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Scenario behind the water color changed from green to pink/red of Lonar Crater Lake, Maharashtra, India

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ABSTRACT

Earlier Lonar Crater Lake water was green colored due to presence of green pigmented algae, and suddenly, it changed to pink/red by growing of pink/red pigmented organisms on the surface of the water. The cause could possibly be due to Fungus which survives on dead organic debris of aquatic life and decayed organic matter and which are capable to impart pink/red coloration to the water body. The news appeared in the newspaper Lokmat dated 11-6-2020, stating that the water of Lonar Crater Lake turned pink/red. Our postulation or our assumption is that the crater lake, being highly eutrophic, fungus growth may be possible on dead debris and decaying organic matter and pink color of growing fungus may have spread over the surface, which may have imparted pink/red color to the water body. Fungus is capable to produce pink red coloration. Since the first observation of the appearance of red pigmented algal bloom were observed on 9th November, 2019, by the authors of this paper as brownish pink coloration amidst the green algae on a large scale, and when the news about pink coloration of the lake first appeared in Lokmat dated 11-6-2020, it was felt necessary to study this phenomena in detail about the cause and the reasons for the pink coloration of the lake. This paper concentrates on fungus, which grows on dead debris of aquatic life. On the basis of earlier studies by different researchers, and the present situation of Lake, to search the answers to the questions, why the lake water looked pink/red colored, what are the causes and the reasons behind this phenomena? A detailed study was conducted and is reported and discussed in detail of the whole phenomena in this paper. Being of preliminary investigations, a small attempt has been made to search the answers to the above questions.

Keywords— Lonar Crater Lake, green algae, microorganisms, fungus growth pink/red coloration

1. INTRODUCTION

Lonar Crater is a meteorite impact crater formed some 656 ka (6,56,000 thousands years)⁽¹⁾. The crater was formed near Lonar village, in the Buldhana District of Maharashtra, having coordinates 19°58'N and 76°30'E. The crater depth is around 150 meters and the diameter of the crater is 1.83 km. Though the rim of the crater is circular in shape, the Crater Lake at the base seems to be oval in shape and how it was formed is unknown. The water of the Crater Lake is highly saline and also highly alkaline in nature, the pH of which is around 10.0⁽²⁾, making it one of the unique natural geological monuments, being of importance to academic and research purpose. The color of the lake water looks light green and dark green in color⁽²⁾, due to a kind of green algae, known as spirulina, floating on the water surface, being lighter than water and which are adapted to survive in this extreme environmental condition. The ecosystem of this lake is totally different from other lakes of saline and alkaline nature in the world, due to high salinity and high alkalinity existing at the same time and showing their characteristic features. There is no outlet, due to the rim holding the lake, has not been destroyed⁽³⁾, for the waters to drain out. There are two theories about the origin of the Lonar Crater. One is the volcanic eruption theory and the other is meteorite impact theory. The volcanic eruption theory supported by earlier researchers suggests that the Lonar Crater was formed due to crypto volcanic activity⁽⁴⁾. The meteorite impact theory is supported by latest researchers. Still the authors feel that the origin of Lonar Crater may possibly be through meteorite impact.

From ancient times, there have been human activities. There are temples situated on the periphery of the lake. Today these temples are found to be in ruined state. Since long, festivals, rituals, worship offerings by devotees were going on. Some agricultural activities were also going on, which has now been stopped completely. Many small-scale industries located in this religious place consisted of soap making, salt making, and glass manufacturing, bricks making etc., hence majority of the area of Lonar Crater were under industries and religious regime⁽⁵⁾ This water was taken by the locals for their business activity.

2. OBSERVATIONS

From prolonged observation of our study of Lonar Crater, it is observed that the thick scum of algae, always spread over the periphery of the water surface of the lake. Alkalinity and salinity of Lonar Crater water body is found to be fluctuating i.e., it is

highest in summer season and lowest in monsoon season⁽⁶⁾. The green pigmented algae is primary predominant, seen along the water surface, throughout the year. [fig. 5 (a) and (b)] This is a normal phenomenon seen and it is a permanent phenomenon. The observation of green algae growing on the water surface during the month of November i.e., on 9th November, 2019, the visiting authors of this paper, observed very thick and dense scum of algae, which covered large area. This seems to be the first appearance of red pigmented halophilic bacteria bloom in the form of brownish pink coloration as seen in the fig. [2 (a), (b), fig 3 (a), (b) and (c)]. The Algae seen on the water surface of Lonar Lake, not only showing green color, but also showing brownish pink color amidst green algae, hence it is a phenomenon to start a pink/red pigmentation. This pigmentation occupied the whole area of the water body and the water looked pink/red colored on 11-6-2020 (Fig. 8). Earlier this type of phenomena has never been observed.

3. RESULTS AND DISCUSSION

Information about Lonar Lake water suddenly looked pink/red in color, first appeared in Lokmat newspaper dated 11th June, 2020⁽⁷⁾, stating that the waters of Lonar Lake suddenly looked pink/red color⁽⁷⁾ (fig. 8). The opinion or views of Dr. Kanekar (scientist)⁽⁷⁾ and Dr. Khadse (scientist - NEERI)⁽⁸⁾ is halophilic bacteria (salt loving) and halophilic archaea, which are photosynthetic organisms and which are capable to produce beta carotenoid, pink pigment, responsible for imparting pink/red coloration to the water body, where high concentration of NaCl salts are found^{(7) (8)}. It is assumed that these microorganisms may have been transported or carried through migrating birds, since long time, the mechanism of transportation of microorganisms may be going on unknowingly, these foreign species may have adapted high salinity and high alkalinity of the Crater Lake and hence the bloom of species growing is observed which are capable to produce carotenoid a red pigment and attribute pink color to the water body which is a biological phenomenon.

Halophilic bacteria (salt loving) or halophilic archaea^{(7) (8)}, to come to Lonar Crater Lake, and on blooming on large scale, imparting pink/red coloration to the water body, by red pigment carotenoid, it is of the opinion that, it may possibly be through these sources, migrating birds fig. 4 [(a), (b), (c) and (f)]. Every year from November to March, migrating birds come to Lonar Crater Lake from different parts of the world having saline nature lakes and also showing pink/red coloration, which harbours microorganisms of halophilic (salt loving) bacteria and archaea, which may be similar to *Dunaleilla salina* (salt loving) bacteria, which possesses a red pigment known as carotenoid, which on multiplying in large numbers over the lake surface made the lake water look pink. These microorganisms unknowingly cling themselves to the migrating birds body, when they come in contact with water of saline nature, they get mixed up in the waters of saline nature which in this case is Lonar lake, This postulation has also been supported by Dr. R.M. Badve (geologist, Pune)⁽⁹⁾. Hence by coming every year these microorganisms may be settling here and little by little they may be multiplying in numbers slowly, because Lonar lake water is not only of saline nature, it is also of high alkaline in nature, hence, it may be difficult for these microorganisms to survive or adjust themselves to high alkaline nature of water because the alkaline nature of the water may not be suitable and hence may die out due to high alkalinity of the lake water or may have adapted themselves to the extreme conditions, for which they bloomed and hence the pink/red coloration was observed. These migrating birds come to Lonar Crater Lake every year and every year, during summers the temperature is found to be very high above 42°C, which shows that every year evaporation rate is high, yet pink coloration has never been observed, recorded or documented. This year also the temperature in summer season was around 42°C to 45°C⁽¹⁰⁾, but this year evaporation rate must be higher than earlier years for which the concentration of salts must be highest than previous years, giving rise to red pigmented microorganisms to bloom, making the water look pink/red color (fig. 8).

The other possibility could be through locust attack. On May 25th 2020⁽¹¹⁾, there was a heavy attack of locust on the Vidarbha region, hence, it is possible that these locust attack may be the carriers of these halophilic bacteria or microorganisms, these microorganisms being lighter in weight may have clinged to the body of these locust, from where they came or their spores must have clinged to the body of these insects unknowingly or they must have carried these microorganisms unknowingly and when passing over Lonar Crater may have fallen on the lake surface, for which they bloomed and increased in large numbers making the color of the water looked pink/red, when right temperature and sunlight was available for them to multiply and increase in large numbers. In India 100 years of record is known of locust attack, which last for 5-7 years. The latest attack was in 1959 to 1962. After 1962, it has again appeared in 2020⁽¹¹⁾.

The possibility could also be through storm, hurricane, cyclone, stormy winds etc., which hit Maharashtra on 1st June 2020⁽¹²⁾, the storm or stormy winds may have carried these halophilic bacteria or microorganisms and when passed over Lonar Crater, may have got mixed up with the water surface by the stormy winds sweeping over the lake surface, for which they multiplied or bloomed and increased in numbers, the suitable environment for them was, may have been attained for them to multiply over the lake surface, it is also possible that the spores of these microorganisms may have been carried through stormy winds, storm, etc., which may have come in contact with the lake water, while crossing over Lonar region, because as per Prof. Bugdane Sir, informed that there was heavy showers over Lonar region after the lake looked pink⁽¹³⁾. Their spores must have been carried due to their being lighter in weight i.e., lighter than air, similar to the phenomena of red rain in Kerala, which took place in the years 1896, 1957, 2001 and 2012. There was a red rainfall phenomenon in some parts of Kerala in the years mentioned above, but a study commissioned by the Government of India, concluded that the rains had been colored by airborne spores from a locally prolific terrestrial green alga from the genus *Trentepohlia*⁽¹⁴⁾. Is it possible then that similar phenomena may have taken place for Lonar Lake to show pink coloration? Because on 1st June 2020, there was a heavy storm over Maharashtra.

After these phenomena occurred, while observing the photos of algal bloom taken in November 9th 2019, it was seen that among the green color, patches of brownish pink color is observed [fig. 2 (a) and (b), 3 (a), (b) and (c)]. From this it was inferred that the pink/red color of the lake water did not appear all of a sudden nor did it appear in a day or two (fig. 8). The detail observations of the photos of 2019, clearly indicated that the process for the coloration of the lake water to look pink/red may have started in

November 9th, 2019, or somewhere around November 2019 or may be earlier than 9th November 2019, and was observed on 9th November 2019 [fig. 2(a) and (b), Fig 3(a),(b) and (c)], i.e., first signs of appearance of pink/red pigmented microorganism or halophilic bacteria in the form of brownish pink coloration, and by June 9th, 2020, it was fully or completely looked pink colored, (fig. 8), which means that for the pink/red coloration to appear on the whole lake water, it had taken approximately 7-8 months, in other words it can be said that for the red pigmented halophilic bacteria to bloom had taken approximately 7-8 months, i.e., from 9th November 2019 to 9th June 2020.

Lonar Crater Lake is static or stagnant water body. It is known that Lonar Crater Lake water ecosystem is anaerobic in function because water body is highly eutrophic. DO (dissolved oxygen) is negligible, phytoplanktons activity produce oxygen which is consumed by aquatic life for their respiration and organic matter decomposition. Maximum anaerobic condition gives off reducing gases and offensive smell, the water body turns into marshy land and microorganisms responsible for the pink/red coloration of the lake water, may be adapted organisms transported or carried by the mechanism of migrating birds in the form of spores and finally may have adapted the highly alkaline and highly saline conditions and became an ecological member of Lonar Crater Lake. Badve et al. mentioned that when the study of lake silts sediment samples were collected from different parts about 35 meters away from the lake, it revealed that anaerobic activity does take place⁽⁴⁾.

At present Lonar Crater has been known as world heritage, hence population of the Lonar village increased due to Lonar being declared as Taluka, and as Lonar Crater became a world tourist place large numbers of visitors come to this place, therefore population of Lonar village increased, simultaneously domestic liquid waste also increased as population increased. On the periphery of 500 – 600 meters of Lonar Crater surrounded by large population, huge amount of domestic liquid waste is generated and if not given proper treatment may percolate in the lake water, which may have given rise to eutrophication or may be the cause for eutrophication of the lake.

Therefore, the contamination and pollution may have increased, Sewage water may have merged or drained into the lake, for which the sediments of the lake got concentrated by organic matter. Many devotees come regularly to pay their homage to their goddess Kamalja Devi with offerings and rituals are conducted, due to this activities also, the water receives continuous organic matter. Oxygen demand is more to digest the organic matter and the lake cannot produce such high demand of oxygen. So it cannot digest the organic matter, hence the lake becomes polluted lake and eutrophied. High salinity and high alkalinity reduce fertility or sustainability for aquatic life. The algae are one of the microorganisms which grow on organic matter. Therefore the algae scum has been observed [fig 2 (a), (b) and 3(a),(b) and (c)]. Hence the dead debris and undigested organic matter remains there, for which anaerobic conditions is developed. Anaerobic condition develops fermentation and foul smell around the lake. It is postulated that on these undigested organic matter or dead bodies, fungus may grow. Fungus is non photosynthetic species. Fungus is an organism growing on dead debris or decaying organic matter and on dead bodies of plants and animals. Various kinds of fungus exist, which are capable to produce varieties of colors (i.e., spectacular colors), it may be one of the reasons, why Lonar Crater water system is suitable to grow fungus, and fungus grows very rapidly and in a very short time, it may have occupied the surface of the water body. It is the fungus, pink in color or red in color that may have attributed the color to the water, the fungus is found to grow on the surface of the water body for which the water looked pink/red colored. This is a biological phenomenon. Algae and fungus always grow on eutrophic water body and hence the color of the water seems to change according to them.

Basically the lake is anerobic in condition, highly eutrophic, the presence of micro and macro nutrients, nitrates⁽⁶⁾ ⁽¹⁵⁾ ⁽¹⁶⁾, Nitrites⁽¹⁵⁾, phosphates⁽²⁾ ⁽⁴⁾ ⁽⁶⁾ ⁽¹⁶⁾, sulphates⁽²⁾ ⁽³⁾ ⁽⁴⁾ ⁽⁶⁾ ⁽¹⁷⁾, Sulphites⁽¹⁷⁾, etc., so that green algae is found growing on eutrophic lake constantly, the water body seems to be green in color. Dead debris of phytoplanktons and zooplanktons undergo decomposition. This decomposition gives rise to the growth of fungus. This type of environment is good for the growth of fungus and hence spectacular colors of algae can be observed as pink/red, algae imparts pink/red color to the water body. This is one of the theories postulated regarding fungus. Badve et al. also has mentioned that microscopic examination of silt samples revealed the presence of rich organic remains such as algal filaments, fungi hypae and spores, diatoms etc.⁽⁴⁾, which clearly indicate that the growth of fungus is possible on the dead debris of organic remains.

If considered that the pink coloration of the lake is due to fungus, then there are two possibilities for them to be found at Lonar Crater Lake, one is through dead debris of organism remains of aquatic life and second is through their spores by way of migrating birds, locust attack or through stormy winds. Similar to the red rain in Kerala⁽¹⁴⁾.

As per studies carried on Sambhar Salt Lake, Rajasthan by Dr. Meenakshi, mentioned that fungal species belonging to Basipetospora or Walemia genera were observed⁽¹⁸⁾. The red rain of Kerala was due to large number of spores of a lichen forming alga belonging to the genus Trentepohlia⁽¹⁴⁾. The strong orange color of the algae, which masks the green of the chlorophyll, is caused by the presence of large quantities of orange carotenoid pigments. A lichen is not a single organism, but the result of a partnership (symbiosis) between a fungus and an alga or cyanobacterium⁽¹⁴⁾.

The question is, from the time the work of physicochemical analysis and the study of Lonar Lake water were started, due to abundance of green algae floating on the surface of water, it is observed as if the color of the lake water seems to be green. The water is not green in color; it is the color of the green algae that makes the water attains green color. Similar is the case of red pigmented algae. How then all of a sudden, the color of the water looked pink/red? One of the local and senior most Person, Prof. Sudhakar Bugdane sir informed that the lake water looked pink/red color, has never been observed before. This is the first time that that this phenomenon has been observed⁽¹⁹⁾. In summers where temperature goes above 45°C at Lonar, evaporation rate is at

its highest peak and hence concentration of NaCl salts is possible. But this is observed every year. Badve et al. mentioned that in 1985, the water of the lake was so less that a great extent of the lake basin got exposed along with the encrustation of salt⁽⁴⁾.

They are some pink lakes in the world, for example 1) Dusty Rose Lake Carriboo J, British Columbia, Canada. This pink lake doesn't have any algae and there isn't any salt content, contributing to the color, so no one really knows; why this Canadian lake is permanently pink⁽²⁰⁾. 2) Laguna Colorada, Bolivia. The color is caused by a combination of red mineral sediments and algae in the waters with a heavy concentration of borax to turn the dark red to pink⁽²⁰⁾, 3) Salina de Torrevieja, Spain, It is one of the most stunning pink lakes, in the world today, even though the salt content of the lake isn't very high⁽²⁰⁾.

There are lakes other than Lonar Crater Lake of saline nature and alkaline nature (soda lakes), where only one parameter dominates i.e., sodium chloride (NaCl) salts for saline nature lakes and Carbonates (HCO₃) and bicarbonates (H₂CO₃) for alkaline nature lakes, but Lonar Crater is entirely different from these two types of lakes i.e., dominance of both the parameters i.e., high salinity due to sodium chloride (NaCl) salts and high alkalinity due to carbonates (CO₃) and bicarbonates (H₂CO₃) salts is observed, hence it is only one of its kind in the world. It is therefore very unique, the uniqueness of its lies in the lake water itself.

Analysis carried by Dr. Meenakshi on Sambhar salt lake has shown that in table 1, out of 5 sampling stations, in station 3 sample, pH was found to be high, whereas chloride content was found to be low, and in station 5 sample, pH was found to be low, but chloride content was found to be high⁽¹⁸⁾, suggesting that salinity is independent of pH. Salinity is not dependent on pH. Salinity is chemically salts of halogen group elements i.e. Cl (chlorine), F (fluorine), (Bromine) and I (Iodine). High pH points to alkaline nature of water body. When the analysis of Lonar Lake water was compared to the sea water⁽¹⁷⁾, it was observed that though the saline nature of sea water is high, yet the alkaline nature was found to be low. Salinity and alkalinity are two different parameters. When it is said that the pH of the water body is high, it means it has high alkalinity not salinity, chemically alkalinity is presence of alkaline minerals and salts i.e., Carbonates (CO₃) and Bicarbonates (H₂CO₃), and hence pH value increases towards alkaline side.

It is also assumed that abiotic phenomena like various chemical species [cations and anions (Mn⁺²) etc.], may be possible to attribute pink color to the water body of Lonar Crater

The phenomena of Lonar Lake water looked pink/red colored is unique because, this phenomena is usually observed where concentration of NaCl salts is high, and the microorganisms responsible for it are halophilic bacteria and halophilic archaea ⁽⁷⁾ ⁽⁸⁾, but at Lonar Crater Lake, where salinity and alkalinity are high, this phenomena has occurred, hence it is a unique phenomena, because in the history of Lonar Crater Lake this phenomena of water looking pink/red colored has never been observed.

4. CONCLUSION

From the observations, the images shown and the discussions, finally scenario behind pink/red coloration of Lonar Lake water are as follows:

- 1) That has been suggested by Dr. Kanekar (scientist)⁽⁷⁾ and Dr. Khadse (scientist - NEERI)⁽⁸⁾ is halophilic bacteria (salt loving) and halophilic archaea, which are photosynthetic organisms and which are capable to produce beta carotenoid, pink pigment, responsible for imparting pink/red coloration to the water body, where high concentration of NaCl salts are found⁽⁷⁾ ⁽⁸⁾. Halophilic bacteria, which can only function at high salt concentrations and are abundant in the world's oceans⁽²¹⁾.
- 2) Our postulation or our assumption is may be non-photosynthetic organism, fungus which grows on dead debris of organic matter or decayed organic matter, which can produce spectacular colors, and responsible for pink/red coloration to the Lonar Crater lake. But it cannot also be neglected that abiotic chemical species may also be responsible for pink Coloration of the lake water.

The more chances or there is every possibility of the halophilic bacteria or microorganisms to come to Lonar Lake is through migrating birds, But it cannot also be ruled out that the locust attack and the stormy winds, may be the cause for the carriers of these microorganisms or possibility of fungus or their spores which survive on the dead debris of microorganisms or on decaying organic matter.

Dr. B. M. Karmarkar has also mentioned that in the waters of Lonar Lake, 14-16 kinds of blue-green algae, some microorganisms and thermophilic bacteria spores are present⁽²²⁾.

Pink algal bloom is related to biotic components activity. It can also be considered chemical activity of abiotic components which can possibly impart pink color of abiotic bloom. It is a real phenomenon. The question is what is the interval between green to pink algal bloom? And what is the frequency of reappearing pink algal bloom phenomena? High salinity and high alkalinity, a unique combination of water, may be the answer is uncertain. It is very difficult to understand at which concentration of salinity and alkalinity responsible to thrive pink algal bloom and which climatic condition is responsible to activate (temperature, sunlight etc.), certain gases which is evolved during decomposition of organic matter for forming chemical ionic concentrations of certain minerals and metals.

Earlier the color of the lake was permanently green due to green pigmented algae spirulina grown on water surface. [fig.5 (a) and (b)]. The growth of green algae on water surface of Lonar Crater lake again it indicates that the water is polluted containing high amounts of nutrients.

Whatever it is, it is true that the lake water of Lonar Crater looked pink/red. This phenomena or event is very complicated and uncertain, but it is not unexplained. A detail study and a lot of efforts are required; if pink/red coloration is due to fungus, then a detail study is required to understand which type of fungus is responsible for pink/red coloration of the lake water of Lonar Crater and how did this type of fungus come to Lonar Crater lake, was it through decomposition of organic matter? or was it through their spores carried by migrating birds, locust attack or through stormy winds etc.,? similar to the phenomena of red rain in Kerala.

4.1 Importance of work

To understand Lonar Crater Lake, installation of continuous monitoring of Lake water is necessary for the following parameters. 1) pH, 2) Ambient Temperature, 3) Salinity, 4) Alkalinity, 5) D.O. (Dissolved oxygen), 6) B.O.D. (Biochemical oxygen demand) and C.O.D. (Chemical oxygen demand). These parameters will describe all the characteristics of Lonar Crater Lake and will be very useful for future generation for academic purpose and research work.

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APPENDIX



Fig. 1: Lonar Crater Lake, the only one of its kind in the world, known for its uniqueness.



Fig. 2: (a) and (b) Concentration of green algae bloom and frothy nature of water and white color bubbles are seen. The patches of brownish pink color are clearly observed amongst green algae, indicating that the process for the salt loving microorganisms to bloom may have just started or it may have started earlier than 9th November 2019. The first signs of appearance of halophilic bacteria⁽⁷⁾, as brownish pink coloration on the water surface. These phenomena were first observed on 9th November 2019 and the photos of these unusual phenomena were also taken on 9th November 2019 by the authors of this paper.

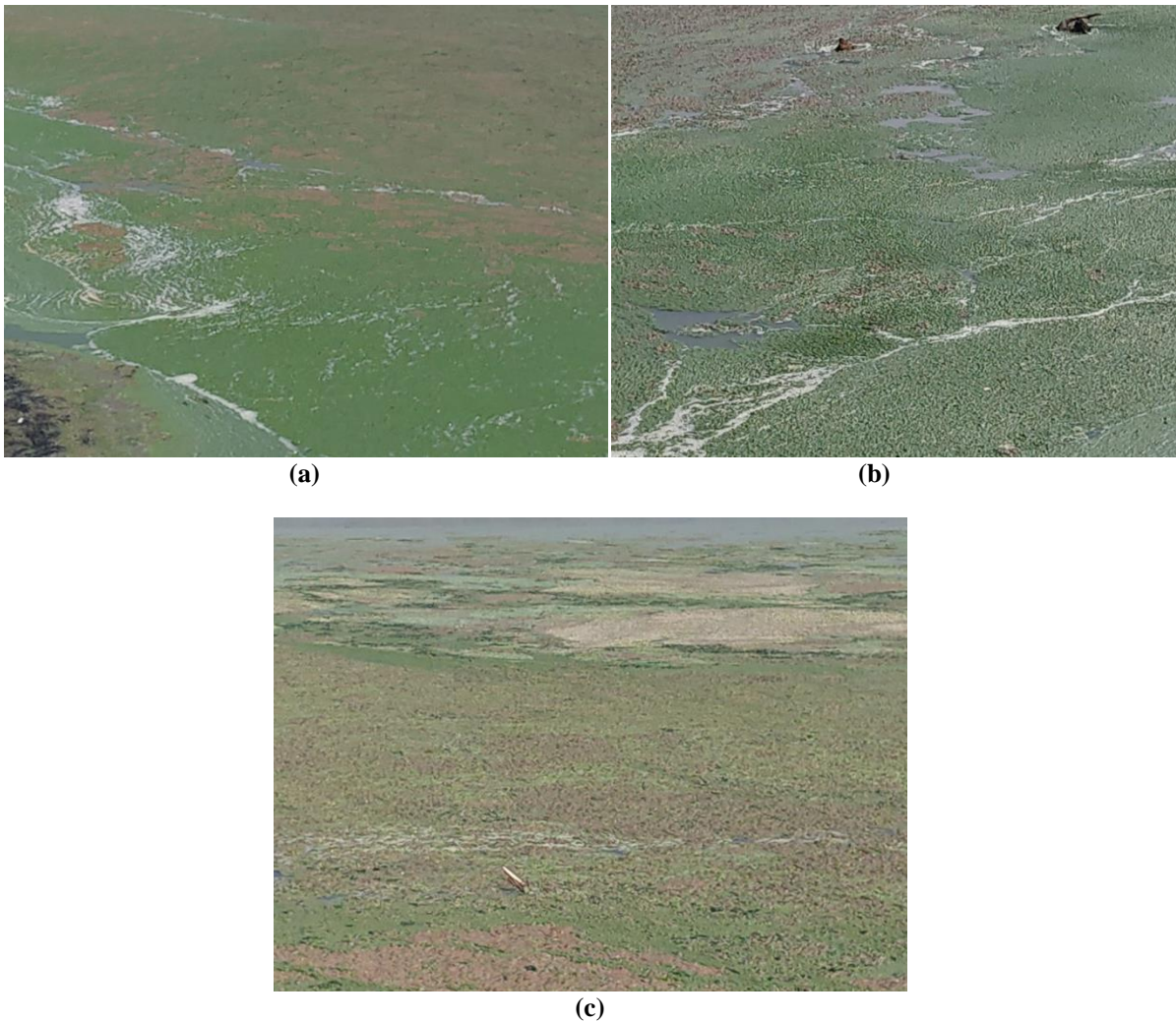


Fig. 3 (a) and (b): Brownish pink patches of coloration seen on a large scale is possibly due to a kind of halophilic bacteria⁽⁷⁾, which is capable to produce red pigment carotenoid for which the color of the lake water looked brownish pink at the initial stage, as seen in the b, indicating first signs of red pigmented algal bloom. (c): Large scale concentration observed of red pigmented halophilic bacteria⁽⁷⁾, brownish pink in color amongst green algae. The first signs and appearance of red pigmented algal bloom. The green coloration is due to green algae known as Spirulina. These photos were taken on 9th November 2019 by the authors of this paper.



(a)



(b)



(c)



(d)



(e)



(f)

Fig. 4 (a), (b), (c) and (f): Migrating birds seen at Lonar Crater Lake. The migrating birds come to Lonar Crater Lake, from different parts of the world, where saline nature of water exists and pink coloration is observed. The migrating birds are postulated to be the main carriers of the halophilic bacteria⁽⁷⁾ or their spores, attached to their body. When they come in contact with water of Lonar Crater, the NaCl (salt loving) microorganisms get mixed up with the saline nature of the water. In due course, when the temperature and sunlight for them is suitable, they multiply or bloom, producing red pigmented carotenoid, for which the water looked pink/red in color. Fig 4 (d) and (e) Water birds seen in the waters of Lonar Crater.



(a)



(b)

Fig. 5: (a) and (b) Lonar Crater Lake water looks green in color due to green algae, spirulina



Fig. 6: Small patches of salts concentration on the dry bed of lake surface Lonar Crater



Fig. 7: Sandy type of soil observed on lake Periphery of Lonar Crater



Fig. 8: Lonar Crater Lake water looked pink/red colored on 9th June 2020. Surrounding the pink colored water, concentration of white colored salts is observed. Photo taken by Prof. Sudhakar Bugdane, an Eminent and senior most resident of Lonar village.