Provincial-Education-rate	0.042	0.441	0.348
Mortality-rate	-0.111	0.386	0.306
Vehicle-density	0.08	0.386	0.271
Elevation-in-Meter	-0.001	0.24	0.164
Max-Average-Relative-Humidity	-0.082	0.174	0.156
Rehabilitation-center	0.029	0.119	0.102
Max-High-Temperature	-0.023	0.122	0.099
Yearly-Precipitation-Average	0.008	0.12	0.089
Primary-Care	-0.004	0.09	0.073

Supplementary Table 17. SHAP Validation Results Using Cat-Boost for Thyroid Cancer Age-Standardized Incidence-rates in Females Iran

Feature Name	Mean Impact	STD Impact	ABS Mean Impact
Sunshine-duration	-0.018	1.503	1.162
Nuclear-Medicine	0.135	0.747	0.718
Max-Daily-Precipitation	0.088	0.666	0.612
Tamin-Insurance	0.28	1.009	0.593
Elevation-in-Meter	0.084	0.957	0.55
Mortality-rate	-0.172	0.574	0.485
Vehicle-density	-0.024	0.397	0.344
Provincial-Education-rate	0.055	0.375	0.304
Min-Low-Temperature	-0.057	0.329	0.276
Graduate-density	0.07	0.363	0.275
Laboratory-availability	0.021	0.343	0.271
Primary-Care	-0.017	0.259	0.203
Yearly-Precipitation-Average	-0.041	0.21	0.172
Max-Average-Relative-Humidity	-0.04	0.191	0.158
Rehabilitation-center	-0.003	0.237	0.154
Max-High-Temperature	0.019	0.188	0.126

Supplementary Table 18. SHAP Validation Results Using Random Forest for Thyroid Cancer Age-Standardized Incidence-rates in Males Iran

Feature Name	Mean Impact	Std Impact	Abs Mean Impact
Sunshine-duration	0.004	0.373	0.299
Elevation-in-Meter	0.005	0.224	0.129
Literacy-rate	-0.029	0.126	0.122
CO ₂	0.005	0.114	0.101
Laboratory-availability	-0.012	0.133	0.096
Marriage-rate	-0.007	0.077	0.066
Physician	0.035	0.077	0.057
Max-High-Temperature	0.009	0.048	0.04
Pharmacy	-0.022	0.048	0.038
Province-area	0.012	0.048	0.037
Tamin-Insurance	0.017	0.049	0.033
Days-with-Frost	0.004	0.029	0.024
Vehicle-density	-0.005	0.024	0.021
Rehabilitation-center	-0.006	0.024	0.021
Graduate-density	0.011	0.02	0.018
Provincial-Education-rate	0.002	0.022	0.016
Ozone	0.003	0.019	0.015
Nuclear-Medicine	0.004	0.021	0.015

Supplementary Table 19. SHAP Validation Results Using XG-Boost for Thyroid Cancer Age-Standardized Incidence-rates in Males Iran

Feature Name	Mean Impact	STD Impact	ABS Mean Impact
Sunshine-duration	-0.034	0.58	0.479
CO ₂	-0.058	0.304	0.262
Laboratory-availability	-0.03	0.183	0.131
Tamin-Insurance	0.018	0.15	0.11
Physician	0.05	0.163	0.102
Marriage-rate	-0.011	0.113	0.099
Ozone	-0.012	0.122	0.084
Graduate-density	0.02	0.064	0.054
Max-High-Temperature	0.004	0.065	0.054
Province-area	0.011	0.081	0.051
Literacy-rate	-0.011	0.067	0.05
Provincial-Education-rate	-0.018	0.04	0.034
Elevation-in-Meter	0.008	0.043	0.031
Rehabilitation-center	0.0001	0.039	0.031
Pharmacy	-0.007	0.037	0.028
Days-with-Frost	-0.007	0.034	0.024
Vehicle-density	-0.009	0.014	0.012
Nuclear-Medicine	0.003	0.016	0.009

Supplementary Table 20. SHAP Validation Results Using Cat-Boost for Thyroid Cancer Age-Standardized Incidence-rates in Males Iran

Feature Name	Mean Impact	STD Impact	ABS Mean Impact
Sunshine-duration	0.015	0.298	0.237
Literacy-rate	-0.038	0.198	0.178
Elevation-in-Meter	-0.008	0.113	0.088
Marriage-rate	0.007	0.105	0.085
Days-with-Frost	0.006	0.112	0.081
CO ₂	0.001	0.102	0.079
Max-High-Temperature	0.023	0.092	0.074
Laboratory-availability	-0.001	0.102	0.06
Nuclear-Medicine	0.008	0.052	0.05
Provincial-Education-rate	0.015	0.072	0.049
Graduate-density	0.019	0.049	0.046
Ozone	0	0.057	0.045
Physician	0.022	0.061	0.045
Tamin-Insurance	0.022	0.064	0.039
Province-area	0.01	0.05	0.036
Pharmacy	-0.011	0.049	0.034
Rehabilitation-center	-0.013	0.041	0.031
Vehicle-density	0.001	0.038	0.028

Supplementary Table 21. Female-to-Male Ratios of SHAP Values for Key Features in Random Forest Model Validation of Thyroid Cancer Age-Standardized Incidence-rates Across Iran (2014–2017)

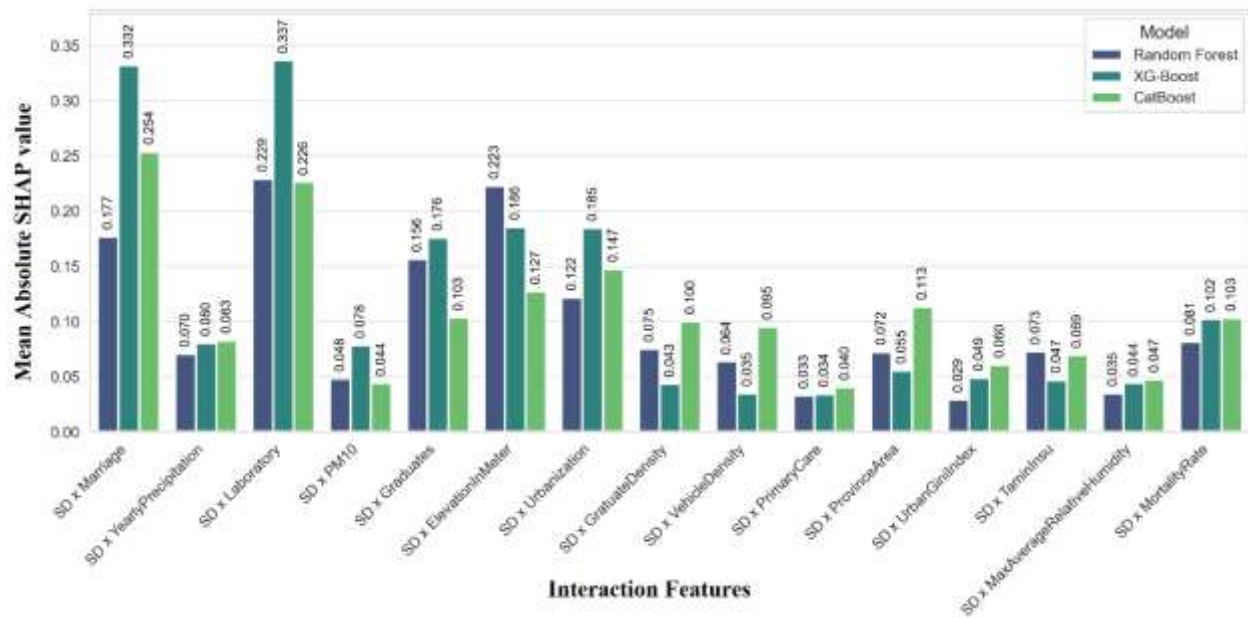
Rank	Feature	Females		Males		Female-To-Male Ratio	
		Mean SHAP	ABS Mean Impact	Mean SHAP	ABS Mean Impact	Mean SHAP	ABS Mean Impact
1	Sunshine-duration	0.112	1.351	0.004	0.299	28	4.5
2	Tamin-Insurance	0.459	0.714	0.017	0.033	27	21.6
3	Elevation-in-Meter	0.112	0.553	0.005	0.129	22.4	4.3
4	Nuclear-Medicine	0.061	0.384	0.004	0.015	15.3	25.6
5	Laboratory-availability	-0.057	0.35	-0.012	0.096	4.8	3.6
6	Vehicle-density	-0.059	0.305	-0.005	0.021	11.8	14.5
7	Max-High-Temperature	0.072	0.189	0.009	0.04	8	4.7
8	Graduate-density	0.082	0.177	0.011	0.018	7.5	9.8
9	Rehabilitation-center	0.048	0.149	-0.006	0.021	8	7.1

Supplementary Table 22. Female-to-Male Ratios of SHAP Values for Key Features in XG-Boost Model Validation of Thyroid Cancer Age-Standardized Incidence-rates Across Iran (2014–2017)

Rank	Feature	Females		Males		Female-To-Male Ratio	
		Mean SHAP	ABS Mean Impact	Mean SHAP	ABS Mean Impact	Mean SHAP	ABS Mean Impact
1	Sunshine-duration	-0.047	1.741	-0.034	0.479	1.4	3.6
2	Tamin-Insurance	0.576	1.354	0.018	0.11	32	12.3
3	Laboratory-availability	-0.29	0.69	-0.03	0.131	9.7	5.3
4	Graduate-density	0.162	0.414	0.02	0.054	8.1	7.7
5	Nuclear-Medicine	0.072	0.36	0.003	0.009	24	40
6	Vehicle-density	0.08	0.271	-0.009	0.012	8.9	22.6
7	Elevation-in-Meter	-0.001	0.164	0.008	0.031	0.1	5.3
8	Rehabilitation-center	0.029	0.102	0.0001	0.031	290	3.3
9	Max-High-Temperature	-0.023	0.099	0.004	0.054	5.8	1.8

Supplementary Table 23. Female-to-Male Ratios of SHAP Values for Key Features in Cat-Boost Model Validation of Thyroid Cancer Age-Standardized Incidence-rates Across Iran (2014–2017)

Rank	Feature	Females		Males		Female-To-Male Ratio	
		Mean SHAP	ABS Mean Impact	Mean SHAP	ABS Mean Impact	Mean SHAP	ABS Mean Impact
1	Sunshine-duration	-0.018	1.162	0.015	0.237	1.2	4.9
2	Nuclear-Medicine	0.135	0.718	0.008	0.05	16.9	14.4
3	Tamin-Insurance	0.28	0.593	0.022	0.039	12.7	15.2
4	Elevation-in-Meter	0.084	0.55	-0.008	0.088	10.5	6.3
5	Vehicle-density	-0.024	0.344	0.001	0.028	24	12.3
6	Graduate-density	0.07	0.275	0.019	0.046	3.7	6
7	Laboratory-availability	0.021	0.271	-0.001	0.06	21	4.5
8	Rehabilitation-center	-0.003	0.154	-0.013	0.031	0.2	5
9	Max-High-Temperature	0.019	0.126	0.023	0.074	0.8	1.7

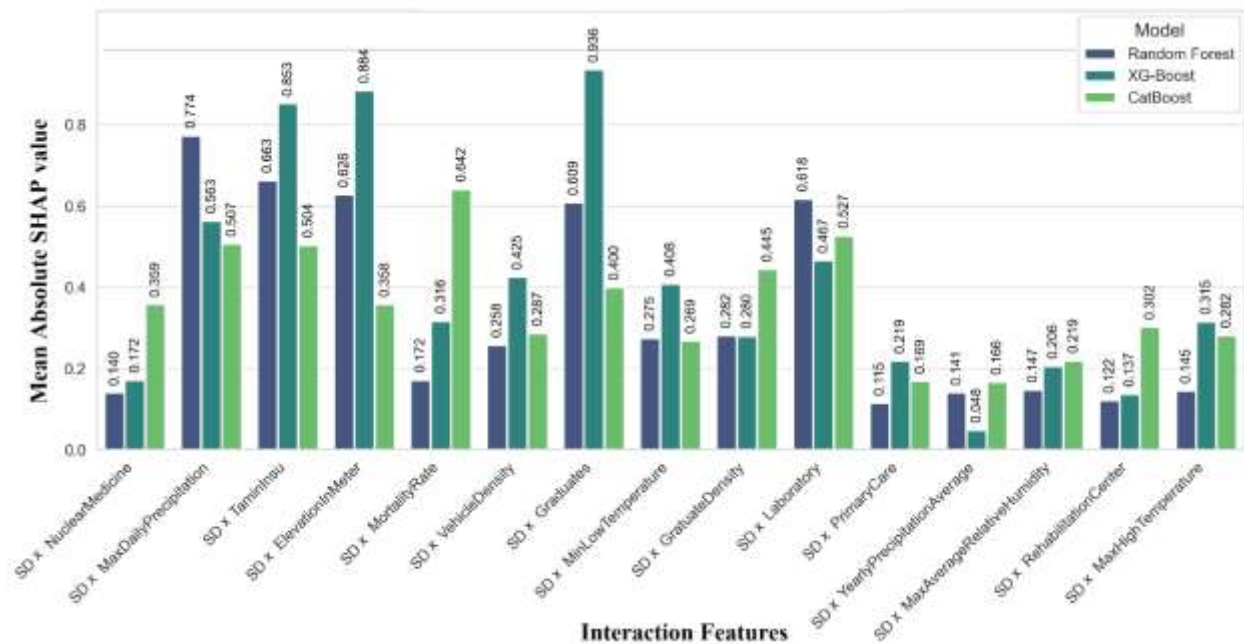


Supplementary Figure 1. Mean Absolute SHAP Values for Sunshine-duration Interaction with other Features across Models in Predicting Thyroid Cancer Age-Standardized Incidence-rates in Entire Population across Iran (2014–2017), **Abbreviations:** SD: Sunshine-duration, SHAP: SHapley Additive exPlanations

Supplementary Table 24. SHAP Values and Statistical Significance of Feature Interactions across Models for Thyroid Cancer Age-Standardized Incidence-rates in Entire Population across Iran (2014–2017)

Feature Interactions	Beta		SHAP Interaction			P-Value	P-Value (FDR)
	Value	Direction	Random Forest	XG Boost	Cat Boost		
Sunshine-duration × Max-Average-Relative-Humidity	-0.2792	Negative	0.034725	0.044153	0.047361	0.0003	0.0043
SD × Elevation-in-Meter	0.2858	Positive	0.22287	0.185569	0.127052	0.0008	0.006
SD × Yearly-Precipitation	-0.1908	Negative	0.070361	0.08037	0.082506	0.0045	0.0224
SD × Urban-Gini-Index	-0.1908	Negative	0.029159	0.048723	0.060398	0.007	0.0263
SD × Urbanization	0.1862	Positive	0.121501	0.184627	0.147182	0.0386	0.1157
SD × Tamin-Insurance	0.1702	Positive	0.072636	0.046776	0.069379	0.0527	0.1283
SD × Mortality-rate	-0.1514	Negative	0.081134	0.102237	0.102592	0.0599	0.1283
SD × Laboratory-availability	0.1487	Positive	0.228998	0.336584	0.22624	0.0872	0.1635
SD × Vehicle-density	0.1518	Positive	0.06365	0.03481	0.095112	0.1166	0.1943
SD × Graduate-density	0.1277	Positive	0.074977	0.043164	0.100029	0.179	0.2685
SD × Primary-Care	-0.1126	Negative	0.032903	0.034102	0.040348	0.2738	0.3733
SD × Province-area	0.1168	Positive	0.071988	0.055352	0.113235	0.3139	0.3923
SD × Provincial-Education-rate	-0.0311	Negative	0.156388	0.17552	0.103272	0.6629	0.7648
SD × PM ₁₀	0.0286	Positive	0.047891	0.078219	0.044108	0.727	0.779
SD × Marriage-rate	0.0187	Positive	0.177001	0.33189	0.253705	0.8271	0.8271

Abbreviations: SD: Sunshine-duration, FDR: False Discovery Rate

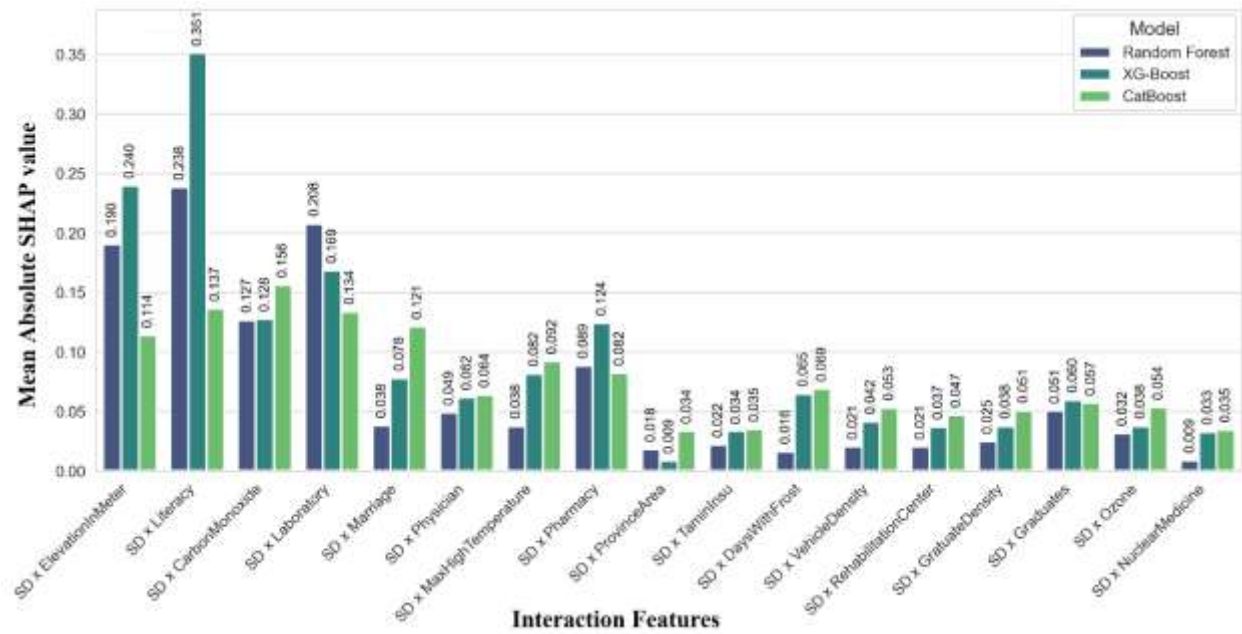


Supplementary Figure 2. Mean Absolute SHAP Values for Sunshine-duration Interaction with other Features across Models in Predicting Thyroid Cancer Age-Standardized Incidence-rates in Females across Iran (2014–2017), **Abbreviations:** SD: Sunshine-duration, SHAP: SHapley Additive exPlanations

Supplementary Table 25. SHAP Values and Statistical Significance of Feature Interactions across Models for Thyroid Cancer Age-Standardized Incidence-rates in Females across Iran (2014–2017)

Feature Interactions	Beta		SHAP Interaction			P-Value	P-Value (FDR)
	Value	Direction	Random Forest	XG Boost	Cat Boost		
SD × Elevation-in-Meter	0.2404	Positive	0.628103	0.884423	0.358049	0.0001	0.0001
SD × Max-Average-Relative-Humidity	-0.2459	Negative	0.146992	0.205623	0.219446	0.0001	0.0001
SD × Yearly-Precipitation-Average	-0.1711	Negative	0.140939	0.048103	0.166248	0.0001	0.0003
SD × Max-Daily-Precipitation	-0.1503	Negative	0.77365	0.563287	0.506996	0.0009	0.0034
SD × Mortality-rate	-0.1395	Negative	0.171595	0.316446	0.641734	0.0259	0.0776
SD × Primary-Care	-0.1453	Negative	0.115017	0.21915	0.169245	0.0321	0.0803
SD × Vehicle-density	0.1265	Positive	0.257909	0.425377	0.28658	0.0404	0.0865
SD × Provincial-Education-rate	-0.0847	Negative	0.608748	0.936288	0.399694	0.0636	0.1138
SD × Laboratory-availability	0.1082	Positive	0.617604	0.466548	0.526622	0.0683	0.1138
SD × Min-Low-Temperature	-0.0812	Negative	0.27452	0.408432	0.268617	0.1119	0.1678
SD × Max-High-Temperature	0.0695	Positive	0.145113	0.315112	0.282245	0.1324	0.1806
SD × Tamin-Insurance	0.0841	Positive	0.663174	0.852727	0.504016	0.1454	0.1817
SD × Graduate-density	-0.0173	Negative	0.281529	0.280327	0.444535	0.7655	0.8833
SD × Rehabilitation-center	0.0084	Positive	0.121541	0.137199	0.302334	0.8503	0.911
SD × Nuclear-Medicine	0.0001	Positive	0.140292	0.171763	0.35854	0.9985	0.9985

Abbreviations: SD: Sunshine-duration, FDR: False Discovery Rate



Supplementary Figure 3. Mean Absolute SHAP Values for Sunshine-duration Interaction with other Features across Models in Predicting Thyroid Cancer Age-Standardized Incidence-rates in Males across Iran (2014–2017), **Abbreviations:** SD: Sunshine-duration, SHAP: SHapley Additive exPlanations

Supplementary Table 26. SHAP Values and Statistical Significance of Feature Interactions across Models for Thyroid Cancer Age-Standardized Incidence-rates in Males across Iran (2014–2017)

Feature Interactions	Beta		SHAP Interaction			P-Value	P-Value (FDR)
	Value	Direction	Random Forest	XG Boost	Cat Boost		
SD × Elevation-in-Meter	0.1616	Positive	0.190491	0.239674	0.114214	0.055	0.6747
SD × Days-with-Frost	0.1599	Positive	0.016354	0.064775	0.069126	0.0794	0.6747
SD × Literacy-rate	-0.1276	Negative	0.238274	0.351145	0.136543	0.2604	0.819
SD × Provincial-Education-rate	-0.0886	Negative	0.050809	0.059839	0.057367	0.2183	0.819
SD × Laboratory-availability	0.0829	Positive	0.207598	0.16858	0.133699	0.4036	0.819
SD × Marriage-rate	0.0779	Positive	0.038352	0.078001	0.12143	0.3509	0.819
SD × Physician	0.0686	Positive	0.049065	0.061963	0.064018	0.4445	0.819
SD × Max-High-Temperature	-0.048	Negative	0.037782	0.081779	0.09218	0.53	0.819
SD × Graduate-density	-0.0654	Negative	0.024949	0.037845	0.050935	0.5113	0.819
SD × Ozone	0.0475	Positive	0.0318	0.03782	0.05353	0.4318	0.819
SD × Tamin-Insurance	-0.087	Negative	0.022018	0.033571	0.035206	0.3766	0.819
SD × Rehabilitation-center	-0.0193	Negative	0.020615	0.037257	0.04717	0.8024	0.8526
SD × Province-area	-0.0353	Negative	0.01845	0.008738	0.033811	0.7799	0.8526
SD × Pharmacy	0.0222	Positive	0.088528	0.124197	0.082169	0.7874	0.8526
SD × Vehicle-density	-0.0456	Negative	0.020708	0.041583	0.053188	0.6842	0.8526

Abbreviations: SD: Sunshine-duration, FDR: False Discovery Rate