

## **Spatial Variation of the Snow Cover Area in Northern Iraq**

**By**

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### **Abstract**

The Study Aims To Identify The Spatial Variation Of The Snow Cover Area Between Weather Monitoring Stations And The Variation Chronological For The Period (2011-2020). It Was Found From The Study That There Is A Spatial Variation In The Area Of Snow Cover; Dohuk Governorate Witnessed The Highest Percentage Of The Snow Cover Area, Which Amounted To (35%) Of The Total Area Of Snow Cover In The Study Area, While Kirkuk Station Recorded The Lowest Percentage Of The Snow Cover Area, Which Amounted To (5%). The Snow Cover Area Also Witnessed A Variation On The Temporal Level, As It Is Noticed That The Highest Snow Cover Area Was Recorded, Which Amounted To (11.4%) In The Year 2011, While The Year 2020 Witnessed A Decline In The Snow Cover Area In The Study Area, As It Constituted (8.7%) Of The Total Area Of The Cover. Snow During The Study Period. The Research Concluded That There Was A Decline In The Area Of Snow Cover In The Last Years Of The Study Period Within The Study Area, With The Exception Of The Mountainous Areas That Are More Than (3000) Meters Above Sea Level.

**Keywords:** Snow Cover, Snow Precipitation, Snow Cover Index, Snow Depth, Spatial Variability Of Snow Cover.

### **Introduction**

The Study Of Snow Cover Is One Of The Important Topics In The Study Of The Phenomenon Of Snow. This Is Due To The Great Relationship Between Snow Cover And Different Climate Elements. It Affects The Radiation Balance Through The Albedo Phenomenon, And It Also Contributes To Changing The Thermal Regime Of The Area It Covers, In Addition To Its Important Hydrological Significance In The Water Balance. Therefore, A Lot Of Scientific Research Tended To Study And Calculate The Snow Cover And Related Factors, And This Research Varied In Its Content And Methods Of Calculating The Snow Cover. Industrial And Remote Sensing, And The Use Of Special Indicators To Determine And Calculate The Snow Cover According To Different Light Beams, Which Resulted In Daily Maps And Images From Global Sites To Monitor The Snow Cover, Especially In Areas With Large Snow Cover Such As The Poles And Alaska. Since 1966, NOAA Has Started Drawing Global Maps To Monitor Spatial And Temporal Changes In Snow Cover By Means Of Remote Sensing Systems And The NDIS Snow Cover Index. (1)

## **1- Theoretical Framework**

### ***Study Problem***

The Study Problem Can Be Formulated With The Following Scientific Questions:

- 1 Is There A Spatial Variation Between Weather Stations In The Area Of Snow Cover?
- 2 Does The Snow Cover Area Vary In The Study Area At The Temporal Level?

### ***Study Hypothesis***

The Proposed Problem Can Be Answered As Follows:

- 1- The Study Area Witnesses Spatial Variation In The Snow Cover Area. 2. Snow Cover Varies Temporally In The Study Area.

### ***Objectives Of The Study***

1. The Study Aims To Know The Nature Of The Spatial Variation Of The Snow Cover Area In The Study Area.
2. The Study Also Aims To Know The Nature Of The Temporal Variation In The Annual Averages Of The Snow Cover Area.

### ***The Importance Of The Study***

The Importance Of The Study Lies In The Fact That It Studies A Very Important Climatic Phenomenon In The Climate Of Iraq, Which Is The Phenomenon Of Snowfall And The Coverage Of This Accumulated Snow From An Area Extending In The Northern Part Of Iraq, And What This Accumulated Snow Cover Represents Of Hydrological And Climatic Importance To Iraq . Also, The Lack Of Studies Related To Snowfall In The Northern Part Of Iraq Gives Importance To This Study, As It Represents A Starting Point For Knowing The Nature Of Spatial And Temporal Variations In The Area Of Snow Cover In The Study Area.

### ***Study Justifications***

1. The Importance Of Snow Cover; It Represents An Essential Resource From The Sources Of Feeding The Tigris River And Its Tributaries In The Study Area, As Well As Its Climatic Effects On Radiation Reflection, Soil Moisture Under The Snow Cover, And Many Others.
2. To Identify The Nature Of Spatial Variations In The Area Of Snow Cover In The Study Area.
3. Changes In The Area Of Snow Cover And Its Retreat Towards Higher Areas.

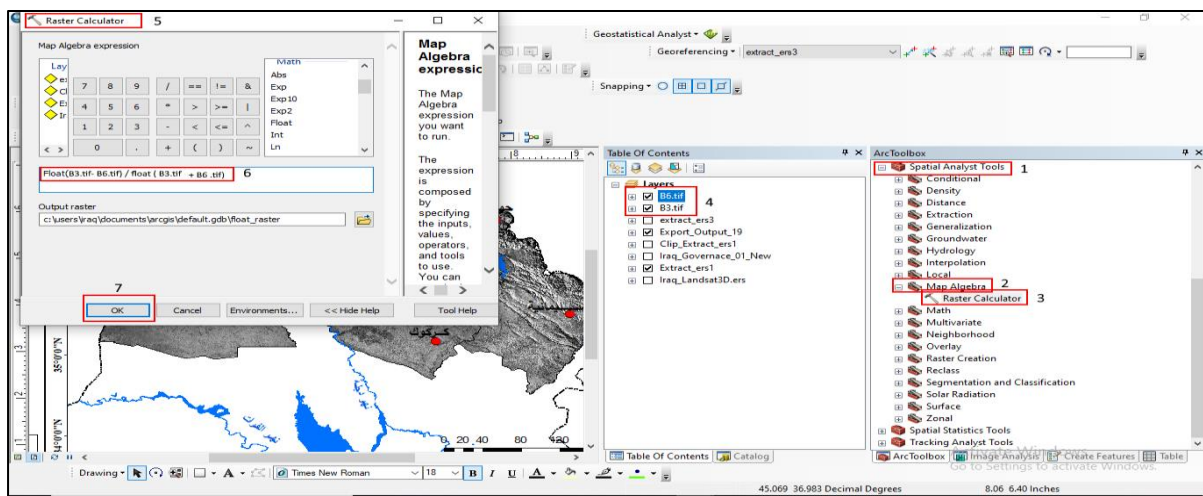
### ***Method Of Work***

In This Research, The Area Of Snow Cover Was Calculated Throughout The Study Area For A Period Of Ten Years, By Using Satellite Images That Were Downloaded From The USGS Website And From The Landseat 8 Satellite, With An Accuracy Of 500 Meters. Visible Fineness Of Clouds; This Is Because Clouds Represent A Factor Affecting The Process Of Extracting Snow Layers From The Visuals, As Snow Can Appear As A Layer Of Clouds Or As A Shadow That Affects The Data Processing Process. The Month Of January Was Adopted Only For A Period Of Ten Years; This Is Because This Month Represents The Most Frequent Month Of Snow In The Study Area, And The Area Of Snow Cover Remains Permanent In This Month, And Thus More Than One Visualization Was Downloaded For Each Month To Cover The Entire Month And The Average Area Was Extracted From These Visualizations. The Snow Cover Index NDSI Has Been Adopted To Calculate The Cover Area From Satellite Visuals And Using The Outputs Of Geographic Information Systems Arc

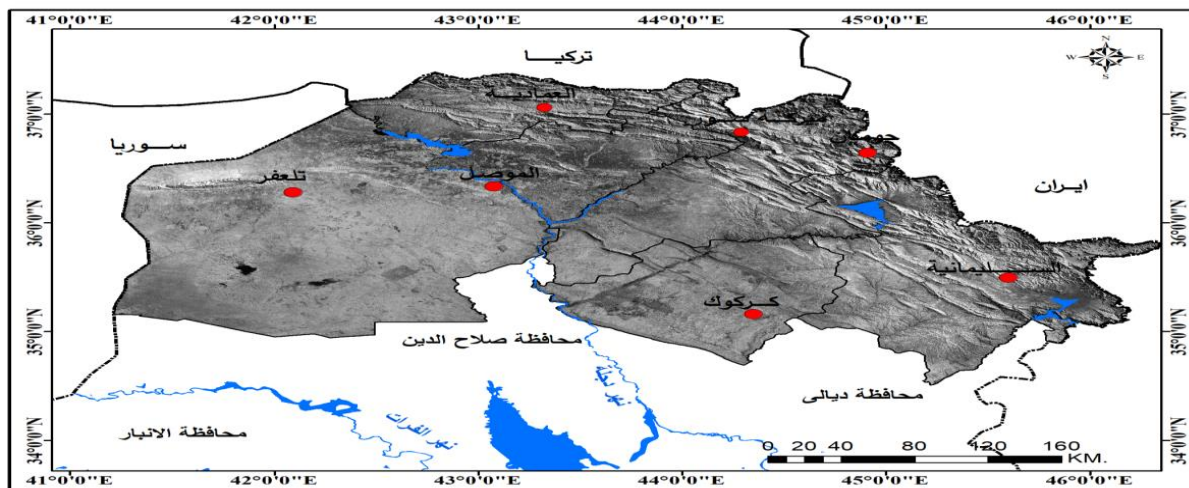
Map GIS V10.8, And Snow Cover Is Calculated Based On The Following Equation: (2) Ormalize Deference Snow Index= Green – Shortwavelentgh Infrared The Snow Cover Index Is Calculated From The Following Equation: (Tekel, 2005, P. 212)  $NDSI = \frac{MODIS_{B4} - MODIS_{B6}}{MODIS_{B4} + MODIS_{B4}}$

Then The Values That We Obtained Were Inserted Into The Excel Program To Calculate The Area Of Snow Cover From The Total Area Of The Study Area After Conducting The Classification Process, And Designing Maps And Graphs That Represent Percentages Of The Snow Cover Area From The Study Area. The Method Of Downloading And Processing The Visuals And Calculating The Snow Cover Area For The Study Area Can Be Summarized In The Following Diagram:

The Work Method To Extract The Snow Cover Area From The Satellite Visuals.



The Satellite Image



Source: The Recherche R Based On: - The Satellite Image Of Landseat 8 On 1/13/2011 Arc Map GIS V10.8

### 1-7- The Spatial and Temporal Boundaries Of The Study:

The Spatial Boundaries Of The Study Area Are Represented In The Northern Part Of Iraq; It Is Located Geographically In The Southwestern Part Of The Continent Of Asia, And It Represents The Northern Part Of Iraq, And It Is Bordered To The North By Turkey, To

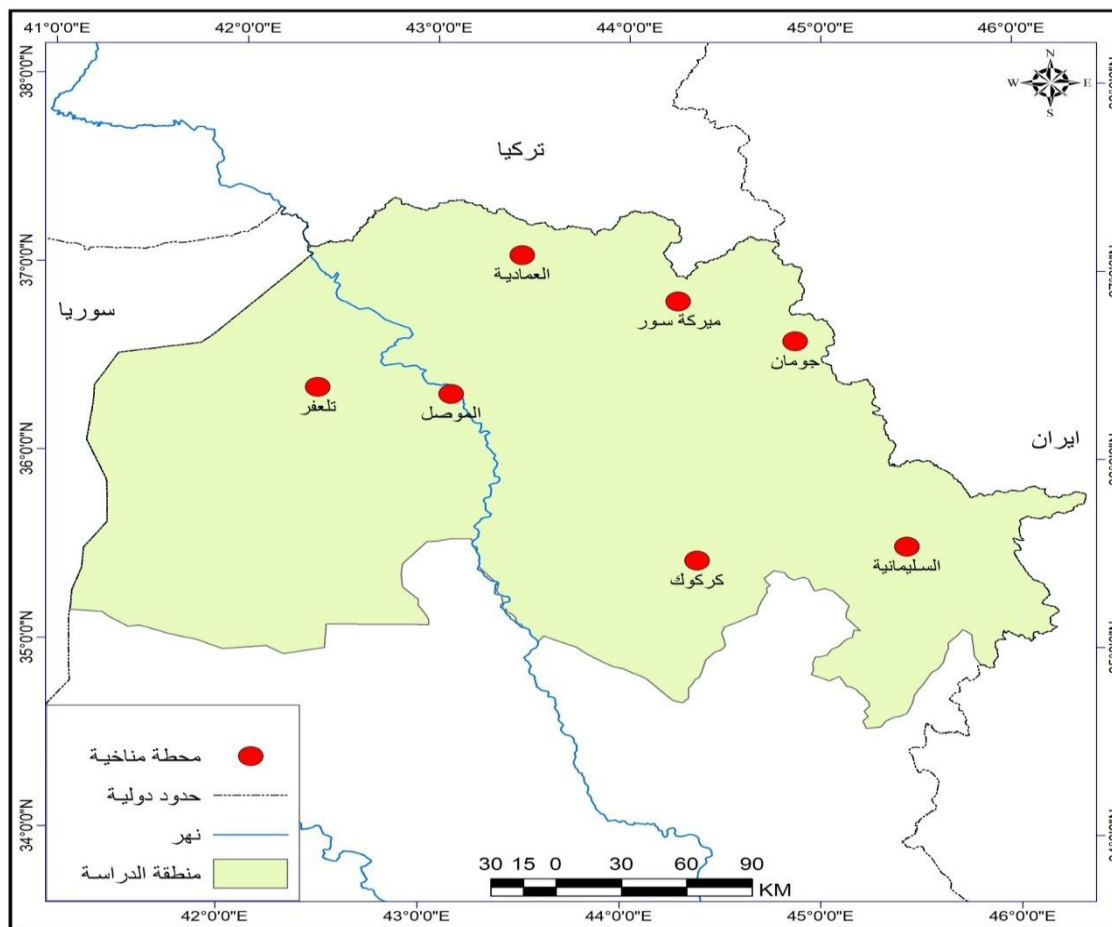
The East By Iran And To The West By Syria, While It Is Bordered To The South By The Sedimentary Plain, And It Was Geographically Represented By The Mountainous And Undulating Region Of Iraq And The Northern Governorates Of Erbil, Dohuk, Sulaymaniyah, Mosul And Kirkuk. The Study Area Astronomically Extends Between Latitudes (34.77°) And (37.23°) North, And Between Longitudes (41.00°) And (46.34°) East. (3) The Study Also Required The Adoption Of Seven Climatic Stations. Ideally Distributed Over The Study Area To Calculate The Snow Cover Area In More Detail, As Shown In Table (1) And Map (1).

**Table (1): Weather Stations**

Stations	Longitude( E)	Latitude (N)	Height Of Sea Level(M)
Amadiyah	43° 29	37° 05	1202
Merkke Sur	44° 16	36° 51	1180
Chuman	44° 86	36° 63	3500
Tel Afar	42° 10	36° 37	273
Mosul	43° 15	36° 32	223
Sulaymaniyah	45° 45	35° 57	883
Kirkuk	44° 42	35° 45	331

**Source:** Researcher Based On: - Ministry Of Transport And Communications, General Authority For Meteorology And Seismic Monitoring, Climate Atlas Of Iraq (1971-2000), Part 1, 2012 - General Authority For Meteorology, Iraqi Kurdistan, Erbil.

**Map (1) The Climatic Stations Included In The Study**



**Source:** The Researcher, Based On:



- 1- The Ministry Of Transport And Communications, The General Authority For Meteorology And Seismic Monitoring, Iraq Climate Atlas (1971-2000), Part 1, 20122- Program. Arcgis 10.3
- 1- The Spatial Variation Of The Snow Cover Area In Northern Iraq:

The Study Area Witnesses A Spatial Variation In Terms Of Area Between The Meteorological Stations Included In The Study, As Well As Variation In The Climatic Controls Of Each Station, Such As The Geographical Location, The Astronomical Location, And The Station's Height Above Sea Level; Together, These Factors Led To The Creation Of Spatial Variation In The Area Of Snow Cover Between Meteorological Stations; In Order To Give A Clearer Picture Of The Area Of Snow Cover In The Study Area, The Area Of Snow Cover Was Calculated For Each Governorate, And Not Limited To The Meteorological Stations And The Area They Represent Within Those Governorates.

Table (2) Shows The Spatial Variation Of The Snow Cover Area Between The Northern Governorates; Dohuk Governorate Witnessed The Highest Annual Average Of The Snow Cover Area In The Study Area, Which Amounted To (5276.7) Km<sup>2</sup>; This Is Because Of The Governorate's Location In The Far North Of Iraq. In Addition To The Nature Of The Governorate's Topography, Which Greatly Contributed To The Governorate's Record Of The Largest Annual Rate Of Snow Cover. It Should Be Noted That This Snow Cover Area Represents (80%) Of The Total Area Of Dohuk Governorate, Which Is (6553) Square Kilometers. On The Other Hand, Kirkuk Governorate Witnessed The Lowest Annual Rates Of Snow Cover In The Study Area, As It Amounted To (753.8) Km<sup>2</sup>; This Is Due To The Predominance Of The Hilly Character Of The Surface Of The Governorate, As Well As Its Geographical Location To The South Of The Mountainous Region. The Percentage Of Snow Cover (7.9%) Of The Total Area Of Kirkuk Governorate. It Should Be Noted That The Governorate Of Erbil Recorded The Second Highest Annual Rate Of Snow Cover In The Study Area, As It Reached (4015.2) Km<sup>2</sup>; This Is Due To The Location Of The Governorate In The Northeastern Side Of The Study Area, Which Represents The Highest Area Above Sea Level, As The Highest Peak Of Jubailah In Iraq Appears, Mount Sheikha Dar (3611) Meters, And Mount Hulker (3607) Meters. The Snow Cover Area Constituted (26.6%) Of The Total Area Of Erbil Governorate, Amounting To (15074) Square Kilometers.

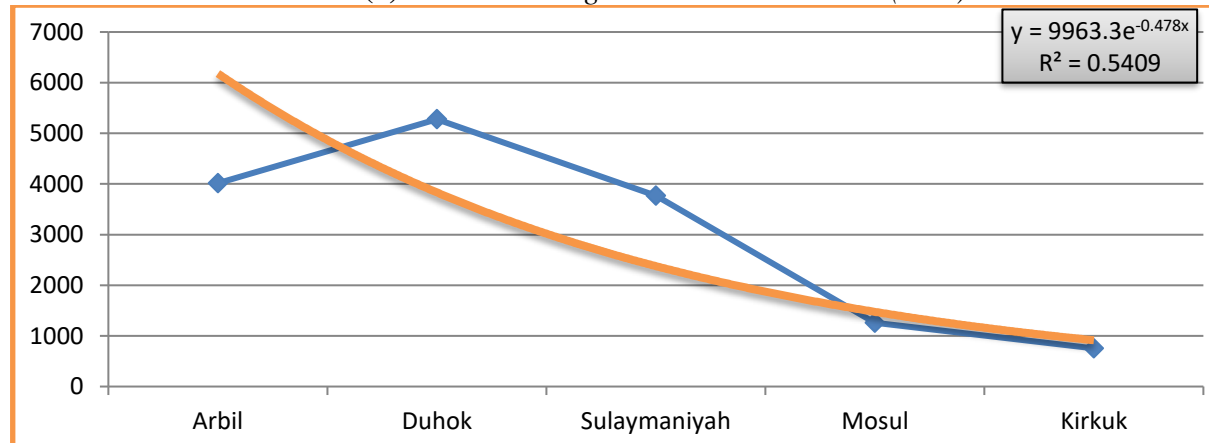
The Northern Governorates Also Witnessed A Variation In The Snow Cover Area At The Temporal Level. It Is Noted That The Dohuk Station Recorded The Highest Area Of Snow Cover In The Year 2011, As It Amounted To (6002.3) Km<sup>2</sup>, And It Constituted (91.6%) Of The Total Area Of Dohuk Governorate, While The Lowest Area Of Snow Cover Witnessed In Dohuk Governorate Amounted To (4389.7) Km<sup>2</sup>, In The Year 2020, A Problem Thus, It Accounts For (67%) Of The Total Area Of Dohuk Governorate. On The Other Hand, The Kirkuk Station Witnessed The Highest Area Of Snow Cover, Which Amounted To (857.5) Km<sup>2</sup>, In The Year 2011, At A Rate Of (9%) Of The Area Of Kirkuk Governorate, While The Lowest Area Of Snow Cover In Kirkuk Governorate Was (627.3) Km<sup>2</sup>, In The Year 2020, At A Rate It Reached (6.6%) Of The Total Area Of Kirkuk Governorate. See Table (2).

**Table (2)** Snow Cover Area (Km<sup>2</sup>) In the Study Area The Year (2011-2020)

Area	Total Area (Km <sup>2</sup> )	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Annual Average
Arbil	15074	4429.9	4378.72	4156.88	4088.62	3952.1	3866.78	3781.46	4361.64	3627.88	3508.4	4015.2
Duhok	6553	6002.325	5912.76	5524.54	5405.085	5166.175	5016.865	4867.555	5882.87	4598.79	4389.7	5276.7
Sulaymaniyah	17023	4287.375	4223.4	3946.1	3860.775	3690.125	3583.475	3476.825	4202.05	3284.85	3135.5	3769
Mosul	37113	1572.425	1534.04	1367.66	1316.465	1214.075	1150.085	1086.095	1521.23	970.91	881.3	1261.4
Kirkuk	9558	857.475	844.68	789.22	772.155	738.025	716.695	695.365	840.41	656.97	627.3	753.8
Annual Total	85321	17149.5	16893.6	15784.4	15443.1	14760.5	14333.9	13907.3	16808.2	13139.4	12542.2	15076.2

**Source:** The Recherche R Based On: - The Satellite Image Of Landseat 8 On (1-31 Janu In Year 2011-2020) And Arc Map GIS V10.

**Figure(1)** Annual Average To Snow Cover Area(Km<sup>2</sup>)



**Source:** Table (2)

### **Temporal Variation Of The Snow Cover Area In Northern Iraq**

The Snow Cover Area In The Northern Part Of Iraq Witnessed Temporal Variation; Due To The Variation In The Moving Climatic Controls Affecting Northern Iraq And Causing Snowfall, As Well As The Variation In The Climate Elements Accompanying Snowfall Spatially Between The Meteorological Stations Included In The Study, Which Is Based On The Variation In The Area Of Snow Cover Spatially Between Those Stations, As It Is Evident From Table (3-3 The Year 2011 Recorded The Largest Area Of Snow Cover, As It Amounted To (17149.5) Km<sup>2</sup>, And Represented (20.1%) Of The Total Area Of The Study Area For This Year, And The Percentage Of Snow Cover Area In This Year Was The Highest, Reaching (11.4%) Of The Total. Of Snow Cover Area During The Study Period. The Year 2020 Also Witnessed The Recording Of The Lowest Area Of Snow Cover During The Study Period, As It Amounted To

(12542.2) Km<sup>2</sup>, At A Rate Of (14.7%) Of The Total Area Of The Study Area In This Year, And At A Rate Of (8.3%) Of The Total Snow Cover During The Study Period. , It Should Be Noted That The Decrease In The Area Of Snow Cover In This Year And The Years That Preceded It Was Caused By The Climatic Changes That Affected The Study Area, Including The Decline In The Strength And Activity Of Air Depressions, Especially The Frontal Ones, Due To The Activity Of The Air Heights That Impede The Progress Of These Depressions That Cause Snowfall In The Study Area.

The Decrease In The Snow Cover Area Leads To Global Warming And An Increase In The Monthly Rates Of Temperature In The Study Area, With A Decline In The Totalitarian State That Creates Cold Clouds And Creates Opportunities For Snowfall. The Temporal Variation Of The Years Of Study Is Noted In The Standard Degree Of Snow Cover Area; It Is Noted That Five Years Recorded A Positive Standard Score For The Snow Cover Area, Which Is (2011, 2012, 2013, 2014, 2018), And The Highest Standard Score For The Snow Cover Area Was (1.4) Degrees Represented In 2011, While The Lowest Positive Standard Score For The Snow Cover Area Was (0.2). Degree And It Was For The Year 2014. While The Other Years Of The Study Period Witnessed The Recording Of A Negative Standard Degree For The Snow Cover Area In The Study Area; The Year 2020 Witnessed The Recording Of The Highest Negative Standard Score For The Snow Cover Area During The Study Period, Which Amounted To (-1.7) Degrees, While The Year 2015 Witnessed The Recording Of The Lowest Negative Standard Score For The Snow Cover Area During The Study Period, Which Amounted To (-0.2) Degrees. See Table (3) And Table (4)

**Table (3)** Snow Cover Area (Km<sup>2</sup>) In The Study Area The Year ( January 2011-2020)

Cover Type	2011		2012		2013		2014		2015		2016		2017		2018		2019		2020		
	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	
Cover Land																					
Water	21586.2	25.3	20818.3	24.4	20562.4	24.1	19709.2	23.1	19282.5	22.6	18941.3	22.2	18429.3	21.6	21244.9	24.9	18173.4	21.3	17234.8	20.2	
High Lands	13907.3	16.3	13907.3	16.3	13907.3	16.3	13907.3	16.3	13907.3	16.3	13907.3	16.3	13907.3	16.3	13907.3	16.3	13907.3	16.3	13907.3	16.3	
Free Lands	8361.5	9.8	9811.9	11.5	10921.1	12.8	11177.1	13.1	12200.9	14.3	12712.8	14.9	13566	15.9	11347.7	13.3	14333.9	16.8	15869.7	18.6	
Low Lands	24316.5	28.5	23889.9	28	24145.8	28.3	25084.4	29.4	25169.7	29.5	25425.7	29.8	25511	29.9	22012.8	25.8	25766.9	30.2	25766.9	30.2	
Snow Cover	17149.5	20.1	16893.6	19.8	15784.4	18.5	15443.1	18.1	14760.5	17.3	14333.9	16.8	13907.3	16.3	16808.2	19.7	13139.4	15.4	12542.2	14.7	
Total	85321	100	85321	100	85321	100	85321	100	85321	100	85321	100	85321	100	85321	100	85321	100	85321	100	

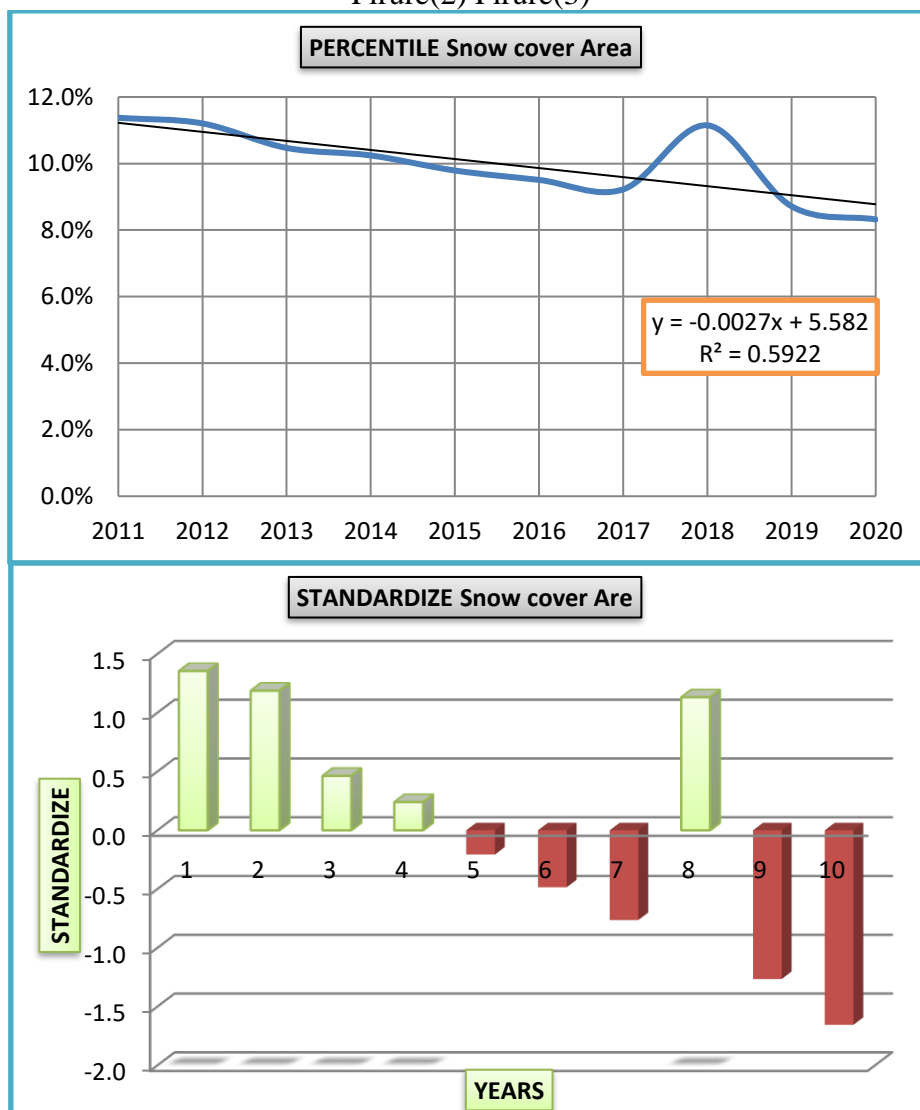
**Source:** The Recherche R Based On: - The Satellite Image Of Landseat 8 On (1-31 Janu In Year 2011-2020) And Arc Map GIS V10.8

**Table (4) Percentile Snow Cover Area(%)&Snow Cover Area(Km<sup>2</sup>)In (2011-2020)**

Year	Snow Cover Area(Km <sup>2</sup> )	PERCENTILE Snow Cover Area	STANDARDIZE
2011	17149.5	11.40%	1.4
2012	16893.6	11.20%	1.2
2013	15784.4	10.50%	0.5
2014	15443.1	10.20%	0.2
2015	14760.5	9.80%	-0.2
2016	14333.9	9.50%	-0.5
2017	13907.3	9.20%	-0.8
2018	16808.2	11.10%	1.1
2019	13139.4	8.70%	-1.3
2020	12542.2	8.30%	-1.7
Total	150762.1	100.00%	
Averag	15076.21	10.00%	
STDEVA	1530.583	1.00%	

Source: Table (4) & Program: SPSS

Firure(2) Firure(3)

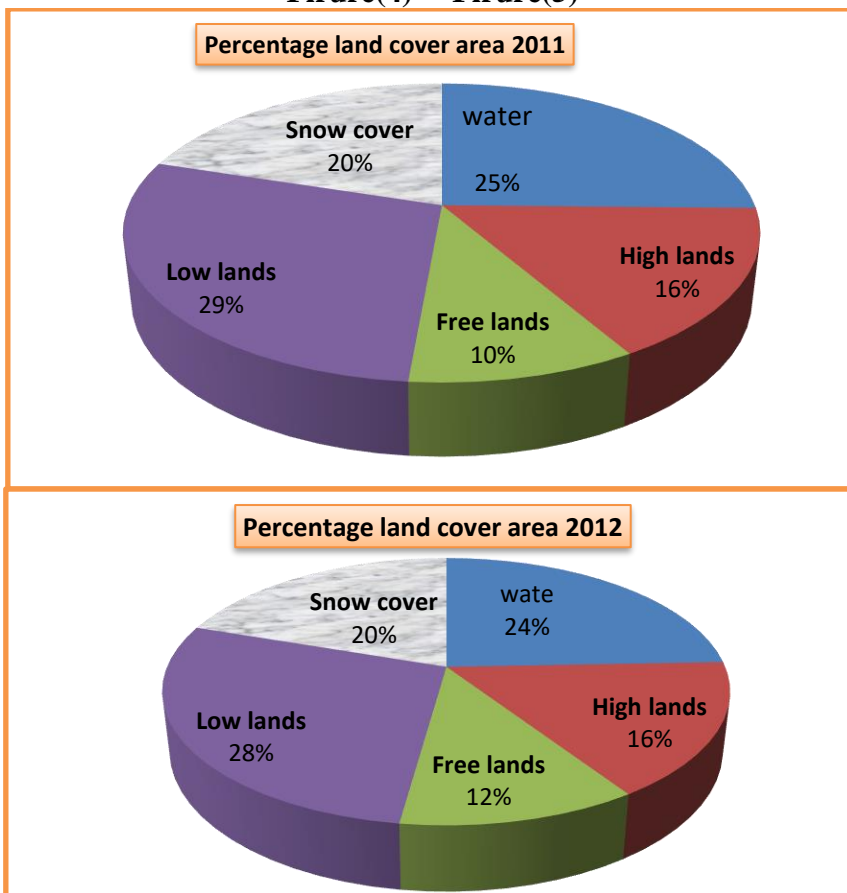


Source: Table (4)

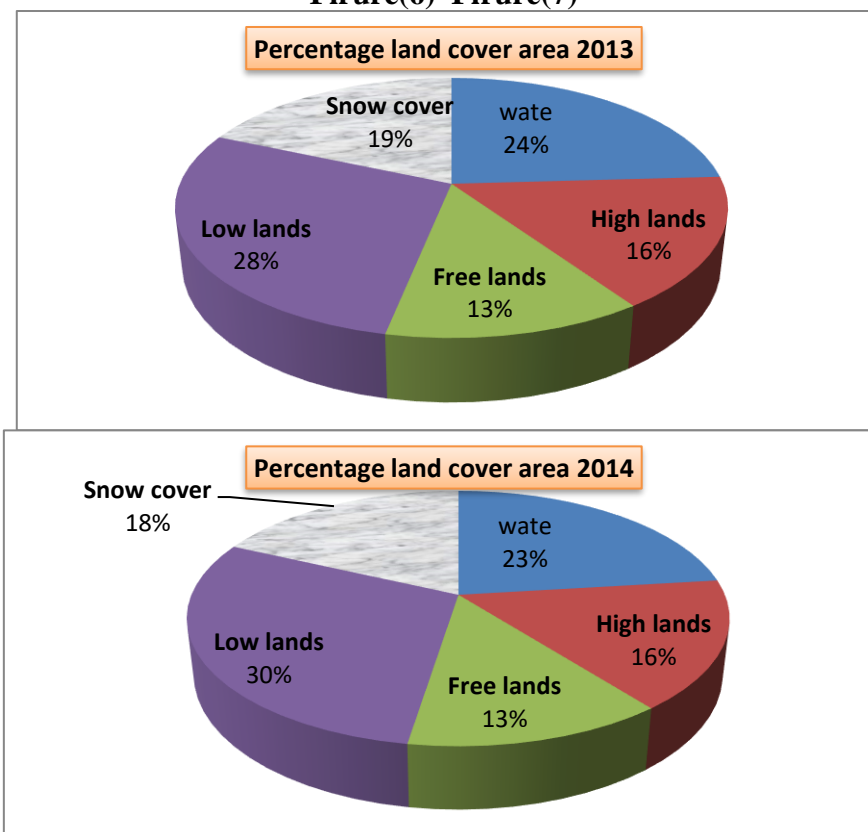
Source: Table (4)



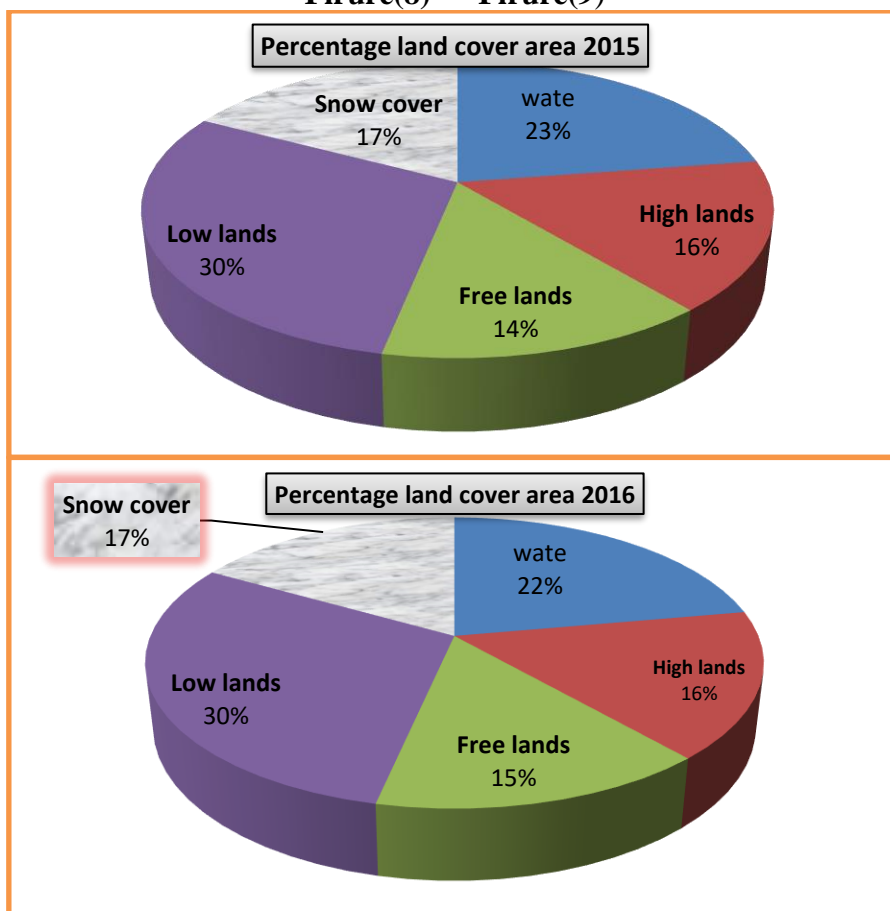
**Firure(4) Firure(5)**



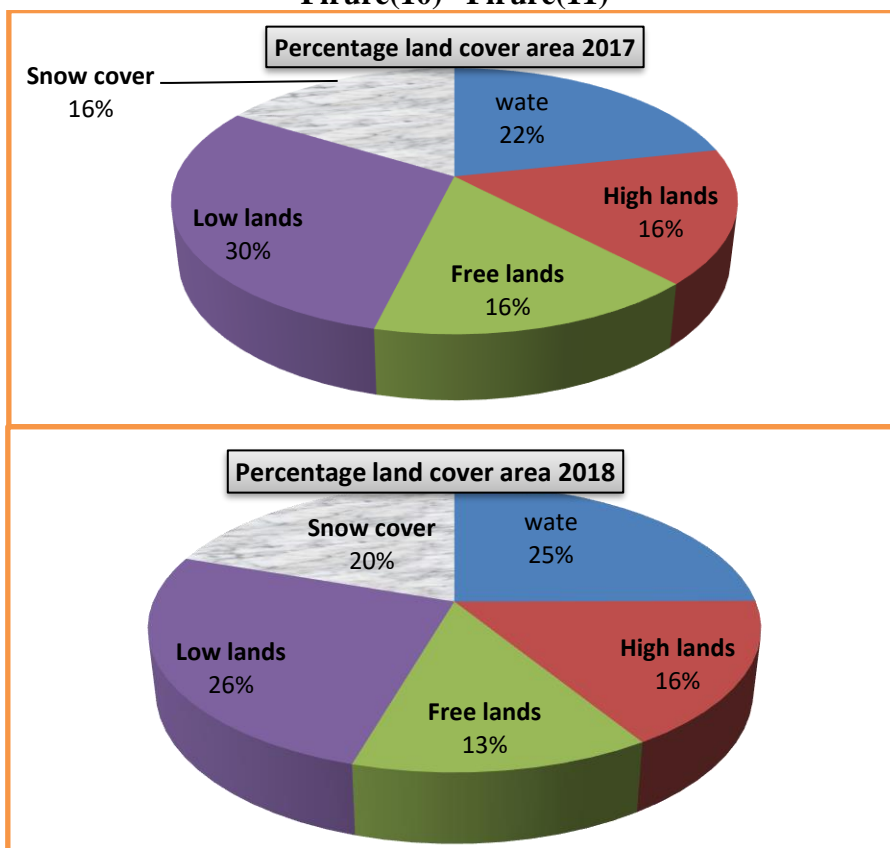
**Firure(6) Firure(7)**



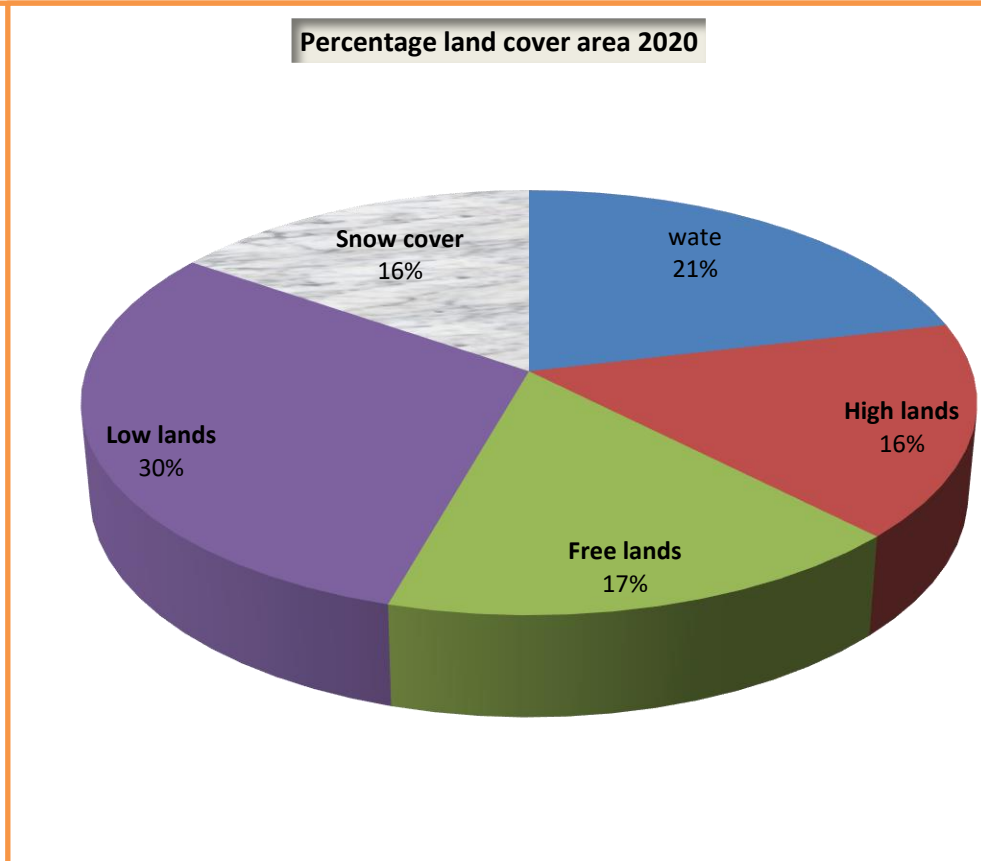
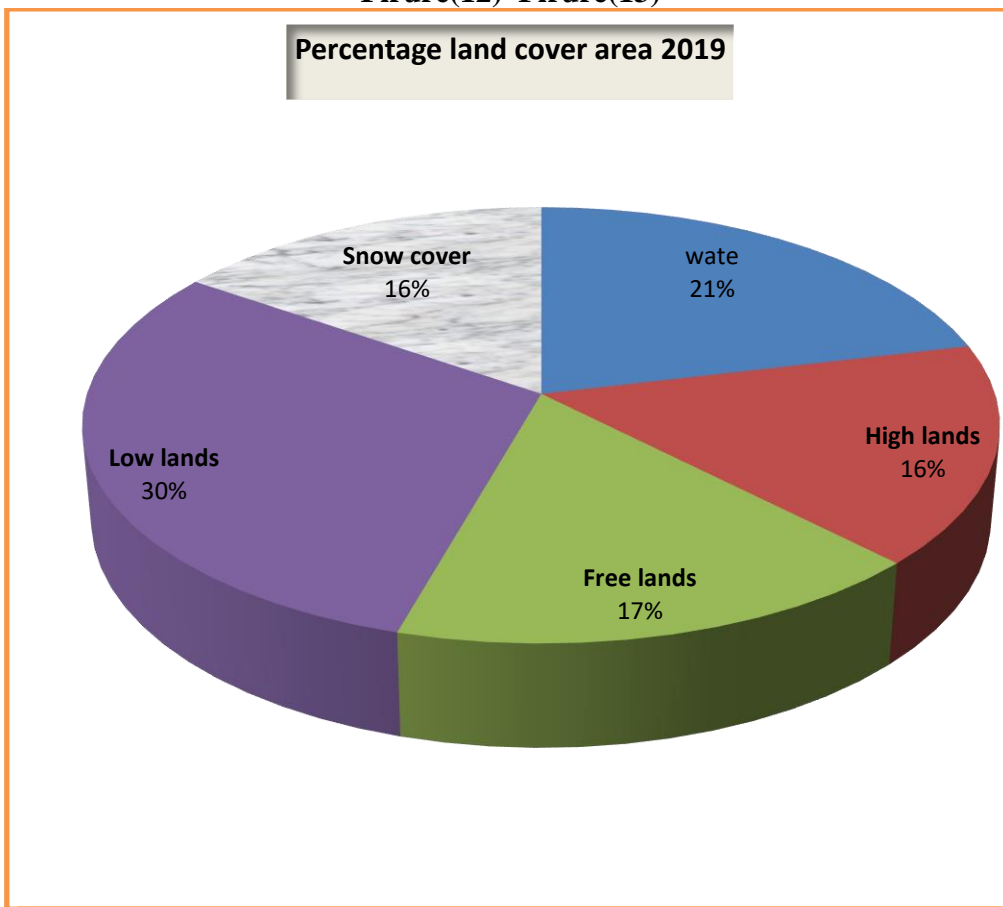
**Firure(8) Firure(9)**



**Firure(10) Firure(11)**

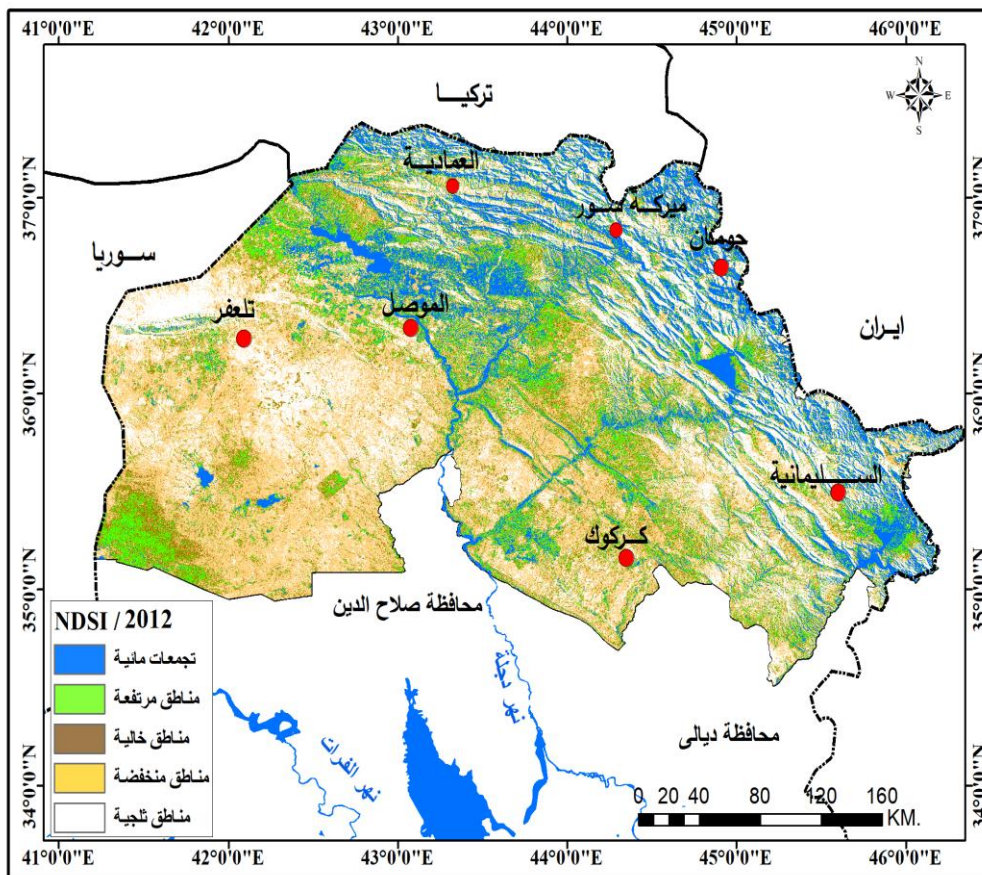
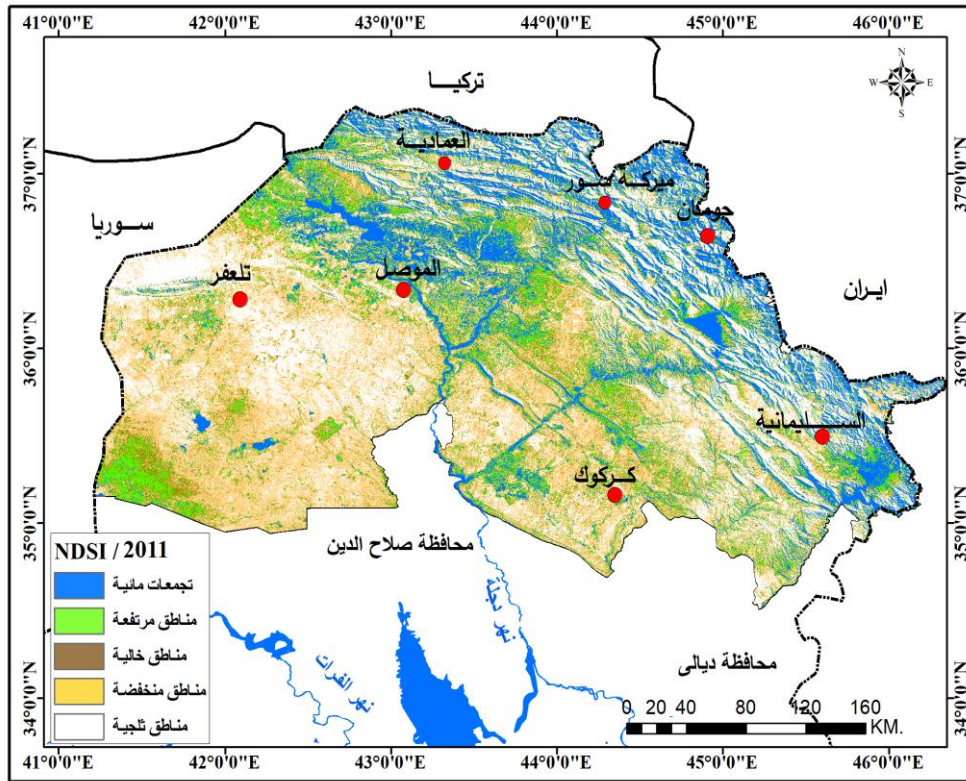


**Firure(12) Firure(13)**



Source: Table (3)

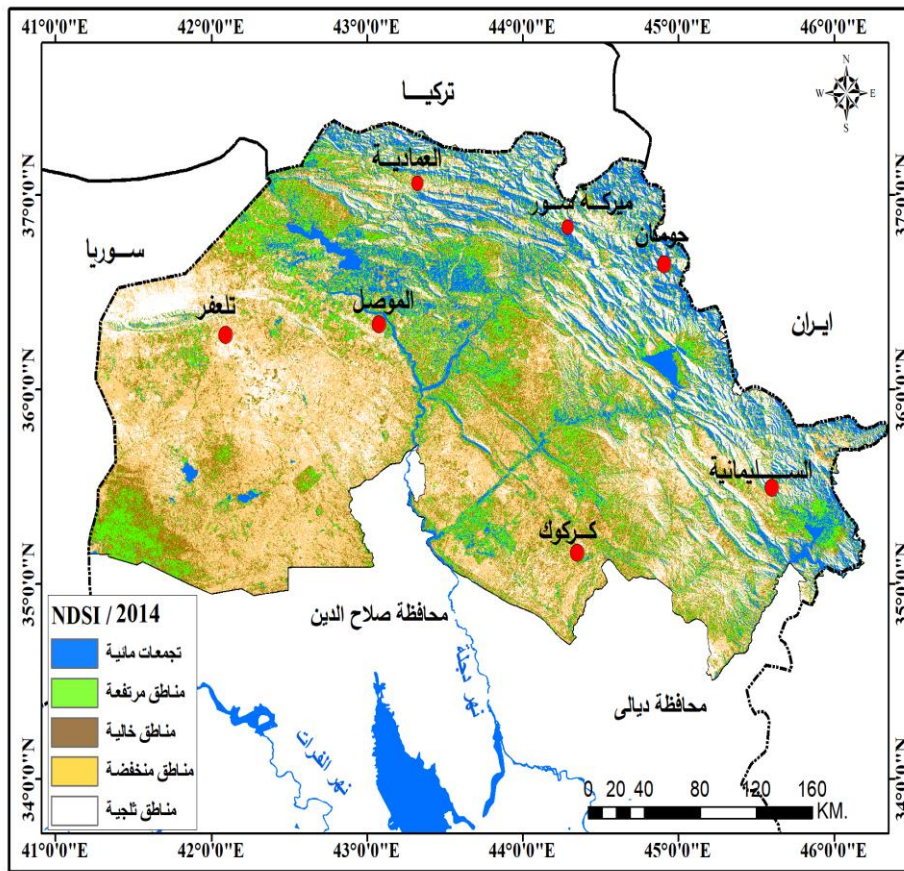
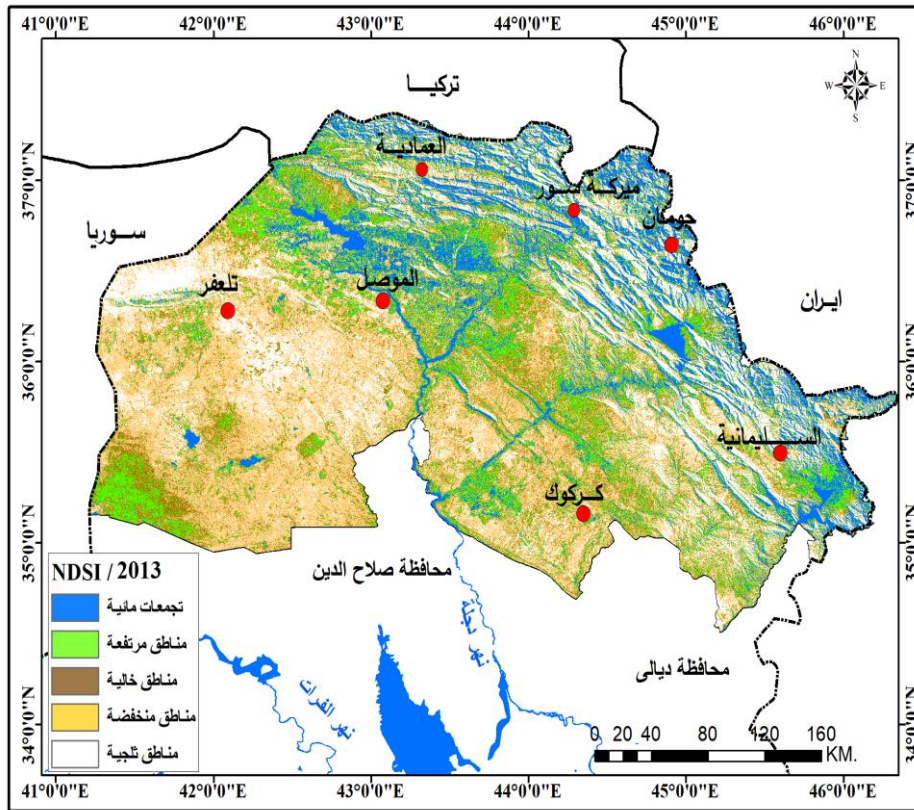
**Map(2) Average Snow Cover For January** **Map(3) Average Snow Cover For January 2012**



Source: The Researcher Based On: - The Satellite Image Of Landsat 8 & Arc Map GIS V10.8



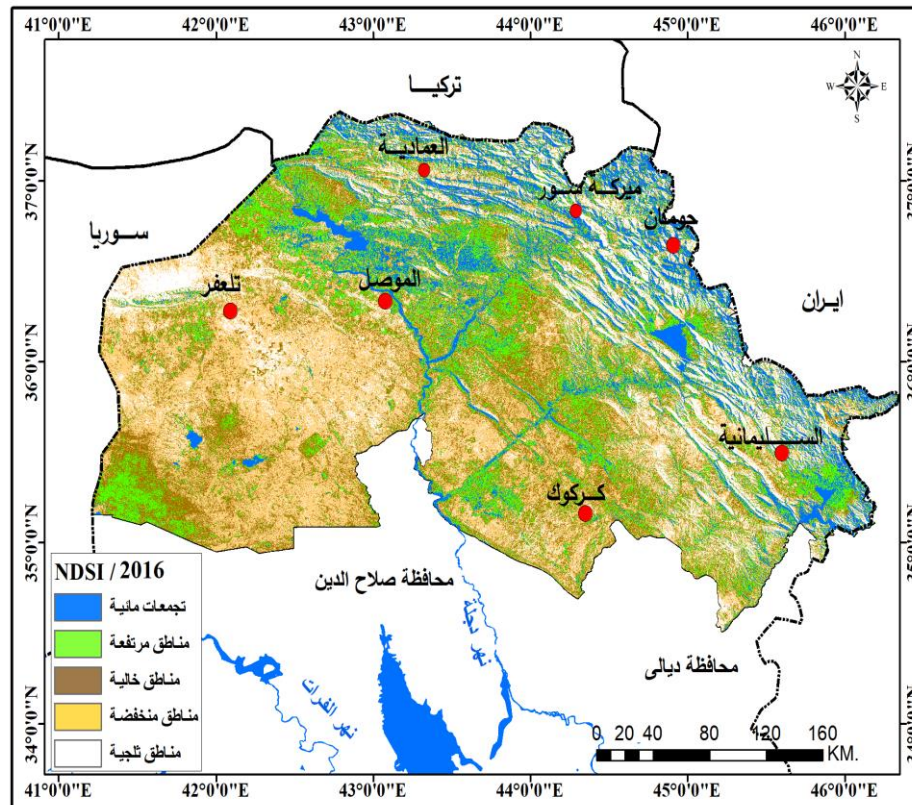
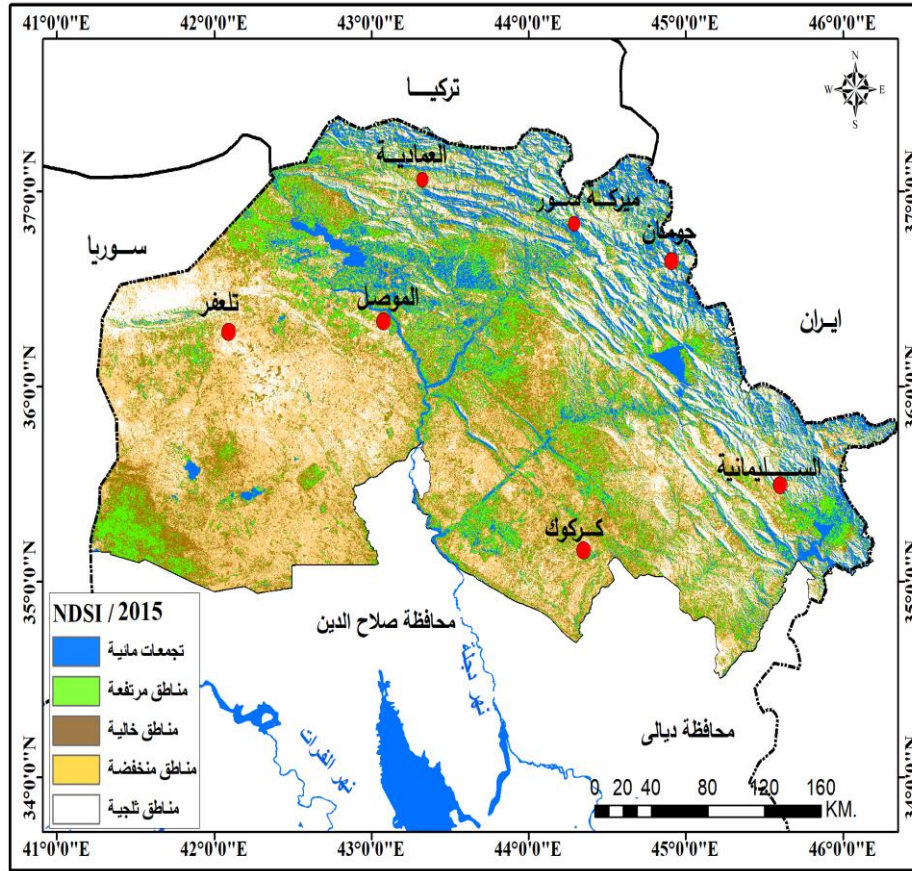
**Map(4) Average Snow Cover For January 2013**      **Map(5) Average Snow Cover For January 2014**





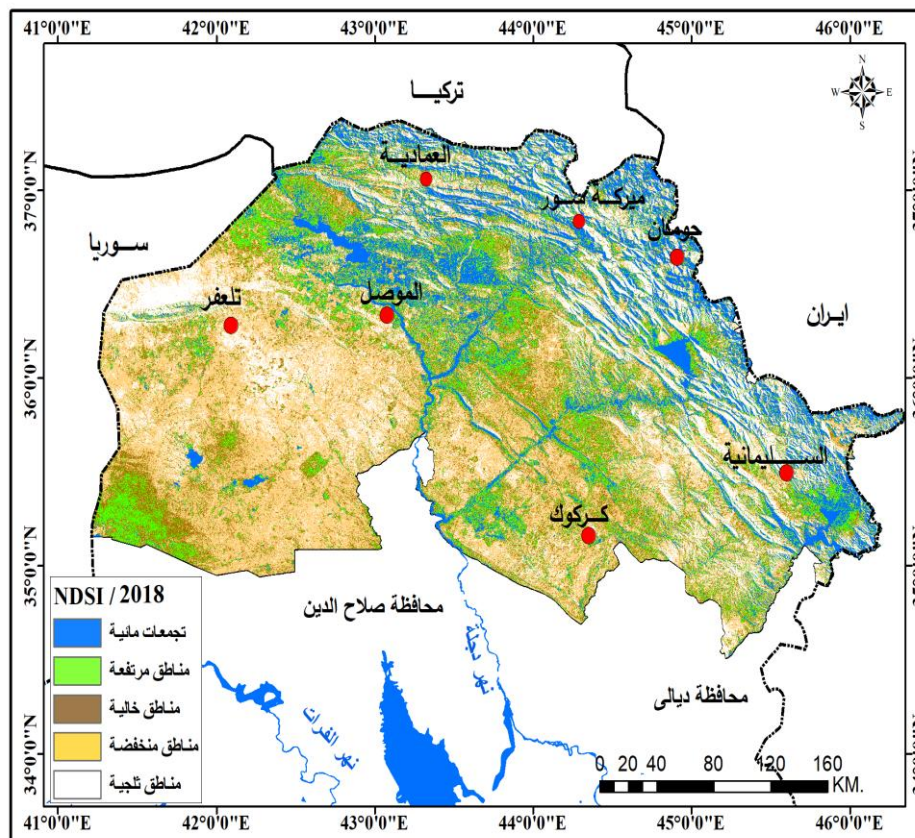
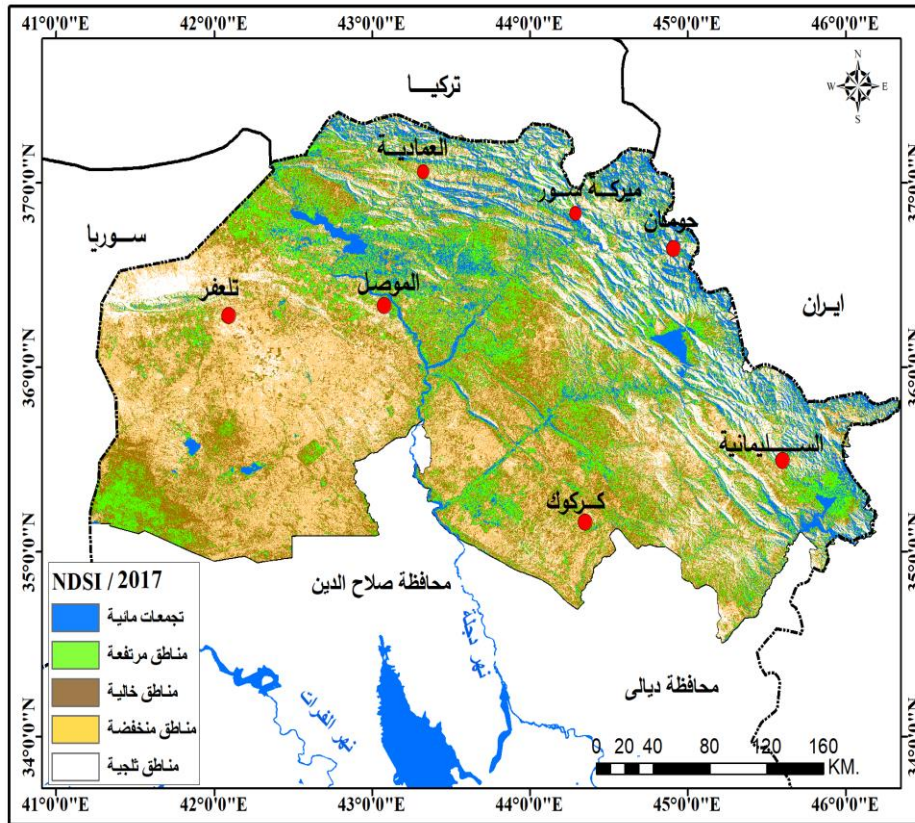
Source: The Researcher Based On: - The Satellite Image Of Landsat 8 & Arc Map GIS V10.8

**Map(6) Average Snow Cover For January 2015**      **Map(7) Average Snow Cover For January 2016**



Source: The Researcher Based On: - The Satellite Image Of Landsat 8 & Arc Map GIS V10.8

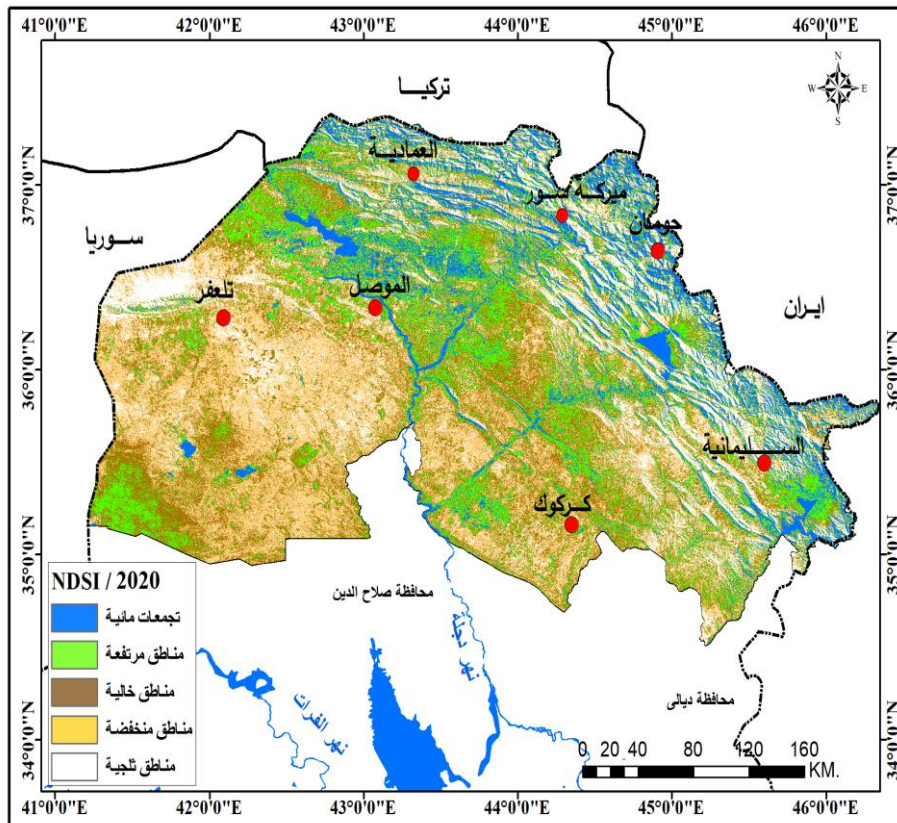
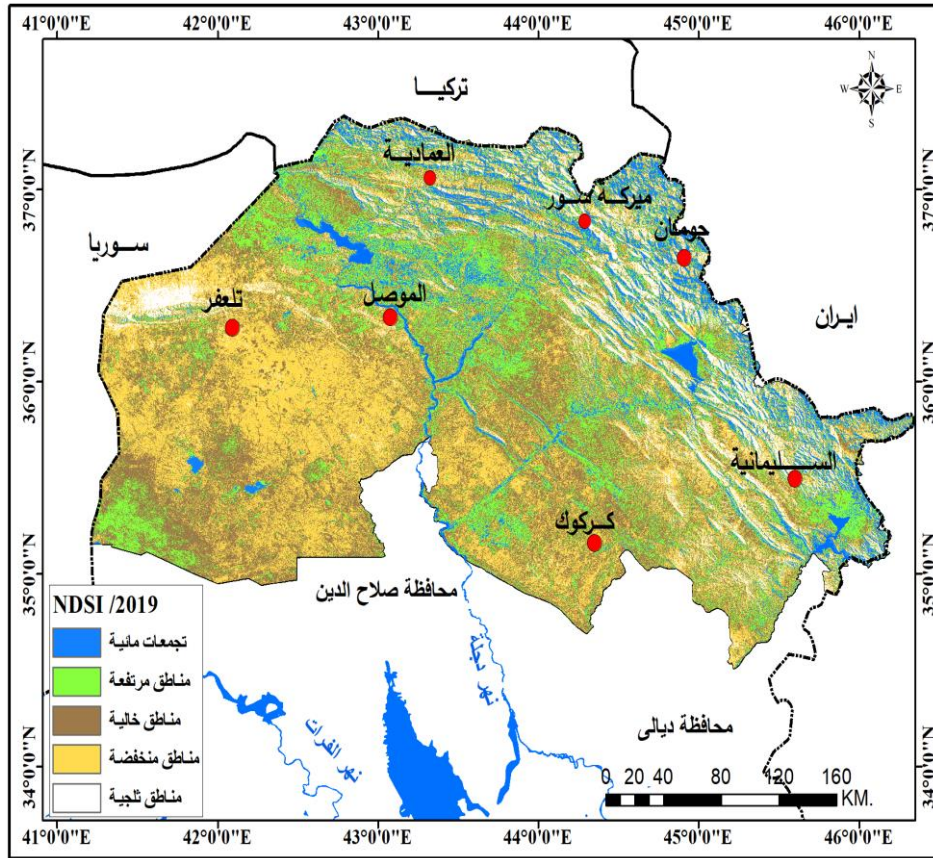
**Map(8) Average Snow Cover For January** **Map(9) Average Snow Cover For January 2018**





Source: The Researcher Based On: - The Satellite Image Of Landseat 8 & Arc Map GIS V10.8

**Map(10) Average Snow Cover For January 2019**      **Map(11) Average Snow Cover For January 2020**



**Source:** *The Researcher Based On: - The Satellite Image Of Landsat 8 & Arc Map GIS V10.8*

## **Conclusions**

- 1- The Study Area Witnessed Spatial Variation In The Annual Averages Of The Snow Cover Area; Dohuk Governorate Recorded The Highest Rate Of (35%) Of The Total Snow Cover Area In The Study Area, While Kirkuk Station Witnessed The Lowest Annual Percentage Of The Average Snow Cover Area In The Study Area, Which Amounted To (5%).
- 2- 2- The Snow Cover Area Witnessed A Temporal Variation During The Study Period; The Satellite Visuals For The Month Of January Showed That The Year (2011) Recorded The Highest Area Of Snow Cover In The Study Area, As It Amounted To (17149.5) Square Kilometers, With A Rate Of (11.4%) Of The Total Area Of Snow Cover In January Of The Study Period, And Thus This Year Recorded The Highest A Standard Score For The Snow Cover Area Amounted To (1.4), On The Other Hand, The Year (2020) Recorded The Least Snow Cover Area During The Study Period, As It Amounted To (12542.2) Km 2, At A Rate That Constituted (8.7%), And It Also Recorded The Lowest Standard Score, Which Amounted To (-1.7).
- 3- 3- The Study Area Witnessed A Decline And Shrinkage In The Area Of Snow Cover In The Study Area Due To The Decline In The Effect Of The Pressure Systems Responsible For The Frequency Of Snowfall, As Well As The Impact Of Global Warming And Climate Changes.

## **Margins**

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