Kashi Decay Mapper: An AI-Assisted Participatory Framework for Structural Decay Monitoring of the Varanasi Ghats

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Abstract. This study introduces Kashi Decay Mapper, a digital platform that allows for documenting and monitoring structural deterioration across selected ghats of Varanasi. The research explores how artificial intelligence and community participation can contribute to heritage conservation through continuous visual documentation and condition assessment. The Varanasi Ghats form one of the world's most significant living heritage landscapes. However, structural deterioration is typically monitored through periodic surveys that are often limited in coverage and frequency. Recent advances in digital heritage documentation and participatory conservation demonstrate the potential of technology-assisted monitoring. Nevertheless, there is no accessible platform that enables citizen, students, and conservation professionals to collaboratively document deterioration in real time. This study seeks to address this gap. A mixed-method approach was adopted including field documentation of three representative ghats, photographic condition surveys, and semi-structured interviews with twenty stakeholders. A prototype AI-assisted framework was created based on the gathered data to recognize common deterioration patterns such as cracks, erosion, biological growth and material loss. The proposed framework demonstrates the potential of participatory AI-assisted mapping for early detection of structural decay and the enhancement of conservation decisions. The study highlights how community engagement and digital tools can contribute to more responsive and sustainable heritage management.

Keywords: Varanasi Ghats, Heritage Conservation, Artificial Intelligence, Structural Decay, Participatory Documentation, Digital Heritage, Living Heritage.

1 Introduction

The Varanasi Ghats are a living riverfront cultural landscape in which built fabric, ritual practices, livelig=hooda and everyday public use are intricately interwoven. Conservation approaches in such places need to take account of both physical fabric, and the values and practices sustained by local communities. [6, 7].
Covering an estimated distance of 6.8 kilometres on the western side of River Ganga, the 84 ghats are testimony to many years of architectural development, religious practices, and community life. While heritage monuments remain individual and independent entities, the ghats have been in use as a functional urban setting where rituals, tourism, commerce, and public activity take place, thus constituting an important part of India's heritage. The importance of preserving the integrity and usability of digital heritage records is also emphasised in research on digital heritage workflows [2].

Even with the significance of the ghats, they are facing a steady deterioration as a result of being exposed to various natural and manmade influences over time. The flooding brought about by the monsoons every year, the erosion, the variation in the levels of underground water, biological action, salt crystallization, thermal effects as a result of the activities of cremation as well as the growing number of tourists that visit them are all contributing to the degradation of the stones and other structures there.

Conservation measures currently used in India are mainly based on regular physical inspection and manual documentation. Though effective to some extent, such processes are laborious, time-consuming and cannot ensure constant monitoring over vast living heritage areas. Local inhabitants familiar with such heritage sites on a daily basis have practical awareness regarding any possible faults arising but do not have a proper digital process for reporting them. Research on participatory heritage-value assessment similarly highlights the need to consider how different stakeholders contribute to conservation knowledge [6].

1.1 Aim of the Study

The present study aims at developing and testing the feasibility of Kashi Decay Maper, a proposed AI assisted participatory framework for documenting visible deterioration at selected ghats of Varanasi. The paper explores three related questions: the extent to which visible deterioration can be classified, how the condition patterns differ across the three selected sites and five structural zones, and reporting features that may help connect the community observations with the expert review and conservation follow-up. The present study does not

demonstrate that platform improves early detection or reduces response time or can be scaled to all ghats these are outcomes for future pilot evaluation.

The study addresses a practical problem: periodic inspections provide valuable professional judgment, but they do not necessarily capture all the changes that occur between visits, nor do local observations feed into a traceable reporting process. The system could be used to complement, not replace, professional inspections with the help of a community. Its possible benefits- earlier awareness, better traceability, more transparent prioritization- are hypotheses to be tested, not outcomes demonstrated by the current prototype. Varanasi provides a suitable exploratory case study because its ghats represent a combination of built fabric, river related exposure, religious practice, tourism and everyday public use.

The rationale behind the choice of Varanasi as a study area is that it is one of the most important living heritage cities in India where cultural performance, religious activities, and heritage buildings are closely related. The 84 ghats of Varanasi are affected by specific degradation processes due to seasonal floods, intense use, cremation, biological growth, and aging structures, hence they constitute a privileged site for surveillance system.

The research gap is defined with caution. Previous literature works have have covered topics like documentation of heritage digitally, participatory conservation, and condition assessment using artificial intelligence. However, these approaches are usually treated and executed separately from one another. In this research work, these approaches have been considered within the context of their possible integration into a proposed process in the context of selected ghats of Varanasi. Contribution of the current research is not to assert that no similar platform exists anywhere else. Instead, it is the context- specific approach which combines various processes.

2 Literature Review

2.1 Relevance of the Literature Review

This literature review considers four related area: living heritage, digital documentation, participatory conservation, and artificial intelligence(AI) enabled condition evaluation. While each approach is related, none can substitute for another. Living heritage considers the connection between physical structure, ceremony, livelihood, and usage. Digital documentation helps to make condition assessments consistent and searchable, participatory conservation could provide additional sources of observations, and AI could assist in structuring image records. Each approach also has its drawbacks. Community reporting could be incomplete and repeated, consistency in documenting conditions and location in digital records is crucial, and classifiers used in machine learning could be sensitive to datasets and annotation. The current paper attempts to merge all of them into the context- specific framework, considering the benefits of monitoring and conservation response as hypotheses that should be verified in the future. This issue align with the existing literature on problems of digital heritage documentation [2] and stakeholder perspectives in value assessment of heritage sites [6].

2.2 The Ghats as Vernacular Heritage

The works by Santana Quintero et al. [2] on digital workflow for heritage documentation include issues related to the creation, distribution, and preservation of documentation and its technical and ethical prerequisites. Heras et al. [6] consider participatory practices for heritage value identification, mentioning the use of specific methodologies such as semi- structured interviews and cultural mapping. Both studies can be used to justify the need for considering participation as an integral element of heritage knowledge development and management and not only as an opportunity to gather photos. In terms of Kashi Decay Mapper, it means that the reporting interface must include feedback and traceable procedures for reviewing the reports.

Lu et al. [3] examine digital-twin-enabled anomaly detection for built-asset monitoring and operation and maintenance. This work supports the relevance of structured digital condition information and anomaly detection, but a digital-twin approach is not equivalent to the CNN prototype developed here. Its findings provide a conceptual and technical point of comparison, not validation of the present model. Kashi Decay Mapper requires transparent reporting of dataset composition, class balance, split strategy, and independent evaluation before performance can be compared confidently with other systems.

Vukmirovic et al. [5] examine local initiatives concerned with public-space comfort and climate adaptation. Their focus is broader than AI-based structural monitoring, so this source is used only to contextualise the role of local initiatives in shared environments. It does not directly demonstrate that citizen reporting improves structural-decay detection. In the present framework, community observations are treated as a potential source of reports that still require verification and appropriate follow-up.

2.3 Critical Synthesis of Literature

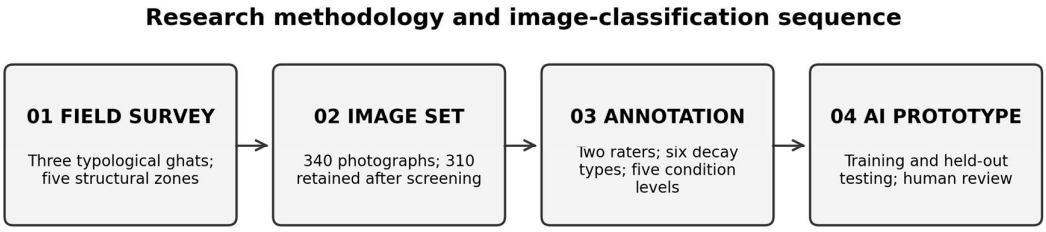
Literature strand	Critical inference / limitation	Relevance to Kashi Decay Mapper
Living heritage	Physical condition is connected to ritual, livelihoods, access, and everyday use; condition scores alone do not capture cultural significance.	Supports treating the ghats as active cultural landscapes and selecting contrasting site typologies.
Digital heritage and documentation [2, 3]	Digital records can improve organisation and traceability, but depend on consistent metadata and a process for review and action.	Informs structured photographic records, location/zone tagging, and proposed status tracking.
Participatory conservation [2, 5]	Participation may broaden observations, but representation, duplicate reports, accessibility, and sustained engagement cannot be assumed.	Informs community reporting as a proposed input while highlighting the need for inclusive user testing.
AI and condition assessment [1, 3, 4]	Image classification can support triage, but depends on representative data, independent testing, and expert review; images cannot prove concealed defects.	Supports a human-in-the-loop classification layer and the need for site-level validation.

The use of machine learning methods for structural health monitoring and heritage assessment research [1,4,7-10] confirms the need to consider image classification as one of the tools for condition recording. However, model precision requires representative input, reliable labelling, and a testing process that would exclude any possible duplicates of images.

3 Methodology

The research uses a mixed methodology that includes filed documentation, interviews with relevant stakeholders, and image classification through an exploratory prototype of artificial intelligence. The filed documentation documents the observed deterioration, the interviews identify the need for reports from the local level and the image classification helps to investigate the use of photography in organization.

Fig. 1. Research methodology and image-classification sequence.



3.1 Study Area and Field Documentation

The ghats of Manikarnika, Dashashwamedh, and Assi were chosen purposely for representing cremation ghat, ceremonial ghat, and neighborhood ghat respectively. The photographic surveys were carried out on the following five areas: (A) Lower step affected by the full monsoon inundation, (B) Upper step affected by intermittent monsoon inundation, (C) Retaining wall anf plinth, (D) Drainage channel and outlet, and (E) Attached structures.

Table 1. Survey zones, condition scale and deterioration taxonomy

Visible conditions were classified as Good, Fair, Poor, Critical, or Collapsed/Lost. Six deterioration categories were recorded: cracks, biological growth, erosion/material loss, step displacement, efflorescence/siltation, and drainage overflow. These categories provide a common documentation vocabulary, defect-specific rating criteria and inter-rater agreement require further standardisation before wider use.

Framework component	Code / level	Definition used in the survey
Structural survey zone	A — Lower steps	Full monsoon inundation

Structural survey zone	B — Upper steps	Intermittent inundation
Structural survey zone	C — Retaining walls / plinths	Retaining fabric
Structural survey zone	D — Drainage channels / outfalls	Drainage infrastructure
Structural survey zone	E — Attached structures	Temples and pavilions
Condition scale	Good; Fair; Poor; Critical; Collapsed/Lost	Five-level visual condition scale
Deterioration taxonomy	Cracks; biological growth; erosion/material loss	Types 1–3
Deterioration taxonomy	Step displacement; efflorescence/siltation; drainage overflow	Types 4–6

3.2 Stakeholder Interviews

Table 2. Stakeholder interview sample composition

Twenty semi-structured interviews involved long-term residents (n=6), boatmen (n=4), temple priests (n=3), Municipal Corporation officials (n=3), and conservation professionals (n=4). Interviews focused on observed deterioration and its perceived causes, existing reporting practices, and requirements for a usable digital tool. Responses were reviewed thematically. Women residents and non-frequenting locals were not separately sampled, so their experiences may be under-represented. Stated interest in a tool does not establish sustained participation.

Stakeholder group	Participants	Share
Long-term residents	6	30%
Boatmen	4	20%
Temple priests	3	15%
Municipal Corporation officials	3	15%
Conservation professionals	4	20%
Total	20	100%

3.3 AI Classification and Data Analysis

Exploratory classification was performed using images labelled with respect to the deterioration types and condition scale by two independently. From a total of filed photographs, some photos were removed due to poor image quality. The paper claims that 20% were used as a held-out test set with 84% accuracy in deterioration type classification and 79% for severity assessment. These preliminary findings should be corroborated using precise details on the test-spilt counts, class distributions, architecture, pre- processing, training parameters, and datasets used. The same image of physical damage should not be included in both training and test sets. Visual inspection of historic masonry and cultural heritage has been examined in the literature but it stresses the requirement of appropriate datasets and thorough validation before implementation [7,8]. Field observations, interview themes, and classification outputs were analyzed together to derive insights into the proposed reporting workflow. The descriptive analysis does not prove any improvements in response time, active participation, or conservation efforts.

4 Results

4.1 Field Survey Findings by Ghat

Manikarnika Ghat. Out of the photos examined,61% were classified as Poor or Critical. Type 1 cracks, which exhibited active fracturing through simultaneous thermal and hydrological cycling cycles (cremation fires and monsoon inundation), were found on all surveyed steps in Zones A and B, and active motion occurred at 14 sites. Type 2 biological growth appeared dense throughout all zones, below the upper cremation platform level: algal crust and moss growth caused by root penetration at 23 sites and joint displacement by roots at 9. Type 5 post-monsoon silt compaction covered the lowest step risers down to 20-30 cm. Type 6 drainage overflow occurred at 2 municipal drain outlets into Zone B, and efflorescence occurred on Zone C wall above outfalls.

Dashashwamedh Ghat. The manuscript reports that 47% of assessed photographs were rated Poor or Critical. The survey notes identify advanced erosion of step edges, displacement at several locations, and recurring drainage overflow as concerns for further assessment. These findings suggest that high public use and drainage conditions deserve attention in site-specific monitoring. The percentage requires the same verification of numerator, denominator, and inclusion rule as the other site-level percentages.

Assi Ghat. The manuscript reports that 54% of assessed photographs were classified as Poor or Critical. Efflorescence and biological growth were prominent in the site-level observations, and some wall panels were described as showing possible subsurface deterioration. Such suspected subsurface conditions require specialist investigation and cannot be confirmed from surface photographs alone. The percentage must be checked against the original records before publication, using a clearly stated denominator and consistent inclusion rule.

4.2 Comparative Condition Assessment

Table 3 represents the modal rating for the condition of deterioration that was most commonly recorded for each type of deterioration at each chosen ghat. It is not based on the actual area affected but rather on the most common qualitative assessment of that category. Each location differs in its pattern: Manikarnika has the critical condition for cracks and biological growth, Dashashwamedh has the critical condition for erosion, displacement, and drainage, and Assi has the critical condition for biological growth, erosion, and the efflorescence. The drainage problem is classified as poor or critical in all the locations.

Table 3. Aggregate Condition Assessment: Three Case Study Ghats by Deterioration Type

Ghat (Type)	Photos	T1 Cracks	T2 Biological	T3 Erosion	T4 Displ.	T5 Efflor.	T6 Drainage
Manikarnika (Cremation)	112	Critical	Critical	Poor	Poor	Poor	Poor
Dashashwamedh (Ceremonial)	116	Poor	Fair	Critical	Critical	Fair	Critical
Assi (Neighbourhood)	112	Poor	Critical	Critical	Poor	Critical	Poor

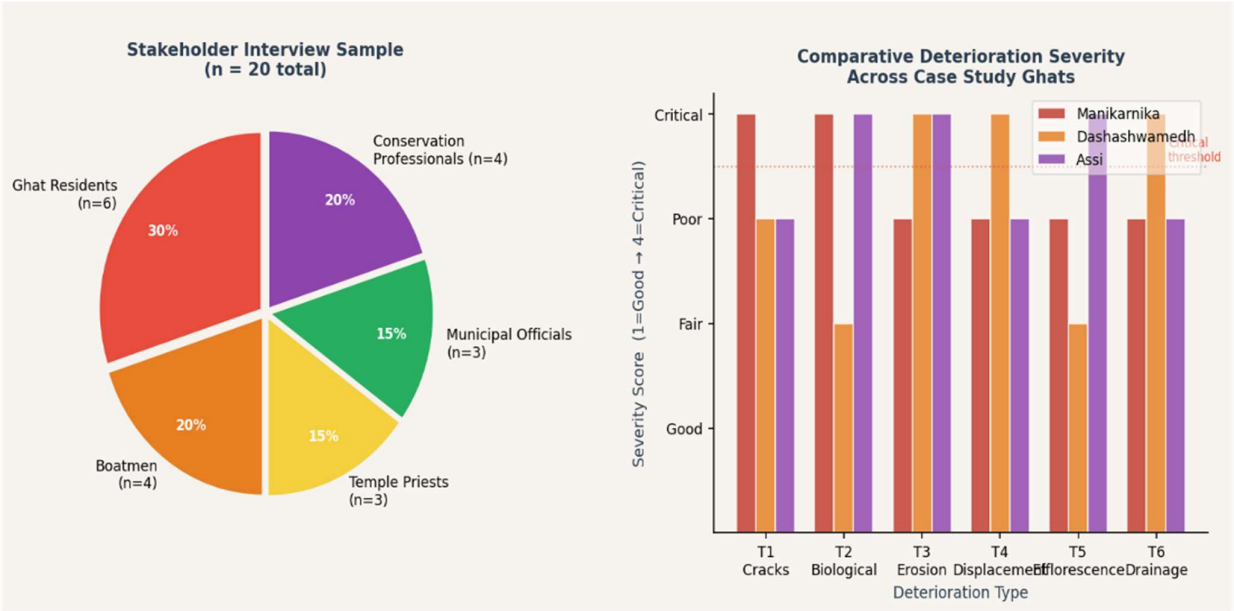


Fig. 2. Stakeholder interview sample composition and comparative deterioration severity across the three case-study ghats. Source: submitted research paper.

From the modal scores, three observations that span across the sites can be drawn. The first observation is that none of the three sites is rated as the worst for all the types of deterioration. The second observation is that all the three ghats are poorly ranked for their drainage systems. The third observation is that Assi has been critically ranked for three types of deterioration despite the neighbourhood classification of this ghat.

4.3 Stakeholder Interview Results

Three recurring themes emerged from the thematic analysis. It was found that there were observable signs of damage like cracks, steps movements, and blocked drainages, but there was no specific procedure by which observations could be followed to action. Participants also talked about the fact there were delays in tackling certain problems. Lastly , participants showed interest in a mobile- based system for observation, if it was short, receipt- confirmed and observable. The above findings are based on the opinions of the purposive sample only, they do not necessarily imply acceptance across the entire population or sustained use over time.

5 The Kashi Decay Mapper Platform

Kashi Decay Mapper is presented as a proposed platform architecture informed by the survey and interviews. It links a community reporting interface, an AI-assisted classification layer, and a conservation review dashboard. The workflow is a design proposal; the current research has not established live multi-user operation, automatic routing to authorities, or improved response time.

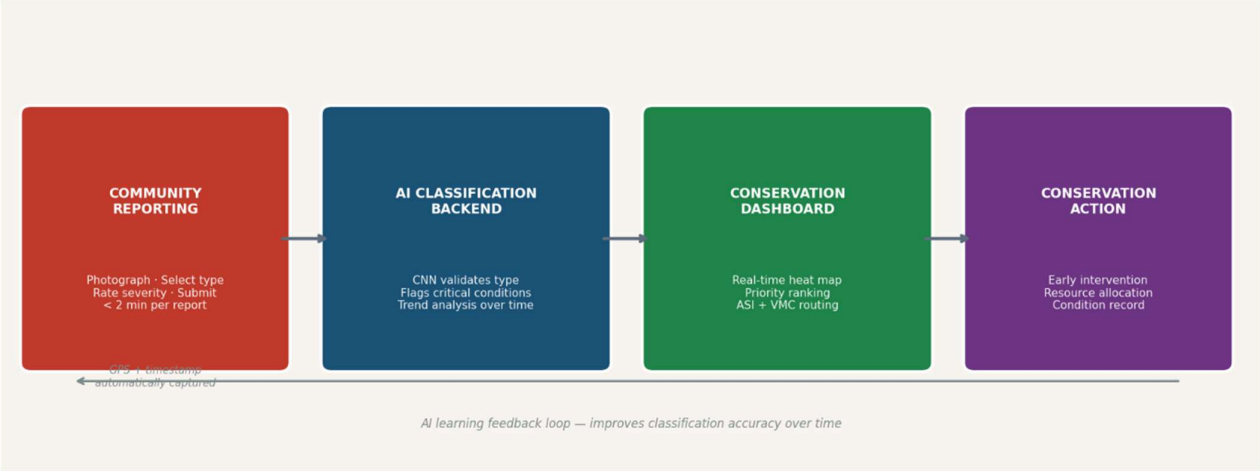


Fig. 4. Kashi Decay Mapper: three-layer platform architecture and data flow.

5.1 Community Reporting Interface

The design of the proposed reporting interface is such that the user can select a site and a structural zone, upload an image, choose a category of visible damage, if applicable, and assign a condition score. The interview responses imply that a quick procedure, a receipt confirmation, and visible follow-up actions could play an important role in the usability of the system. These are design requirements deduced from the results of interviews and not usability findings of an actual deployment.

5.2 AI Classification Backend

The proposed AI layer would suggest a deterioration category and condition rating, flag uncertain cases, and support preliminary triage. It should not automatically diagnose structural safety or replace expert judgement. The current reported accuracy is based on a limited dataset, and model outputs should be checked by a qualified reviewer—especially for critical, ambiguous, or out-of-distribution images. Future technical evaluation should report class-wise precision and recall, macro-F1, confusion matrices, severity agreement, and false-negative rates for critical conditions.

5.3 Conservation Authority Dashboard

Table 4. Proposed prioritisation weights (illustrative)

Prioritisation factor	Weight	Proposed interpretation
Condition severity	40%	Higher-severity observations receive greater priority
Deterioration rate	30%	Change over time is considered
Heritage significance	20%	Cultural and heritage value is considered
Intervention cost ratio	10%	Cost is considered alongside urgency

6 Discussion

6.1 Contribution to Heritage Conservation Practice

The Kashi Decay Mapper adds a site- specific strategy for heritage conservation through the combination of systematic condition assessment, local observations, and computer-aided image analysis. The five-zone assessment format, six category deterioration classification scheme, and five- scale condition rating create a reliable structure for documenting visible decay on the lower and upper steps, retaining walls, drainage facilities and adjoining buildings. Such an approach acknowledges the ghats as a dynamic riverfront site, where tangiblr material is highly interwined with the rituals, livelihood activities and other daily functions. Thus, this site-specific methodology helps to incorporate the values of heritage sites into heritage conservation [2,6].

This comparative analysis indicates that the patterns of deterioration vary for Manikarnika, Dashashwamedh, and Assi. There were cracks and biological growth in Manikarnika; erosion, step displacement, and drainage issues in Dashashwamedh; biological growth, erosion, and efflorescence in Assi. Poor and critical ratings have been awarded to drainage issues on all the three ghats, which implies a common concern worth investigating. This analysis indicates that the monitoring activities must be site-specific and take into account multiple deterioration categories instead of ranking ghats by one overall indicator. The assessment is limited to the chosen sites and observations made during it; the actual condition of 84 ghats and structural severity of defects is not confirmed here.

Stakeholder interviews also show that residents, boatmen, priests, officials from the municipal administration and conservationists can provide various types of knowledge regarding the changes observed and the reporting needs. Interviewees stressed the necessity to have a short reporting procedure, confirmation of receipt and follow-up. These requirements form the basis of the proposed reporting platform workflow, where the local reports will be sorted out for verification and not accepted as diagnoses. This approach is appropriate for the participatory heritage conservation, which values community knowledge as an important part.

6.2 What Still Needs Testing

The classifier performance achieved by the authors – 84% accuracy for deterioration type and 79% for severity – gives a rough idea whether image-based sorting might help in structuring field observations. There is some research on machine learning and visual inspection of heritage buildings that would provide a ground for considering such approaches [1, 4, 7–10]. Nonetheless, the presented numbers should not be considered as final proof of the effectiveness of this approach since this system is incapable of diagnosing structural safety of buildings. The paper needs to include a more detailed technical description of the algorithm – architecture, pre-processing, number and distribution of training and test data, annotation procedure, and class-wise precision, recall, F1 score, and confusion matrix. Independence of training and test data should be verified in order to ensure that there will not be any similar pictures of the same defects..

A number of areas within the framework still need to be tested. The platform has not yet been deployed on a live multi-user basis, and its performance under long-term testing by community members or by integration with conservation agencies has not been evaluated. The number of respondents in the interviews is small and they do not include women respondents or non-ghat users. There are 310 pictures in the image dataset and this is from a small sample period; thus, it cannot allow generalization of results to all ghats and under all seasons, lighting and water levels.

Future research efforts should increase photo documentation of other ghats during different seasons, verify the annotation process using independent expert evaluation, and provide reproducible results of model evaluation. A pilot system should be tested among a wider range of users. Usability, traceability of reports, responsiveness, and follow-up inspections based on the observations submitted should be evaluated. The AI system should only serve as a decision support tool, where diagnosis of structural problems, risk evaluation, and decision-making should stay with professionals.

7 Conclusion

Feasibility of using the Kashi Decay Mapper - an AI-based participatory system to document visual decay at selected ghats in Varanasi – was investigated through the use of field documentation, interviews with twenty stakeholders, and prototype analysis of image classification. This research provides a five zone framework for surveys, a taxonomy of six categories of decay, and a five level condition scale that may be used for recording conditions in the different ghats.

The comparative analysis of the levels of deterioration on the three ghat areas, namely Manikarnika, Dashashwamedh, and Assi, suggests clear differences in patterns of visible deterioration on a site level. Manikarnika shows more instances of cracking and biological growth, whereas Dashashwamedh ghat area shows more signs of erosion, displacement, and drainage problems. Biological growth, erosion, and efflorescence have been noticed on Assi ghat area. Poor to Critical ratings have been assigned to drainage for all three ghats. The above observations can only be used as a basis to determine problems which deserve a detailed inspection; however, they cannot be generalized to the whole 84-ghat riverfront.

This proposed platform consists of the community reporting system, the AI-supported triaging system, and the conservation monitoring system. It is designed to help make the observation more organized and trackable rather than replace the professional inspection for structural safety. The interviews have suggested that easy submissions, acknowledgment, and feedback might be critical design considerations. But whether or not these are sufficient to keep the users engaged or change the institutional reaction should be tested through pilot study.

The dataset for images used contains only 310 viable pictures from a limited field study period. The current write-up fails to contain all the information required for reproducing the model evaluation procedure. The sample for interviews has limited number of interviewees and does not include any representation of female residents and non-locals. The proposed framework has not been validated using real user experience or integration with the conservation authority. The future work needs to develop the dataset over the course of different seasons and ghats. It is important to present class wise scores, confusion matrix and annotation agreement results. Independent expert validation and usability/ institutional piloting need to be done.

Under these constraints, Kashi Decay Mapper provides a situation-based tool linking community findings with documentation and initial image processing. The effectiveness of the tool would hinge on sound evidence, broad community engagement, expert monitoring, and a clear institutional mechanism of moving from report to inspection and action.

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