Synopsis of thesis

Biodeterioration of Selected Historical Monuments by Lower Plants and Cyanobacteria

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By:

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Introduction

Biodeterioration is defined as "the undesirable changes in the properties or qualities of a material or a structure by the vital activities of organisms" (Allsopp *et al.,* 2004). It occurs on humid and illuminated substrates such as old buildings, structures and historical monument walls. The biodeterioration of monument is caused by cyanobacteria, lichens, bryophytes and allied vascular plants (Herrera L. K. *et al.,* 2004). This biodeterioration process is mostly initiated by pioneering microorganism cyanobacteria. These microorganisms are attached to the surfaces, to each other and embedded in the self-produced matrix resulting in the formation of biofilms. These biofilms extensively cover the exposed surface that caused the disfiguration and discoloration of the structures. On these biofilms, propagules of other biological organisms adhere leading to further colonization by macro-organisms. These macro-organisms create large scale fouling and is known as biofouling (Bixlar and Bhushan, 2012). The macro-organisms which cause biofouling are called as biofoulants. Cyanobacteria are primitive photosynthetic organisms, which evolved more than 3.5 billion years ago and are still found around almost everywhere. They live on both terrestrial and aquatic habitats (Knoll, 2008). They are pioneering colonizers on barren rock surfaces and show the formation of biofilms. Colonies of such microorganisms are able to survive in the harsh exposed environments because of the outer slime layer. This makes the surface suitable for colonization by other groups like bryophytes. With the passage of the time, the bryophytes fully colonize the surface forming dense bryophytes assemblages that further damage the surface of the monument. This is facilitated by root-like but simpler structures known as rhizoids that penetrate where high porosity exists (Altieri & Ricci, 1997). Calcium is taken up from the substratum and is easily trapped in the apoplast region. Similarly, lichens secrets different acids which play their role in deterioration (Bajpai & Upreti, 2014). The resultant effect on the monuments it the formation of cracks and crevices with passage of time.

The conservation of monuments requires information on the diversity of biofoulants and the role they play during the process of deterioration. With an aim to ensure the effective conservation of important monuments, this study has been proposed with the following objectives,

1. Identification of the diversity of biofouling lower plants and cyanobacteria at the selected sites using morpho-taxonomic as well as modern methods.
2. Analyzing the specificity of biofoulants for specific geological substrates.
3. To study the specific role of different biofoulants on the process of biodeterioration.
4. To suggest measures for the control of these biodeteriogens.

Methodology:

The methodology followed during the study has several components which have been outlined in the diagram below.

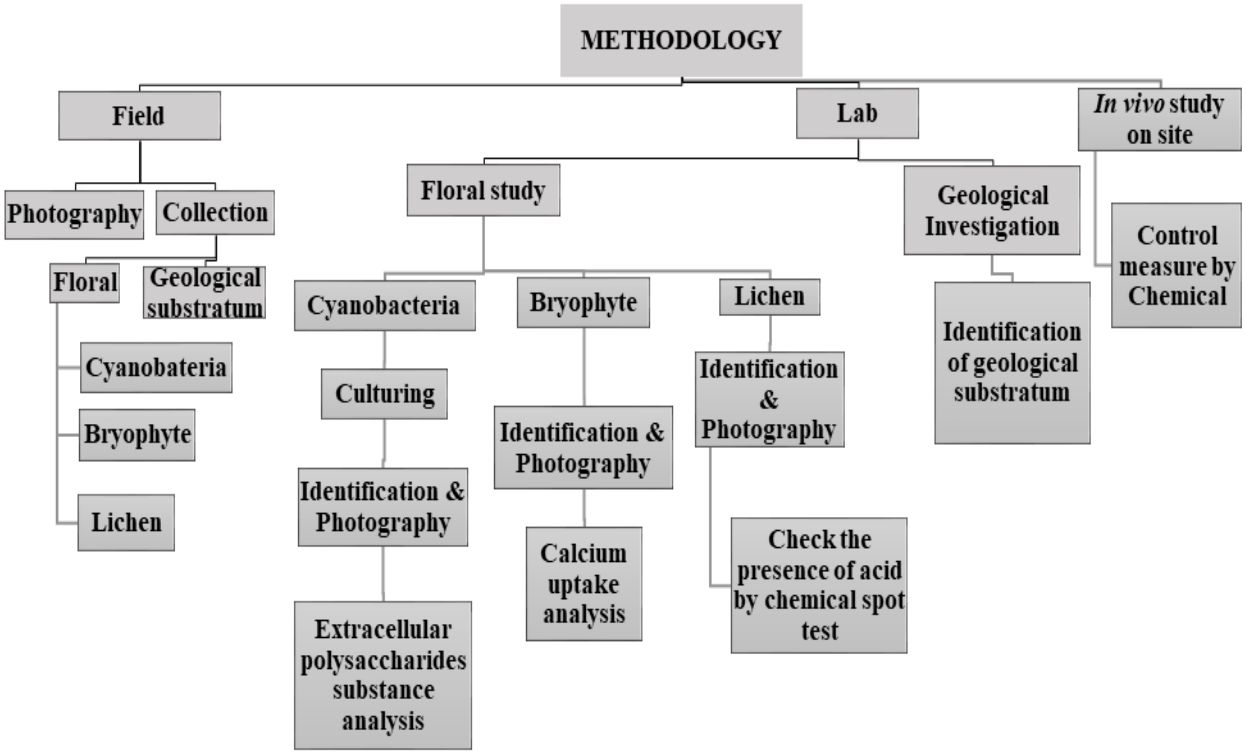

Fig. 1: Outline chart showing methodology followed in study

Study area

Gujarat has a rich cultural past which has been preserved in its large diversity of monuments present all over the state. They include monuments from Lothal which date back to 2500 BC to the 19th Century Tambekar Wada in Vadodara. Some of these monuments have been provide protection by the Archaeological Survey of India and the number of such monuments currently stands at 317 (ASI, 2020). Appreciating their importance some of these sites have also

been designated as World Heritage Sites by UNESCO. Several sites which represented different ages, substratum and structural types were visited and monuments from two sites were finalized for the study. The study included monuments from two broad sites namely Champaner-Pavagadh complex and The Maharaja Sayajirao University of Baroda campus. Champaner is a historical city in the state of Gujarat and is located in Panchmahal district (Anon, 2007). The Champaner-Pavagadh complex is a famous heritage site and is listed as a UNESCO World Heritage site since 2004 (Sinha *et al.*, 2004). The site has many historical important monuments that are endangered due to bio-deterioration. Among them, three monuments namely Makai Kothar, Navlakha Kothar and Jain Temple which are located on the hill of Pavagadh were selected for the study. Three other monuments namely Saher ki Masjid, Mandavi and Amir Manzil (not-protected by ASI but under supervision of ASI) at the foot hill of Pavagadh in Champaner town were also selected. The Maharaja Sayajirao University of Baroda campus (MSU) in Vadodara city is also one of the selected site. The buildings of the University were constructed from 1880 onwards and were earlier known as Baroda College (Trivedi, 1933). Two buildings, the Arts faculty building and the Dadabhai Naoroji (D. N.) hall building were selected for the current study. The Arts faculty building which houses one of the largest masonry domes was modelled after the great dome of the GolGumbaz in Bijapur (Anon, 2010). This dome is currently more than 130 years old. The D. N. Hall building which was initially part of a boy's hostel, houses the Department of Architecture since 2000 and is also more than 100 years old. Basic periodic maintenance work is undertaken at both these buildings as they are still in use. However, the facades of both these buildings have a rundown look and the architectural beauty has been spoilt due to the growth of different groups of biofoulants. This was the major reason for the selection of these buildings for the current study.

Results and Discussion

The results of the different objectives of current study are summarized below and they have been discussed in detail citing relevant literature in the thesis.

1. Identification of the diversity of the biofouling lower plants and cyanobacteria with their specific substratum

A total of 36 species of biofoulants have been identified from the selected monuments sites. Five species of cyanobacteria, one of microalga, seventeen species of bryophytes and eight species

lichens were identified to be growing on the selected monuments of the Champaner-Pavagadh complex. while eight species of cyanobacteria and two species of bryophytes were observed on the selected monuments of MSU campus. On the building of the MSU campus, among the cyanobacteria members of the order Chroococcales and among bryophytes, members of Pottiales were dominant. The dominant members at the Champaner-Pavagadh complex among the cyanobacteria were members of Synechococcales and Nostocales while members of Marchantiales and Pottiales were dominant among the bryophytes. Among the lichens identified, the crustose lichens were dominant and while one member each of foliose and squamulose-foliose lichen was also noticed. They were recorded from different geological substrata such as brick, stone, lime coating surface and mortar. Majority of the cyanobacteria were isolated from lime coating surface and mortar, while bryophytes from mortar and brick surfaces. All observed lichens were saxicolous because they were all found growing on stone. The characterization of geological substratum, mainly revealed the presence of calcareous materials (primary silica and secondary silica), ferruginous materials and feldspar in thin section and powder X-Ray Diffraction (XRD) analysis.

2. Role of specific cyanobacteria, lichen and bryophytes in the process of biodeterioration

Each group of organism has a different role in deterioration. The cyanobacteria secrete polysaccharides either into the external environment or synthesize them extracellularly by cell wall-anchored enzymes and these are referred to as exopolysaccharides. Exopolysaccharide are complex in nature and have the ability to enhance the aggregation of soil particles, prevent desiccation and facilitate trapping of nutrients (Costa *et al.*, 2018). This resulted in the formation of biofilms which facilitates the colonization by other plant groups. This results in the discoloration and deterioration of the monuments. To understand the composition of the exopolysaccharides, characterization of EPS of five species of cyanobacteria (*Chroococcidiopsis cubana, Desmonostoc muscorum, Nostoc punctiforme, Leptolyngbya foveolarum, Leptolyngbya crispata*) and one species of microalga (*Asterarcys quadricellulare*) were done by High Performance Thin Later Chromatography (HPTLC) method. Each isolated strains of cyanobacteria and microalga revealed the presence of three to five monosaccharides as observed by HPTLC fingerprint profile. In bryophytes, cell wall has a role for uptake of some nutrients and non-essential cations because fixed negative charge sites present on it (Wells & Brown,

1987; Bates 1992). Calcium which is the major exchangeable cation component from the monument substratum (Inoue *et al.,* 1981; Bates 1992) gets fixed to the negative charges of carboxyl groups of pectin polysaccharide in the matrix of the cell wall. Such cations easily diffuse through the apoplast regions and are also readily accumulated in this region and can be analysed for cation uptake. Calcium uptake was studied in the commonly found bryophyte species. The uptake was compared between one moss, *Hyophila involuta* and one liverwort, *Asterella angusta*. Flame photometry revealed that *Asterella angusta* had a higher calcium uptake compared to *Hyophila involuta*. In lichen, several secondary metabolites including unique acids are responsible for deterioration of the monuments. For the identified lichens, the results of the spot tests and the secondary metabolite composition from literature was evaluated to understand its role in biodeterioration.

3. Measures for control the biodeteriogens

Based on available literatures, an *in-vivo* experiment to test the efficacy of different control measures was devised. However due to the COVID-19 pandemic the experiment could not start in April 2020 and started only in October 2020. Two different chemicals were selected based on their physical properties like color, transparency and water repellant capacity after literature analysis (Gupta & Sharma, 2011) and interaction with experts from the ASI. Two chemicals that possessed the above properties were selected. Both these chemicals are silane-siloxane based compounds and their trade names are BS 290 and SMK 1311(Wacker). The experiment has been initiated at the dome of the Arts Faculty building of the MSU campus. The observations have been collected and discussed.

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