STM JOURNALS

Research & Reviews: Journal of
Space Science & Technology
https://journals.stmjournals.com/rrjosst

ISSN: 2321-2837 (Online)
ISSN: 2321-6506 (Print)
Volume 13, Issue 2, 2024
May–August
DOI (Journal): 10.37591/RRJoSST

Review RRJoSST

Geospatial Measurement of Shrinking Lake Mead Using Multi-Temporal Datasets From 1987 to 2020 and Its Relationship with the Climate Change

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Abstract

The study provides an overview of the relation between climate change and its harsh consequences, and thereby revealing evidence of extremes conditions such as drought. Lake Mead of USA is one such example which is a readily contracting lake. The reason is fast temperature increment, human exploitation, etc. therefore leading to jeopardized and devastating effects on life structure. GIS and Remote Sensing has emerged as an extraordinary key instrument for generating worldwide scientific information identified with different geo-environmental issues. Multi-temporal Landsat satellite imageries and meteorological data of 1987, 1997, 2007 and 2020 are adopted in the study. The Modified Difference Water Index (MNDWI) is taken into consideration. Reported reasons behind the shrinkage are the tenacious dry season and overusing the lake water. The average precipitation of the lake during 1985–2015 is 1.4mm, and average annual temperature of Arizona is 33.34 °C and the temperature can go up to 40°C; extreme temperature and less rainfall leading to drought. The water inflow Colorado River has been less while the lake's outflow has been more, as most of the water evaporates due to high temperature. The consequences of overcharged water, intensified by the effects of climate change, are starkly visible in the "bathtub ring" of white minerals on the shores of Lake Mead, showing its decline from its highest water levels. If not looked into the matter, the temperature of the region would increase by 3°C. Protection of a lake from pollution or degradation is a major aspect of development as concluded.

Keywords: Geospatial, MNDWI, Climate Change, Lake Mead, Pollution, Degradation

INTRODUCTION

The increase of global CO_2 which surpassed alarming level of 400 ppm, leads to global warming, resulting in abrupt climate transformations, mainly due to human intervention (Garfin 2014) [6]. which includes high temperature, vanishing of lakes levels, low precipitation, and ice cover expanding etc., in late years. Lakes are esteemed accessible freshwater source on the Earth's surface due to their number of ecosystem benefits. As rising surface temperatures intensify evaporation over land and lakes, it reduces lake levels and surface areas, and are exacerbated by decreasing precipitation in many regions of the world. Contracting lakes will additionally disturb the simultaneous issue of deficiencies of food and water. A lake as 'a landlocked body of water occupying some kind of basin' (Ferrari 2008) [1]. For several decades now, the rapid shrinking of Lake Mead has become a subject of concern. Serious and maintained dry season will pressure water sources, effectively over-used in numerous zones, driving expanding rivalry among ranchers, energy makers, metropolitan

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Received Date: July 12, 2024
Accepted Date: July 26, 2024
Published Date: July 30, 2024

Citation: Suman Sinha. Geospatial Measurement of Shrinking Lake Mead Using Multi-Temporal Datasets From 1987 to 2020 and Its Relationship with the Climate Change. Research & Reviews: Journal of Space Science & Technology. 2024; 13(2): 11–17p.

occupants, and plant and creature life for the region's most precious resource which is water (McParland and Barrett 2009) [10]. The objective of the study is to assess the spatiotemporal change caused by climate change in Lake Mead and the climate factors leading to lake shrinkage and thereby causing extreme weather conditions due to very high temperature and evaporation. Integrated geospatial techniques using multi-temporal satellite data can detect changes in land and natural resources (Sinha and Santra 2019) [15].

STUDY AREA

Lake Mead is the largest manmade reservoir of USA operated and maintained by the Bureau of Reclamation. It is the largest reservoir in the United States by volume (3.5479 × 1010 m^3) and has the enough capacity to hold the entire average annual flow of the Colorado River for 2 years (Forsythe et al. 2012) [2]. The reservoir is an important source of water for millions of people in seven Western States and Mexico. The Lake is located between 36.25°N to -114.39°W in Clark County, Nevada and Mohave County, Arizona, Nevada (Figure 1). The man-made lake gets most of its water from snow soften in the Colorado, Wyoming, and Utah Rocky Mountains (Forsythe et al. 2012) [2]. In recent years studies show that the main source of water for Mead Lake, which is Colorado River, is evaporating due to an increase in temperature. About half of the 16% decline in the river's flow occurred during the stretch of drought years which was from 2000-2017 (Murray et al. 2009) [5]. Lake Mead shows recent annual evaporation exceeding 2m (Kennedy 2014) [4]. If the temperatures continue to increase and serious are not taken, drastic consequences can occur such prolonged period of drought which in return would take lives of living beings. location of Lake Mead map showing in Figure 1.

MATERIALS USED

To study the trends of shrinking lake data of both spatial and non-spatial are being considered as mentioned in Table 1. Inter-Annual Precipitation of Lake Mead Region from 1989-2019 are discussed in Table 2. The highest temperature of each year of Las Vegas of the selected time period for study are presented in Table 3. The average high temperature of spatial data's month of acquisition for every year of Las Vegas of the selected time period for study are mentioned in Table 4.

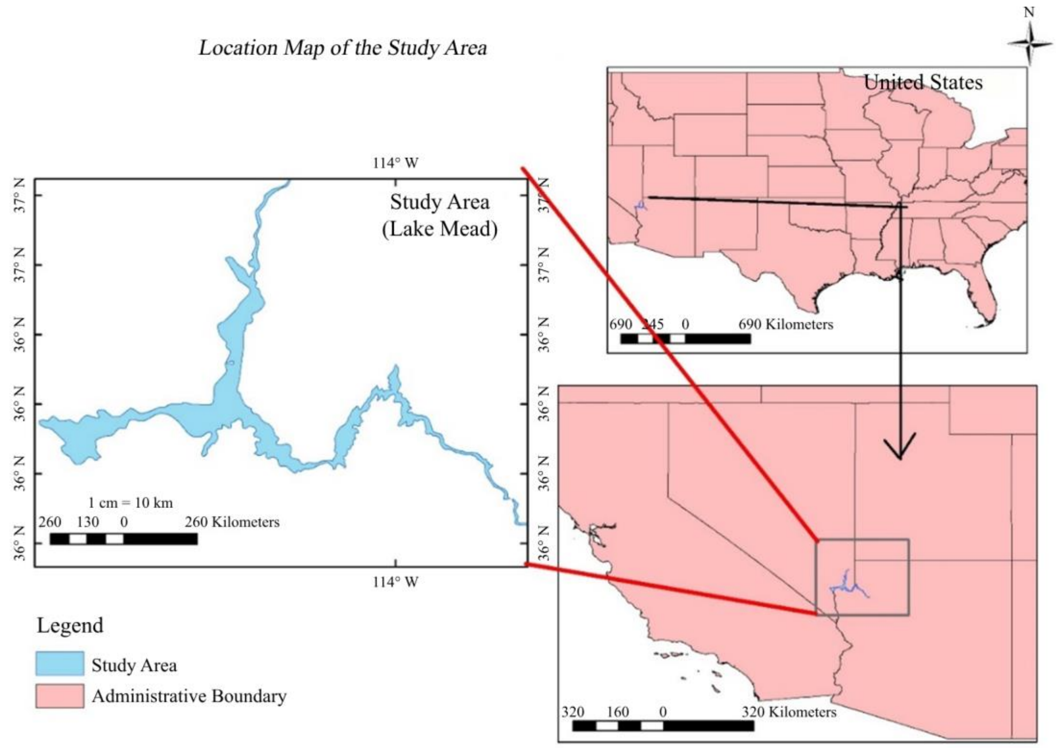

Figure 1. Map showing location of Lake Mead.

Spatial Data

Table 1. The satellite data and sources of each of the images that were used for this study.

Name of the lake	Satellite	Date of acquisition	Source
Lake Mead	Landsat 4-5 TM/C1/Level 1	22nd April,1987	USGS Earth Explorer (https://earthexplorer.usgs.gov/)
Lake Mead	Landsat 4-5 TM/C1/Level 1	3rd May, 1997	USGS Earth Explorer (https://earthexplorer.usgs.gov/)
Lake Mead	Landsat 4-5 TM/C1/Level 1	15th May, 2007	USGS Earth Explorer (https://earthexplorer.usgs.gov/)
Lake Mead	Landsat 8 OLI/ TIRS/C1/Level 1	5th July, 2020	USGS Earth Explorer (https://earthexplorer.usgs.gov/)

Non-Spatial Data

Table 2. Inter-Annual Precipitation of Lake Mead Region (1989-2019)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	19.71	22.47	20.12	6.12	11.42	8.9	15.39	11.41	4.52	46.8	43.87	15.56
1988	28.99	11.82	0.36	42.67	2.35	6.61	23.34	37.27	0.92	0.63	6.48	10.59
1989	27.92	7.81	6.9	0.04	7.82	0.38	12.9	22.04	2.31	5.96	0.1	2.04
1990	33.54	21.22	7.7	11.35	13.73	13.44	35.97	26.91	26.3	3.69	5.59	3.15
1991	20.57	20.07	46.38	0.09	13.97	1.42	13.48	13.46	15.71	7.46	10.06	23.7
1992	28.04	50.1	90.71	1.91	19.64	2.64	7.87	15.7	6.24	43.51	5.55	50.05
1993	95.44	107.28	31.08	3.58	7.53	10.89	1.71	11.76	6.96	9.07	25.3	9.82
1994	4.79	26.58	16.22	10.63	9.27	1.42	12.89	12.36	6.52	8.38	16.8	31.26
1995	68.89	23.13	35.76	16.48	17.62	10.72	7.45	7.98	9.99	3.65	5.54	8.5
1996	11.54	35.3	8.88	3.17	9.22	1.37	30.99	4.81	9.21	12.92	28.04	18.65
1997	36.22	10.65	3.91	7.02	2.75	5.2	13.23	20.18	57.87	3.76	12.83	8.93
1998	14.77	82.89	30.23	17.94	10.42	7.07	47.03	19.51	40.23	20.81	14.72	5.07
1999	10.07	11.66	2.98	34.54	6.92	18.31	54.74	12.31	18.92	1.3	1.34	1.27
2000	5.04	36.47	17.83	2.35	0.56	4.3	6.92	36.28	0.66	43.9	5.76	2.02
2001	36.9	38.77	24.88	11.83	1.38	0.59	15.53	22.01	1.73	3.15	8.51	11.9
2002	0.76	0.59	3.2	0.86	0.05	0.1	7.4	1.4	16.06	16.69	12.72	4.07
2003	2.39	56.62	29.16	20.27	2.72	0.04	9.01	29.12	9.57	0.9	17.68	14.35
2004	3.24	46.57	4.26	26.39	0.1	0.5	14.45	13.78	7	79.58	56.07	46.72
2005	71.22	81.29	18.23	19.24	3.8	4.58	21.25	36.81	0.65	31.39	4.09	0.83
2006	3.42	4.69	30.77	10.18	0.91	7.89	32.01	6.56	14.37	30.77	0.08	5.47
2007	4	8.78	2.24	5.34	0.51	0.79	44	20.85	23.47	1	29.49	26.19
2008	36.34	17.67	3.03	0.15	7.92	0.76	20.3	24.19	3.67	7.34	23.37	40.3
2009	10.79	30.16	0.43	7.88	1.94	3.12	19.53	8.07	8.35	0.68	2.66	23.38
2010	65.37	40.56	27.83	10.22	1.22	1.83	10.58	15.64	1.64	38.38	5.64	95.01
2011	0.69	34.66	9.21	9.58	9.72	0.06	23.28	5.06	18.31	30.58	13.52	11.51
2012	3.54	9.96	15.28	10.86	0.01	0.09	38.3	48.34	16.49	18.23	1.24	26.98
2013	16.28	6.75	6.86	2.65	1.54	0.24	22.73	31.64	41.51	6	29.27	2.37
2014	1.81	10.64	1.9	8.36	0.55	0.02	26.34	39.8	44.86	0.54	1.58	22.14
2015	18.67	11.66	22.86	5.24	21.02	7.99	26.14	22.18	6.13	31.8	9.08	6.85
2016	36.45	3.5	3.72	39.67	7.76	6.51	20.89	31.23	15.73	9.16	10.42	52.42
2017	47.26	23.99	6.78	2.82	6.64	0.02	55.54	26.86	20.77	0.03	0.05	0.6
2018	1.05	0.43	0.7	0.04	0.16	0	1.33	0.77	0.17	1.01	0.33	0.14
2019	1.27	2.65	0.82	0.48	1.18	0.05	0.19	0.1	0.22	0	2.63	1.25

Source: https://power.larc.nasa.gov/data-access-viewer/

Table 3. Highest temperature of each year of Las Vegas of the selected time period for study.

Year	Highest temperature (°C)	Year	Highest temperature (°C)
September 06, 2020	45	July 11, 2003	46
August 05, 2019	45	July 13, 2002	45
July 25, 2018	46	July 02, 2001	45
June 20, 2017	47	June 15, 2000	45
July 28, 2016	46	July 01, 1999	44
June 27, 2015	45	July 16, 1998	47
July 23, 2014	44	July 16, 1997	43
June 30, 2013	47	July 24, 1996	45
July 11, 2012	46	July 29, 1995	46
August 24, 2011	44	June 30, 1994	46
July 18, 2010	45	August 02, 1993	46
July 18, 2009	45	August 19, 1992	44
July 08, 2008	44	July 05, 1991	44
July 05, 2007	47	July 01, 1990	44
July 15, 2006	45	July 19, 1989	46
July 19, 2005	47	July 17, 1988	44
August 11, 2004	44	July 14, 1987	44

Source: https://www.currentresults.com/Yearly-Weather/USA/NV/Las-Vegas/extreme-annual-las-vegas-high-temperature.php

Table 4. Average high temperature of spatial data's month of acquisition for every year of Las Vegas of the selected time period for study.

Year	Month	Temperature (°C)
1987	April	28
1997	May	35
2007	May	32.77
2020	July	40

Source: https://www.climatespy.com/

METHODOLOGY

The relevant data, collected from different sources, and has been divided into two types; spatial data and non-spatial data. In the case of spatial data, four years of satellite data has used between 1987-2020 time period with 10 years interval. All the satellite images (Landsat 4-5 TM; 1987, 1997, 2007), (Landsat 8 OLI/ TIRS; 2020) was downloaded from USGS earth explorer. When it comes to non- spatial data collection, various websites are taken into account. NASA power for range of precipitation of Lake Mead region, Current Results weather and science facts for highest temperature of each year of Las Vegas and climate spy for showing average high temperature of spatial data's month of acquisition for every year of Las Vegas are been referred. As the values of rainfall are not much fluctuating in the entire region since 1987 to 2020, the collected spatial data of the month July 2020 has been considered as we could not access the data of the same season as others due to high cloud coverage. methodology used to proceed the comparative analysis for each lake flow chart showing in Figure 2.

The database creation was done with the help of GIS software ArcMap version 10.4. Modified Difference Water Index (MNDWI) was applied to decide diminishing patterns in the lake surface region in determined time stretches. The Modified Normalized Difference Water Index (MNDWI) utilizes green and SWIR groups for the upgrade of untamed water highlights (Santra et al. 2020) [14]. It likewise decreases developed region includes that are regularly corresponded with vast water in different files.

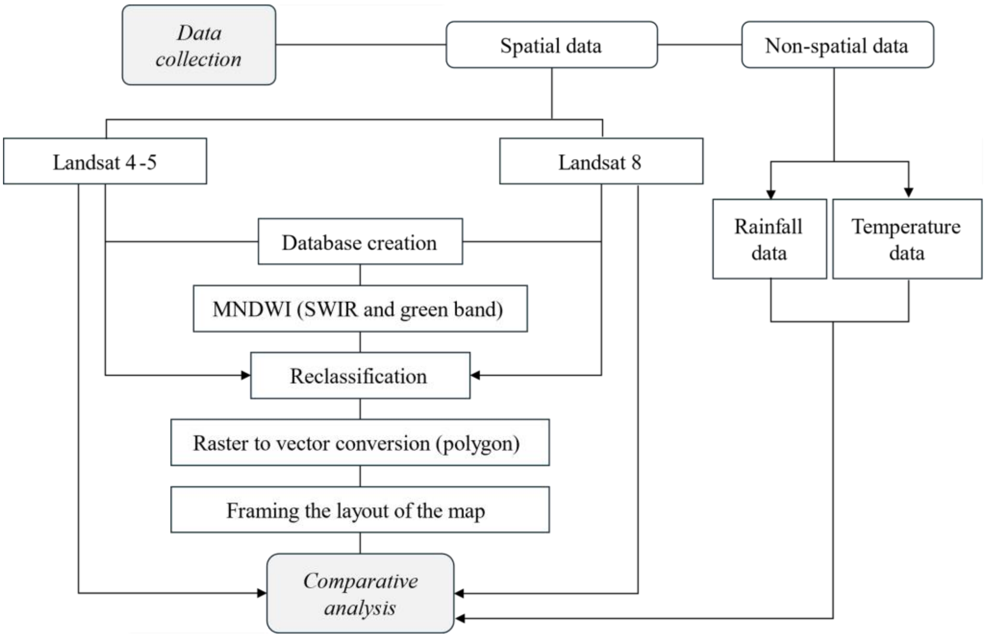

Figure 2. Flow chart showing the methodology used to proceed the comparative analysis for each lake.

MNDWI = (G -SWIR_1) / (G +SWIR_1)

where G is equal to green band and SWIR is equal to Short Wave Infrared band. The second phase of the work is reclassifying the information collected after calculating the digital indices. The data has been classified into water bodies and non-water bodies with indicators as 1 and 0 respectively. Thereby converting the data into shapefile and calculating the area in square kilometer. Figure 2 depicts the methodology flow.

RESULT AND DISCUSSION

In this study, images of the years 1987, 1997, 2007 and 2020 of the lake with an interval of 10 years has been taken in consideration to examine the shrinkage. Evidences from both spatial and non-spatial data has been collected to observe the variable trends of the lake. The man-made lake storing water, gives benefits to millions of people. Lake Mead is in an environment with a subtropical hot desert climate (Holdren and Turner 2010) [8] and falls under Köppen climate classification: BWh.

Firstly, considering the non-spatial data, it gives information of persistent increasing temperature and decreasing rainfall in the region. Arizona and Nevada basically has 4 seasons out of which July is monsoon, yet little rainfall is observed, as the area is in a condition of hot dry climate. The last time moderate rainfall observed was on 1999 in the month of July 54.74 mm and straight after 19 years in 2017 a good amount of rainfall was seen with 55.54 mm (Table 2). 2018 and 2019 goes through the worst phase with almost no rainfall. 0.52 and 0.89 is the annual rainfall for both the years respectively (Figure 4). In the considerate study time period that is 1987- 2020, most of the highest temperature month in seen in July (Table 3). To give a visual representation of temperature increase and rainfall an illustration is done for Tables 2 and 3, in Figures 3 and 4. Due to this high temperature increase with every preceding year the result is high rate of evaporation, leading to water loss. Moderate measure of evaporation from open surface waterbody is a basic and persistent interaction in the water cycle. In any case, if this measure of vanishing increment exceeds the moderate sum, the outcome is enormous volume of water misfortune. Highest temperature of each year of the selected time for study of Las Vegas graph showing in Figure 3 Precious water is vanishing into thin air which is great loss to population living in the area. As the states are anyway in shortage of precipitation due to the dry climatic pattern, the news of building a reservoir attracted rapid increase in urban growth. Various purposes like

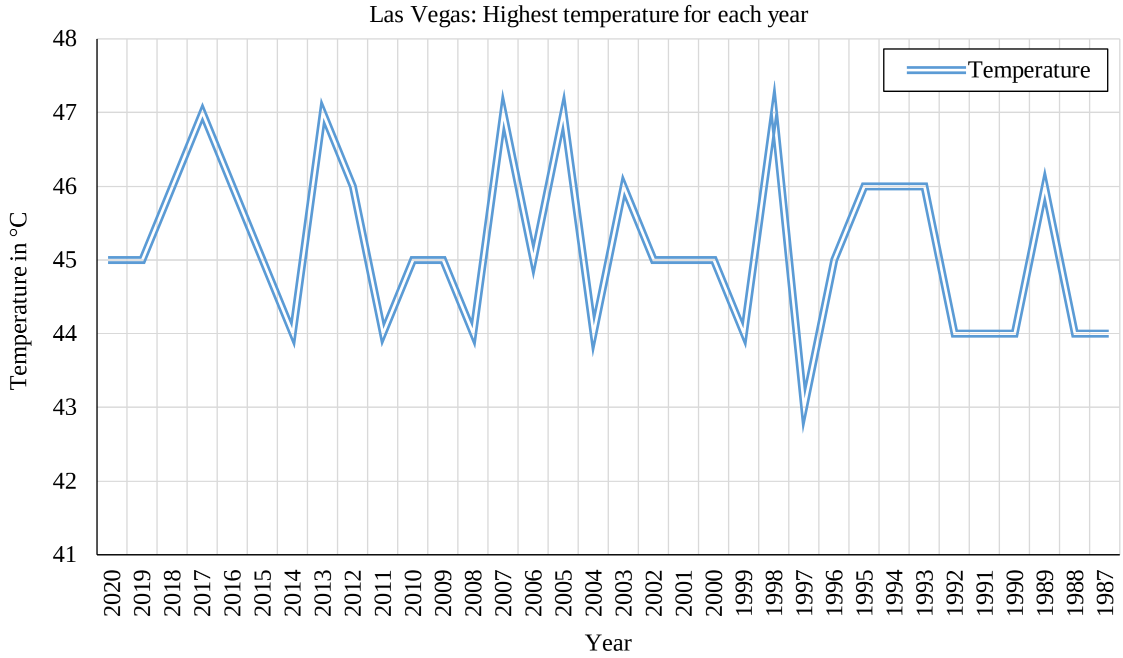

Figure 3. Graph showing highest temperature of each year of the selected time period for study of Las Vegas (refer to Table 3).

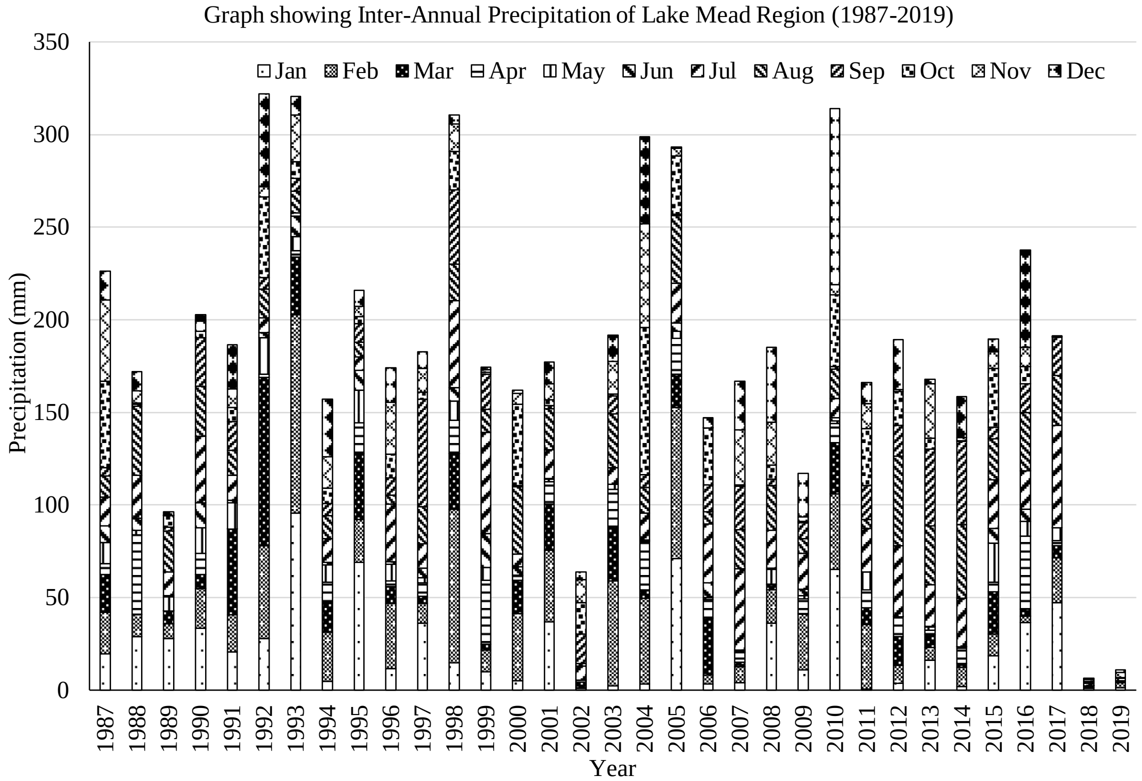

Figure 4. Graph showing Inter-Annual Precipitation of Lake Mead Region (1987-2019) (refer to Table 2).

irrigation, hydropower generation (Gutekunst 2019) [7], etc. were broadly used by people. Therefore, the rise in demand of water increases, which puts pressure on water quantity. Inter-Annual Precipitation of Lake Mead Region showing graph in Figure 4.

Taking into account the next set of information that is drawn from the spatial data. The area of every classified image has been broadly divided into two categories:

1. Water index indicated as 1 (water has positive value)
2. Land index indicated as 0 (other factors has zero or negative values)

The entire lake area covered 590.668 km^2, the average temperature of the month April is 28°C (Table 4) and the rainfall is 6.12 mm (Table 2), in the year 1987. It has been depicted in the classified image (Figure 5) that the lake was filled with water and no swamp, or any other land-cover occupied any part of the lake except water. From the figure, it is revealed that the lake water extended from the north to the south. For instance, some similar information related to the unconcerned change in the lake, was prepared by Ferrari (2008) [1]. The computed average inflow prior to closure of Glen Canyon Dam in 1935 through 1963, was 11,337,000 acre-feet. Lake Mead (1987) of Classified Image shown in Figure 5. It must be pointed out that from 1983 through 1987, the Colorado River drainage basin average inflow was 10,549,000 acre-feet therefore minimal impact to the annual water inflow (Lukas and Payton 2020) [9]. Therefore almost no shrinkage and the lake being large due to proper inflow by Colorado river. Lake Mead (1987) of Classified Image shown in Figure 5.

In the year 1997, the area of the lake was reduced to 560.28 km^2. The average temperature of the month May this year is 35°C (Table 4), along with rainfall 2.75 mm, (Table 2). The highest temperature of the year is in the month of July with 43°C (Table 3). In the classified image of the lake (Figure 6) not much change can be visible at a glance. Though a decrease in 5% has been witnessed when the area of the area of the lake was calculated. The lake's elevation was 1,081.77 feet—147.23 feet below capacity and 133.99 feet below its last peak in 1998 (Lukas and Payton 2020). The annual volume of water evaporated from Lake Mead exceeded 1.1 million acre-ft in 1998 and 1999 (Holdren and Turner 2010).

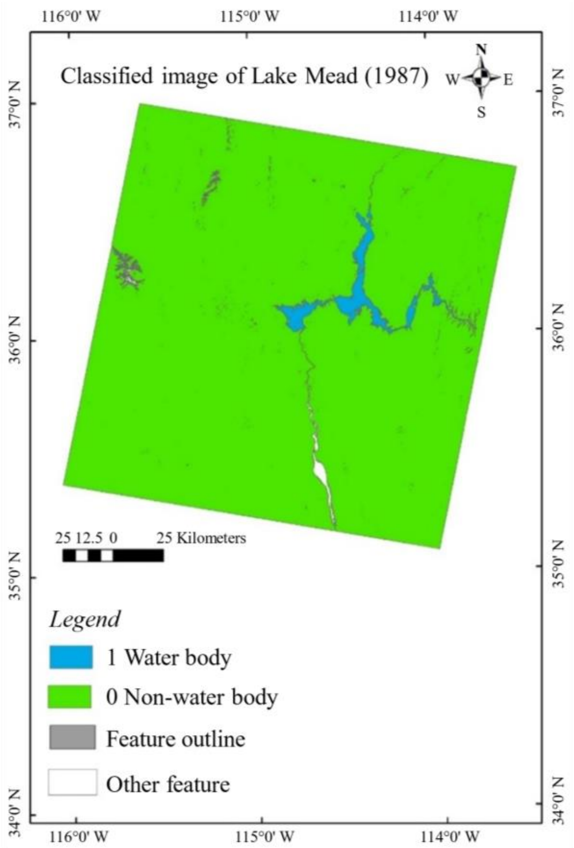

Figure 5. Classified image of Lake Mead (1987).

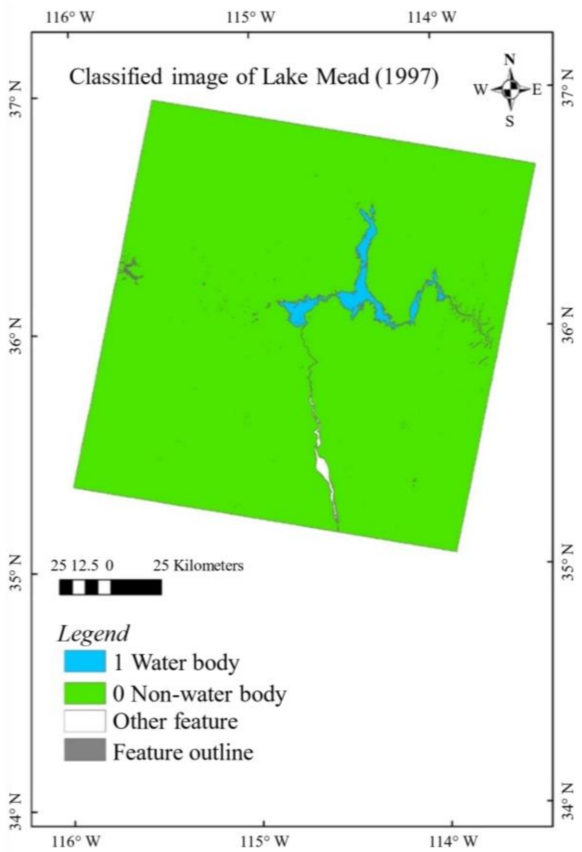

Figure 6. Classified image of Lake Mead (1997).

In the year 2007, the area of the lake drastically reduced to 376.51 km^2. In the classified image of the lake (Figure 7) we see a reduction from all over the lake area. The reduction can be viewed within no time. The average temperature of the month May is 32.77°C (Table 4), and the rainfall is 0.51 mm (Table 2), in the year 2007. A decrease in 48% has been witnessed from the year 1987. The highest temperature of the year is in July with 47°C (Table 3). The lake would shed more 12 feet to 1,075, or about 33% capacity, said by Brad Udall, director of the National Oceanic and Atmospheric Administration's Western Water Assessment program at the University of Colorado, to The New York Times in the section of energy and environment. Eight studies completed from 1991 to 2007, predict that climate change will reduce the snowpack runoff that feeds the Colorado River from 6% to 45% over the next half-century. Average annual evaporation at Lake Mead was 1,896 millimeters (6.22 feet). In 2020, the depreciation of the lake continued (Quinlan 2010) [13].

The entire lake area in 1987, which covered 590.668 km^2, shrank to 341.61 km^2 in 2020. The average temperature of the month July is 40°C and the rainfall is 2.5 mm (Table 2), in the year 2020. It has been seen that there is a perceptible change in the lake overall. From everywhere the lake the shrinkage has been seen in the classified image (Figure 8). A report from The Spokesman Review revealed agency's models project Lake Mead will fall below 1,075 feet for the first time in June 2021. That's the level that prompts a shortage declaration under agreements negotiated by seven states that rely on Colorado River water: Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming. At the beginning of 2020, Lake Mead levels are predicted to be at approximately 1,070 feet and then predicted to fall to as low as 1,053 feet in the summer of 2020. September 06, 2020, was the hottest day of the year with almost 46°C temperature (Table 4). The Bureau of Reclamation also projected that Lake Mead will drop to the point they worried in the past could threaten electricity generation at Hoover Dam which serves areas like Arizona, California and Nevada (Stern and Sheikh 2020).

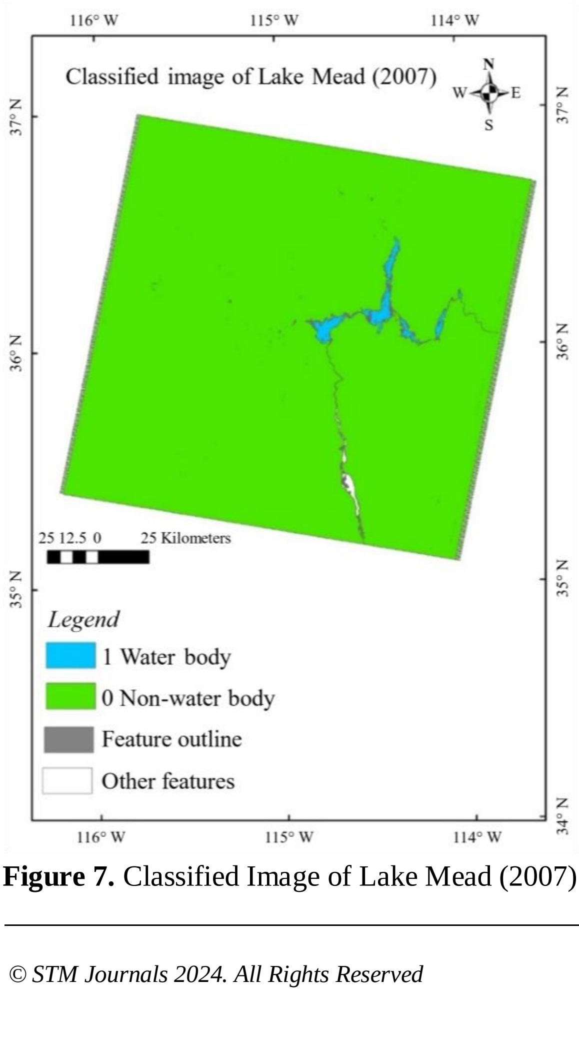

Figure 7. Classified Image of Lake Mead (2007).

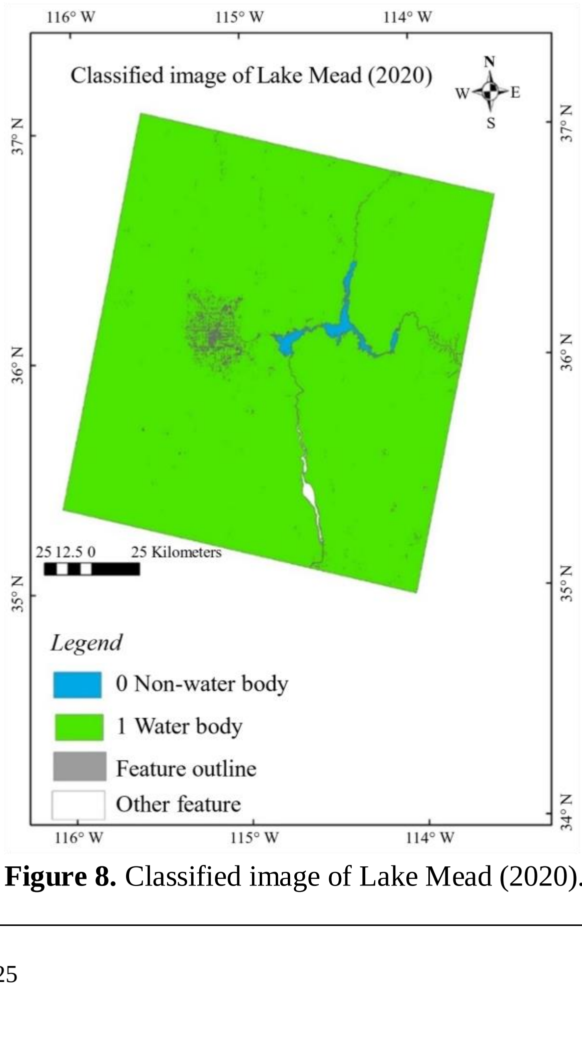

Figure 8. Classified image of Lake Mead (2020).

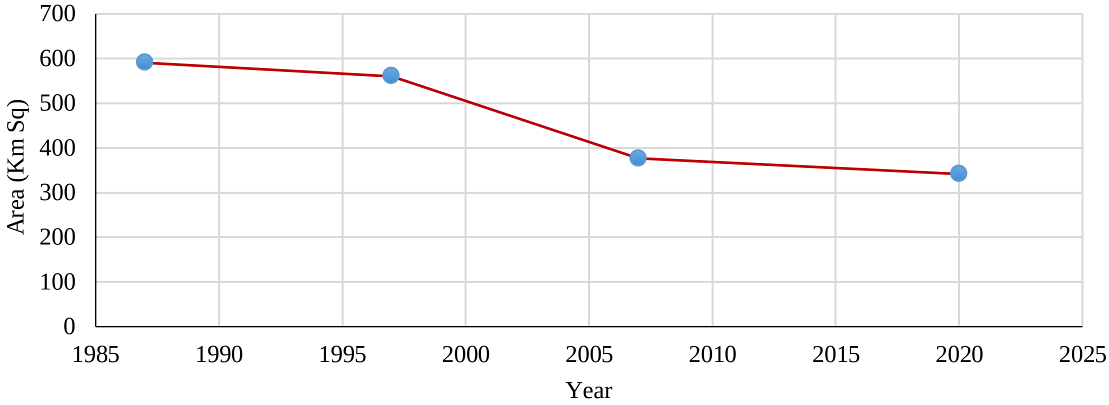

Figure 9. Graph Showing Trends of Shrinking Pattern in area of Lake Mead (1987-2020).

Variable trends in water level and lake area were observed throughout the analysis period, however progressively lower values were observed (Figure 9). The charts and images in this paper give evidence that environmental change is going on now and that it is affecting the accessibility of Colorado River water supplies. The consequences of overusing the water, intensified by the effects of climate change, are starkly visible in the "bathtub ring" of white minerals on the shores of Lake Mead, showing its decline from its highest water levels (Stern and Sheikh 2020). The 2020 State of the Science Report confirms that temperature trends in the Colorado River Basin are increasing and precipitation, snowpack water volume and annual stream flow trends are decreasing (Westenburg et al. 2006) [17]. As the rise decreases at the lake increases, the ability to produce power declines. The major effects target the people living in the rural areas of Arizona and Nevada as the hydropower electricity cost is considerably low than the wholesale electricity market (Stern and Sheikh 2020) [16].

Environmental change brings forth outrageous climate occasions and one of them is shortage of water. If not taken strict and sustainable measures at the nick point the expense of keeping up and improving drinking water would increase (Metz 2021) [11]. Preservation endeavors have demonstrated diminishing the use of water. Other than hydropower generation, electricity generation by geothermal, wind, and solar power can be considered. As the area is blessed with abundant renewable resources like sunlight, wind power generated by them lead to sustainable development as well as cost effective. The pressurizing factor over water used to produce power would be less. A significant development in the basin in 2007 was adopted for the Colorado River. Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead was made in response to drought in the Southwest and the decline in basin water storage. Under the guidelines, Arizona and Nevada, which have junior rights to California, would face reduced allocations if Lake Mead elevations dropped below 1,075 ft or the "trigger levels". Thus, beginning in 2020, Reclamation coordinated a review on the effectiveness of the 2007 guidelines. Forthcoming reconsultation on the 2007 guidelines also will encompass negotiations related to renewal of the Upper and Lower Basin Drought Contingency Plans (Moreo and Swancar 2013) [12]. Throughout the last 150 years, the American West is experiencing dramatic hydrologic change from environmental factors and anthropogenic activities. Fluctuating rainfall patterns, unpredictable climate, high levels of evaporation, declining snow melt runoff and current water use patterns are factors that put a strain on water management resources (James 2020) [3].

CONCLUSION

Climate change is a long-term change in the average weather. Increased warming, drought, and insect outbreaks, floods, all caused by or linked to climate change. In this paper, we can depict the main reason for shrinkage of the lake is due to increasing temperature and decreasing rainfall year by year, which at the end links to changing in climate Future dry seasons are projected to be generously more sweltering. Odds of more serious continuous, extreme, and longer enduring than in the authentic record in Colorado River Basin can be anticipated.

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