Digitally Documenting Indian Water Heritage: Challenges, Strategies and Standardisation

Maniyarasan Rajendran[1], Athira TP[2]

[1]Associate Faculty, CARE School of Architecture, Trichy, India – maniyarasan@care.ac.in
[2] Project Consultant, World Monuments Fund India – athiratp101@gmail.com

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Abstract

Traditional water systems across India were developed by local communities as adaptive responses to the hydrological needs of the region, shaped by geographic terrain and natural drainage patterns. These systems, comprising *kunds*, *vavs*, *bawaris*, *baolis*, *bawdis*, *kalyanis*, *jhalras*, *johads*, *eri*, *pushkarnis*, *kulams*, among others, represent a diverse and context-specific legacy of sustainable water management. Despite their historical and ecological significance, many of these structures today remain neglected, structurally compromised, or polluted. Yet, in the face of intensifying water scarcity and the escalating impacts of climate change, these vernacular systems offer critical insights into resilient water practices.

This research underscores the importance of documenting traditional water heritage structures as a means of preserving the embedded indigenous knowledge systems and promoting their integration into contemporary water management strategies. It particularly emphasizes the role of digital documentation techniques, which enable the precise recording of the site condition at a specific moment in time. However, the process of digitally documenting such structures poses various technical, logistical, and contextual challenges.

The research paper aims to develop standardized methodologies for the digital documentation of traditional water systems in India. It does so through a typological review of water heritage structures of India, followed by an in-depth analysis of five case studies of digital documentation by the author from distinct geographical regions. By examining the approaches adopted, the challenges encountered, and the mitigation strategies employed in each case, the paper proposes a set of context-sensitive standards and guidelines. In a landscape where technical manuals and standard protocols for digital documentation are limited, this paper aims to serve as a foundational reference for future documentation and conservation initiatives.

1. Introduction

Water is the most important resource for any settlement to flourish and sustain itself. According to NITI Aayog, India is experiencing an unprecedented water crisis, with close to 600 million individuals living under conditions of high to extreme water stress. The country ranks 120 out of 122 nations on the global water quality index, with approximately 70% of its water sources being polluted (NITI Aayog, 2019). Over a span of three years, the count of severely polluted rivers in India has risen from 32 to 45. This surge is primarily attributed to factors such as untreated domestic sewage, inadequate wastewater infrastructure, poor implementation of environmental regulations, and unchecked water extraction practices (NIDM, 2022). As a result, urban areas are facing significant pressure on their groundwater resources.

Against this backdrop, traditional water management systems in urban settings emerge as crucial in addressing contemporary water scarcity challenges. These systems, found in varied forms across India, embody rich reservoirs of indigenous and traditional knowledge, carefully adapted to local geographical features, natural drainage patterns, groundwater conditions, and aquifer locations

1.1 Aims and Objectives

The aim of the research paper is to develop standardized methodologies for the digital documentation of traditional water systems in India. It achieves this through a series of objectives. First, it conducts a typological review of traditional water heritage structures across the country to understand the diversity and distribution of these systems. It then undertakes a detailed analysis of five case studies from different geographic regions, each representing a unique approach to digital documentation. Through these case studies, the paper examines the methods employed, identifies the challenges encountered during the documentation process, and evaluates the strategies adopted to overcome them. Based on these insights, the study proposes a set of context-sensitive standards and guidelines tailored to the Indian context for the effective digital documentation of traditional water systems.

2. Literature Review

2.1 Mapping and Typology of Traditional Water Systems of India

The 2012 United Nations Conference on Sustainable Development (Rio+20) emphasized that water lies at the heart of sustainable development. The Sustainable Development Goal 6 focuses on clean water and sanitation for all. Achieving water security requires the protection of vulnerable water systems, the mitigation of water-related hazards such as floods and droughts, the safeguarding of essential water services, and the integrated and equitable management of water resources (WWAP, 2015).

In urban environments, the primary sources of water typically manifest as groundwater and stormwater. Traditional water systems, in particular, often utilize a combination of these sources, demonstrating sophisticated hydrological knowledge and adaptation to local conditions. Across India, these systems have evolved into a wide variety of forms, including lakes, reservoirs, stepwells, ghats, water channels, and irrigation networks. This study specifically focuses on the typologies of stepwells and tanks, which are prominent examples of traditional water systems found throughout different regions of India. In the Indian subcontinent, stepwells are widely seen in the northernmost and central regions, including Delhi, Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat, and Maharashtra, and in the southern states of Telangana, Karnataka, Tamil Nadu, and Kerala (Piplani and Kumar, 2019).

Medieval architecture incorporated a range of passive cooling techniques, such as harnessing the stack effect, utilizing wind capture and tunnel systems, facilitating cross ventilation, employing sun-shading devices, and making use of diffuse sky radiation. Additionally, the design of open spaces—including *verandahs*, courtyards, and open-to-sky areas within otherwise enclosed structures—played a crucial role in maintaining thermal comfort (Di Turi and Ruggiero, 2017). Similar climatic adaptations can also be observed in the architectural design of Indian stepwells. The stepwells also served as shelter points, providing water for cattle and humans along trade routes (Parmar and Mishra, 2024).

The state of Gujarat is home to a distinctive and architecturally complex form of stepwell known as the Vav, characterized by a traditional well integrated with an underground stepped corridor. These structures were commissioned by the Solankis, the Waghelas, and the Shahs of Gujarat and are notable for their elaborate sculptural artistry, multi-storeyed pavilion towers, and intricate networks of stone pillars and beams that provide structural stability to the side walls (Pawar, 2021; Mistry et al, 2024; Pandey, 2020). Prominent examples of this typology include the Rudabai Ni Vav at Adalaj, Bai Harir Ni Vav in Ahmedabad, and the Rani Ki Vav at Patan.

Rajasthan, one of the most water-scarce regions in India, has developed a rich variety of traditional water management systems. In Jodhpur, these structures are locally referred to as *baoris*, *johads*, and *jhalras*. The *bawaris* of Jaipur, such as the Sarai Bawari and Atreya Bawari, typically feature a series of steps descending toward the water on one side, often accompanied by a well at the opposite end, with arched partitions separating the two. Similarly, the *baoris* of Jodhpur follow a comparable layout but are distinguished by more elaborate surface carvings. Some structures are designed as multi-storeyed, incorporating a bullock-driven water wheel mechanism that lifts water from the well to the first or second level (Bhattacharya, 2015). The galleries and chambers encircling these stepwells were frequently adorned with intricate carvings, serving as cool and tranquil retreats during the intense heat of the summer months (Davies, 1989). The *jhalras* of Jodhpur, exemplified by structures like Toorji Ka Jhalra and Mayla Bagh Ka Jhalra, are usually square or rectangular in plan. They are characterized by crisscrossing steps leading down to the water level and often include a projecting platform along one of the edges.

Several areas of Delhi are home to historic *baolis* (stepwells), among which Agrasen Ki Baoli, the Red Fort Baoli, and Rajon Ki Baoli are particularly notable (Chakrabarti, n.d.). These structures commonly feature multiple tiers, with flights of steps descending toward a rectangular well, parts of which are often submerged. The stairways are flanked by thick masonry walls, and each tier is lined with rows of arched niches. Typically, the upper niches are shallow and primarily ornamental, while the lower niches are deeper, providing shaded spaces that historically served as resting and gathering areas.

Kunds represent another typology of water reservoirs commonly found in the Braj region and parts of Rajasthan. These are stepped tanks, often privately owned either by individual households or specific caste groups (Dhiman and Gupta, 2011). Historically, *kunds* located within forested landscapes (vans) served as scenic and spiritually significant sites, closely associated with the legendary encounters of Krishna and Radha, as well as with rituals performed by other deities in Krishna's honour (Sinha, 2010). While some *kunds* possess naturally irregular edges, others are constructed with deliberate geometric precision, typically in square or rectangular forms, and often feature ghats and elaborately carved architectural details (Sharma, 2024). In addition to their religious significance, these water structures provided essential access to water for cattle. It was also common practice to establish a temple or shrine near the *kund*, commemorating the deity or sacred event linked to the location. Some examples include Radha Kund, Shyam Kund, and Brahma Kund, located in Govardhan.

Around one-third of Tamil Nadu's irrigated land relies on *eris* (traditional tanks) for water. *Eris* has historically served multiple critical functions, including acting as a flood-control system, reducing soil erosion, conserving runoff during heavy rains, and replenishing groundwater in nearby areas. Their existence helped create favourable microclimates in the regions they supported. In the absence of *eris*, paddy cultivation would not have been feasible. Similarly, *ooranis*—small ponds that gather rainwater and runoff from surrounding catchments—traditionally met the drinking, washing, and bathing needs of nearby village communities (Murthy et al., 2022; Bhattacharya, 2015).

Kulams are traditional ponds found in Kerala, typically associated with houses, temples, or serving broader community purposes. While some *kulams* feature simple steps leading to the water at designated sections, others exhibit more intricate designs, including crisscrossing step patterns. A notable example is the *kulam* at the Peralassery Subramanya Temple, distinguished by its series of descending steps and symmetrical layout that together create a striking visual impact. Beyond their role in water storage, these tanks also served an important ritual function, providing spaces for ceremonial purification (Unni, 2024).

Kalyanis are traditional water tanks seen in Karnataka, historically used to collect and store rainwater for everyday purposes such as drinking, bathing, and washing. These structures are typically designed as stone-paved ponds with banks that gradually slope toward a central point, ensuring that only about half of the water surface remains in direct contact with the soil (UT and Murthy, 2013). *Kalyanis* constructed adjacent to temples, known as *Pushkaranis*, held significant socio-religious and cultural importance within Indian traditions, while also serving as reservoirs to supply water for temple activities. Beyond their sacred value, these tanks contributed to the recharge of surrounding wells, which was one of the key reasons why ancient rulers allocated resources for their upkeep.

The regions of Bijapur and Bidar in Karnataka are renowned for their complex historic water management systems, particularly the *bawdis*. Notable examples include the Chand Bawdi, dating to the 16th century, and the Taj Bawdi, constructed in the 17th century. In addition to functioning as vital water sources, these *bawdis* also served as resting places for travellers, offering shelter and respite along their journeys.

India has a rich diversity of traditional water systems, particularly stepwells and ponds. It is essential to document these stepwells and study the traditional knowledge systems associated with them.

2.2 Existing Documentation Techniques in Conservation Practices in India

In India, heritage documentation is predominantly carried out using manual methods, which typically involve the use of measuring tapes, distometers, and hand-drawn sketches. The resulting outputs are generally limited to two-dimensional drawings, including plans, elevations, and sections. This process of data collection is particularly labour-intensive, time-consuming, and often necessitates the involvement of at least two or more individuals. Architectural documentation, condition assessments, and conservation proposals are conventionally produced in this two-dimensional format. On rare occasions, three-dimensional models are created to enhance visual representation and understanding, utilizing visualization and rendering software such as SketchUp, V-Ray, Revit, and Lumion. However, intricate architectural details are often difficult to accurately capture through manual methods, and crucial information regarding the structure's colour, texture, and material qualities is frequently lost in the process.

In recent years, there has been a growing trend towards the adoption of photogrammetry techniques in conservation practices across India. Photogrammetry is the science of obtaining reliable information about the properties of surfaces and objects, using sequential photographs to generate 3D reconstructions (Schenk, 2005). This shift towards photogrammetry is largely attributed to the increasing accessibility and affordability of photogrammetry, as well as the proliferation of training programs nationwide. Conversely, the use of more advanced technologies such as LiDAR and laser scanning remains limited among individual practitioners, primarily due to the high costs associated with the necessary equipment and software. Consequently, the application of such advanced techniques is largely restricted to well-funded institutions and organizations, such as CEPT University and the Indian Institutes of Technology (IITs), which possess the requisite infrastructure and financial resources.

3. Digital Documentation of Water Heritage: Case Studies

To effectively study the design and traditional knowledge systems embedded within water heritage structures, the initial step involves mapping and listing the diversity and distribution of different typologies. Documentation subsequently becomes a critical phase of this process. Heritage documentation is an ongoing process that supports conservation efforts by providing timely and relevant information necessary for monitoring, maintenance, and understanding of heritage sites. It serves both as an action and an outcome, fulfilling the information requirements of heritage management (RecorDIM, 2007).

Although manual documentation methods are feasible, they present significant challenges while documenting water heritage, particularly when different levels of stepwells are difficult to access. In this context, digital documentation techniques, particularly photogrammetry, offer a highly effective alternative for capturing detailed site information. The following section presents selected case studies of photogrammetric documentation of stepwells by the author from various regions of India. Each case highlights distinct challenges encountered during the process and the strategies adopted to address them.

3.1 Bai Harir Ni Vav, Ahmedabad

Project Description: This is a collaborative site-specific exploration of the Bai Harir Ni Vav Stepwell in Ahmedabad, Gujarat, with ASI Vadodara Circle and the University of Melbourne. The study examines the connection between Indian architecture and classical dance, using the digital conservation tool of photogrammetry to facilitate the need for interdisciplinary conservation strategies addressing public engagement and structural conservation. The research proposes simulation-based experimentation to evoke fantasy and abstraction, combining digital tools with choreography to foster visitor engagement. These digital representations offer a unique platform for experimentation and creative exploration, providing opportunities beyond those possible within the physical realm.

Resources: The primary imaging device used for data capture was a Canon 5D Mark IV. A total of 1850 photos were captured in 8 hours, and processed in Agisoft Metashape Professional (Agisoft LLC, 2024) in 10 hours.

Figure 1. Section of Bai Harir Ni Vav Stepwell, Ahmedabad generated through photogrammetry documentation.

Technique: After the pandemic-led restrictions were lifted, photo-scanning of the stepped well was undertaken for two days. The photo scans of the stepped well, including its five levels and the ground level, were then processed in Agisoft Metashape, creating dense point cloud files with mesh and textures. A full-frame digital camera, a wide-angle lens (24mm), and a tripod were used during the data-capturing process. RAW photo files were post-processed and added to the photogrammetry software. Using a tripod was helpful in negating the varying light and shade conditions through the stepped-well. With Metashape point cloud files as base, platforms such as Unity (Unity Technologies, 2024) and Blender (Blender Foundation, 2024) were used to create a 3D model of the site.

After compiling all available data and creating a 3D model of the site in Unity, a week was spent in the motion capture TrakLab at the University of Melbourne. After a few days of setting up the virtual environment alongside the physical setup of the motion capture studio, a sequence of camera positions was choreographed, responding to the architecture visible in the frame. The product of this exploration was a performance in the TrakLab to an invited audience of VCA students and staff, who watched the live movements. One could witness the creative interpretation of the site's architecture, created using photogrammetry, through the virtual performance on the screen. The performance in the virtual site was screen captured as a method of documentation for future dissemination to an audience beyond those present in the studio.

Output: The data output was in the form of a projected point cloud and the 3D model in Agisoft Metashape Professional.

Challenge: The extensive file size as a byproduct of the data capture process from high-capacity cameras and lenses presents a significant challenge in photogrammetric documentation. For instance, this research endeavor required a thorough exploration of the virtual site at a 1:1 scale, generating a sizable 31GB file

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that proved cumbersome to share across two countries. However, compromises on workstation capabilities, graphics card specifications, and internet connectivity were made to mitigate these challenges, and an optimized model was shared for appropriate resolutions.

Bai Harir ni Vav, a stepped well, extends up to five floors below ground level, reaching a depth of approximately 60 meters. While the upper floors receive ample daylight, descending further alters the light quality, posing challenges for capturing continuous detail in photographs. Its inward structure resulted in multiple visible depths at each point, causing multiple copies of the same unit in Photogrammetry, leading to noise blobs in the lower levels of the 3D model. The authors tackled this challenge by dividing the models into multiple segments and transferring them between Agisoft Metashape, Unity, and Blender software. The ultimate compilation of the model occurred in Unity, enabling exploration of the virtual space through motion capture.

The challenges are an opportunity to understand that in the absence of established standards or guidelines, the research relies on exploration and adaptation to progress effectively. Incorporating new media technologies necessitates adapting to available resources, time constraints, and budgetary considerations.

Inference: This research explored the impact of digitized online databases and exhibits on enhancing accessibility to heritage sites worldwide. Photogrammetry plays a crucial role in digitizing and preserving cultural heritage, making it accessible to a global audience. Virtual tours, interactive exhibits, and online resources enable global audiences to explore historical structures remotely. Photogrammetry enables the creation of accurate digital representations, fostering accessibility to heritage sites worldwide, enhancing these experiences, and offering detailed insights into architectural heritage. Detailed photogrammetric 3D models serve as valuable educational tools. Through photogrammetry, intricate details of historical structures are captured precisely, aiding in academic endeavours.

3.2 Modi Ka Chopda, Jhansi

Project Description: The project aimed to digitally record at least four of the structures in the town by the city municipality. Modi ka Chopda, being the oldest and well-known in the locality, was selected as the pilot site for the project. The documentation of the historic seven-level stepwell was done under strict time constraints. Despite environmental challenges, a comprehensive dataset had to be created in a span of 3 days, forming a critical resource for future conservation planning.

Resources: A full-frame handheld camera and drone were used for data capture. Manual documentation was done to capture the profile measurements. A local drone operator was engaged after two days, and the data capture was coordinated remotely. A total of two days were spent on site for primary documentation.

Technique: The photogrammetry was done using a hand-held DSLR and drone-based aerial photographs. Manual measurements were taken for architectural profiles and details. Remote drone operation was done with real-time online guidance to supplement missed captures.

Output: The data output was in the form of a photogrammetric model having the four accessible dry levels that were captured directly. Approximately 900 images were captured from the first four levels, and another 350 additional images of the lower submerged levels were captured for the complete documentation. Manual profile drawings and measurements supported the digital model.

Figure 2. Site plan and section of Modi Ka Chopda, Jhansi, generated through photogrammetry documentation

Challenge: The stepwell presented a unique set of challenges for digital documentation. The team had only two days on site, under the initial expectation that the well would be fully dewatered in advance. However, on arrival, it was found that the seven-level stepwell remained filled with water up to the sixth level—a common condition for this site, even during peak summer months. The dewatering process was delayed due to bureaucratic processes and site management. The site was only partially accessible during the planned field time. Continuous water presence over the years had left the walls covered in moss and other biological growths, making conditions unfavourable for high-quality photogrammetry.

Cultural sensitivities due to the presence of temple spaces and religious activities were another challenge. In the Indian context, the presence of a temple within the stepwell complex meant the structure was actively used. Parts of the stepwell were treated as sacred, with rituals, offerings, and coin tosses taking place, while other areas had degraded into dumping zones. Additionally, coordinating and directing a drone operator remotely without direct on-site supervision was a difficult task.

Inference: This case illustrates the necessity of flexible and hybrid approaches in heritage documentation. Photogrammetry alone was insufficient given the environmental conditions; Manual measurements provided critical supplementary data. It also highlighted the importance of incorporating remote collaboration strategies, especially when site conditions and administrative processes do not align with documentation timelines. In living heritage sites with active religious use, cultural dynamics significantly influence accessibility and require sensitive management alongside technical planning.

3.3 Naganna Bavi, Hyderabad

Project Description: The project focused on capturing the condition of a neglected and vegetation-infested stepwell recently rediscovered through rising heritage awareness efforts in and around Hyderabad. The documentation was pivotal towards supporting ongoing manual conservation surveys and providing detailed photogrammetric models that revealed surface conditions, structural cracks, vegetation coverage, and material decay, significantly aiding conservation planning and heritage revival efforts.

Resources: A full-frame DSLR camera with a wide-angle lens was used, along with a drone for aerial and hard-to-access documentation. On-site conservators supported the manual recording and preparation of drawings in AutoCAD. Initial site cleaning was facilitated by the active interest and support of government bodies and the collaborating organization.

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Technique: Photogrammetry was done using handheld DSLR photography for detailed structural recording and drone-based photography for capturing the overall site surroundings and inaccessible lower levels. Manual drafting was done by the conservators, which was supplemented and enhanced through the photogrammetric references.

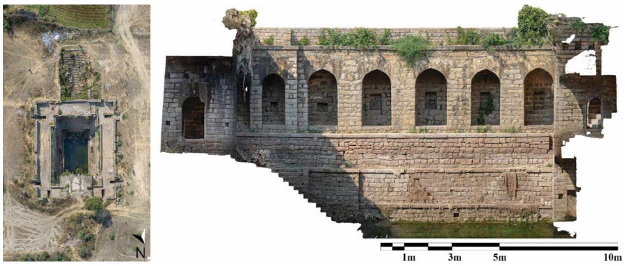

Figure 3. Site plan and section of Naganna Bavi, Hyderabad, generated through photogrammetry documentation

Output: The data output was in the form of a complete photogrammetric model of the site with information on colour, surface conditions, and vegetation growth. Manual CAD drawings were supported and verified with photogrammetric data. The resulting baseline digital record provided a comprehensive indication of areas with vegetation infill, cracks, surface decay, and structural damage.

Challenge: Extensive prior neglect has led to heavy vegetation and root intrusion. The presence of large bat colonies disrupted accessibility and documentation in the initial phases. Partial site clearing necessitated careful working around residual biological elements.

Inference: Early cleaning and site preparation, prompted by broader public awareness, significantly improve the feasibility of documentation projects. Vegetation and biological habitation must be considered in planning both technical and health-safety aspects of fieldwork. Combining photogrammetric models with manual conservation drawings offers a more comprehensive and actionable record, crucial for restoration planning. Photogrammetry provides critical visual and condition data that traditional methods alone cannot fully capture, making it an indispensable tool for heritage conservation projects.

The following two case studies from the Hyderabad & Trichy present documentation in highly context-specific environments, one marked by physical inaccessibility, and the other by symbolic architectural form, thus offering unique insights into adaptive documentation strategies.

3.4 Nilayam Stepwells, Hyderabad

Project Description: The Nilayam Stepwells, located in a region with limited public access and heavy neglect, were challenging to document due to hazardous entry points and deteriorated inner surfaces. The project was undertaken with the help of local labourers and construction workers who facilitated safer access by setting up a temporary safety system with ropes. The documentation required a cradle-like rig to carefully lower the photographer and assistant into the narrow well, one metre at a time, due to the steep drop and unstable steps. This phased descent enabled image capture at incremental depths, ensuring comprehensive coverage while maintaining personal safety.

Resources: The project used a full-frame DSLR with a 24mm wide-angle lens for handheld photography. Manual support was offered by local masons and workers who also participated in handling the safety rig. A secondary assistant accompanied the photographer for guidance and gear support during the descent. Limited light availability inside the well demanded additional lighting through headlamps and reflective gear.

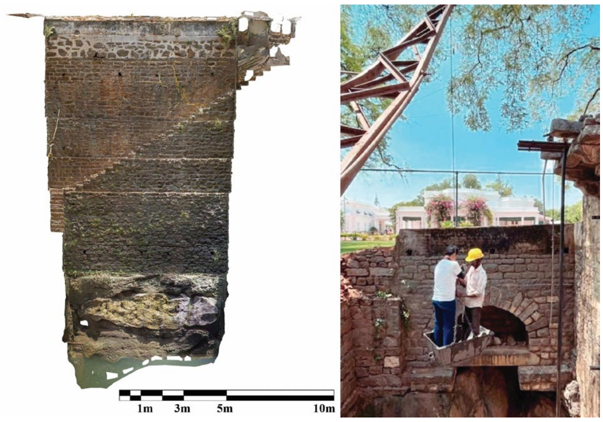

Figure 4. Site section of Nilayam Stepwells generated through photogrammetry documentation (Left), and the apparatus used for data capture (Right)

Technique: Photographs were captured incrementally from top to bottom, at approximately one-metre intervals, with the cradle being gently lowered by two workers above. Each photo was taken from a stable standing position within the suspended platform. The documentation focused on capturing wall textures, step geometry, and the overall spatial configuration. RAW files were processed and compiled using Agisoft Metashape to create a dense point cloud and mesh model.

Output: A complete vertical photogrammetric model of the well interior was created, revealing the state of erosion and irregular stone patterns on the walls. A stitched orthographic section of the shaft was developed. Supporting CAD drawings of sections and key profiles were prepared based on photogrammetry outputs.

Challenge: Safety and access were the primary challenges. The inner wall surfaces were slippery and uneven due to algae and wear, and no permanent access steps were usable. The cradle system was devised on-site with local improvisation. Light conditions were minimal inside the narrow shaft, affecting the photo quality in deeper levels. Furthermore, the confined space and vertical depth required considerable planning to avoid motion blur or loss of balance while operating the camera.

Inference: This case highlights how local collaboration and ingenuity can enable documentation in inaccessible and unsafe conditions. It reinforces that safety measures must precede all documentation activities, and once assured, even rudimentary equipment can achieve high-resolution outputs. The experience also reflects the need for site-specific rigs and improvisation in heritage documentation workflows for subterranean structures.

3.5 Swastik Tank, Thiruvellarai

Project Description: The Swastik Tank, located at Thiruvellarai, Tamil Nadu, is an architecturally unique stepwell distinguished by its symbolic plan. First documented manually in 2018 as part of a student studio, the structure was revisited in 2024 using drone-based photogrammetry. The revisitation allowed for an overlay of digital imaging with the previous hand-drawn documentation to produce a hybrid interpretive model—merging analog interpretation with digital precision.

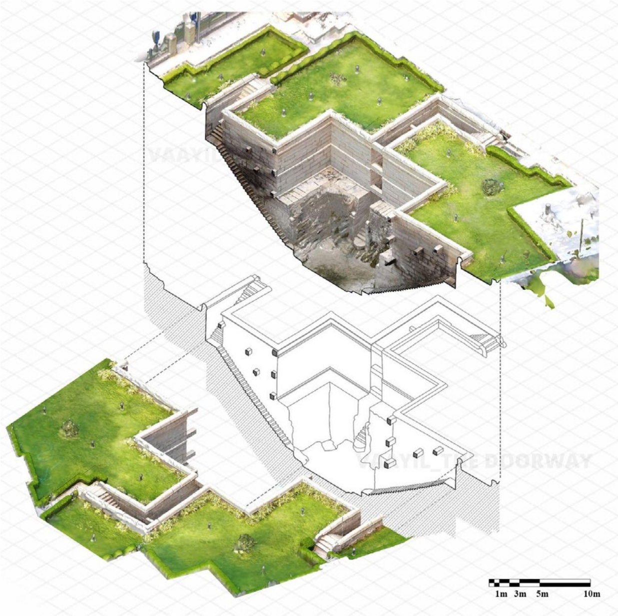

Figure 5. Orthomosaic and sectional visualization of Swastik Tank, Thiruvellarai. Source: Ragul Ravichandran, Vaayil, Coimbatore

Resources: A drone equipped with a 20MP camera and GPS stabilization was employed for the aerial survey in 2024. The original 2018 dataset consisted of manual measurements, sketches, and hand-drawn plans. Students who had participated in the earlier effort supported the digital revisit, offering firsthand comparison of material and form changes.

Technique: A team of students and experts set out to document the stepwell again after 6 years. While one team started traditional documentation, the other started aerial photogrammetry. The drone survey was conducted in orbit mode and nadir mapping to capture the overall shape and proportional layout of the Swastik design. High-overlap images (80%) were processed through Agisoft Metashape. The manual drawings from 2018 were scanned and digitally aligned with the photogrammetry outputs to create a layered visualisation.

Output: A precise orthomosaic and 3D model of the tank were produced, revealing both the geometric integrity and any material alterations over time. The final deliverable was a hybrid drawing set consisting of digitally augmented hand-drawings, section overlays, and photorealistic 3D renders that allowed both narrative and measurable interpretation.

Challenge: Reconciling the hand-drawn documentation with photogrammetry data required geometric calibration and alignment of both outputs. The symmetry of the Swastik plan, while visually evident, posed technical challenges for matching manually recorded line drawings with metric data. Furthermore, coordinating drone permissions in a semi-sacred site required sensitive negotiation with temple authorities.

Inference: The Swastik Tank project reveals the potential of integrating archival documentation with newer digital workflows. It demonstrates how hybrid outputs can retain the narrative richness of hand drawings while leveraging the accuracy of photogrammetry. This also validates the role of long-term engagement and re-visitation in building robust heritage records.

4. Role of Community Engagement in Documentation of Water Heritage

UNESCO defines living heritage as the practices, expressions, knowledge, and skills that are passed down from generation to generation. This includes oral traditions, performing arts, social customs, rituals, festive events, traditional craftsmanship, and knowledge related to nature and the universe (UNESCO, 2019). The 2003 Convention for the Safeguarding of Intangible Cultural Heritage emphasizes the importance of involving communities and individuals in preserving living heritage, recognizing their central role in maintaining its continued relevance and sustainability (UNESCO, n.d.). In the context of stepwells, the community’s continued interaction with the site through rituals, festivals, and oral histories positions them as living heritage, rather than abandoned monuments.

Community participation in documentation can be transformative. It reorients documentation from a passive archival act to an active co-creation of heritage narratives. This collaborative model ensures the continuity of intangible cultural practices, promotes local stewardship, and enhances the sustainability of conservation outcomes (Waterton & Smith, 2010). Community engagement plays a vital and multifaceted role in the digital documentation of stepwells, which serve as important spaces for placemaking within historic urban landscapes (Nikam, 2024). As such, the documentation of stepwells can serve as platforms for dialogue, education, and empowerment. Such documentation processes and digital visualizations align with ‘digital return’, of using digital tools to recontextualize heritage for and with communities, thus democratizing access (Geismar, 2018).

Community as Participants in Documentation: During fieldwork, engagement with both the local public and students is inevitable. Managing curiosity, public interaction, and supervising student teams, as seen in cases like Thiruvellarai, is a practical aspect of conducting documentation activities. Architecture students were formally involved through academic exercises in measuring, drawing, and documentation workshops.

Local Knowledge as Critical Resource: Conversations with local residents often helped identify stepwell locations and provided valuable historical and cultural context, which greatly enriched the documentation process beyond just technical recording.

Digital Outputs as Engagement Tools: Virtual reconstructions, 3D models, and digital visualizations serve as tools to raise public awareness, foster appreciation, and encourage sustainable tourism. They particularly resonate with younger audiences, making heritage more accessible and engaging.

Community Stewardship for Long-Term Preservation: Stepwells are intertwined with the social life of communities. Documentation captures both tangible and intangible heritage—structures, rituals, festivals, and daily practices. Approaches like the "Living Heritage Approach" emphasize that community participation is critical, complementing physical conservation undertaken by official agencies like the ASI.

Citizen Science and Community-Led Documentation: Emerging models encourage communities, especially youth, to actively participate in documentation using simple digital tools. This democratizes heritage documentation, fosters local pride, and strengthens the relationship between communities and their water heritage.

In essence, the community engagement encompasses multiple roles, including those of both managers and participants in the documentation process, as well as sources of crucial information, beneficiaries of digital outputs, and long-term stewards of the heritage. Documentation both benefits from and supports community involvement, ensuring stepwells remain living heritage sites rather than static monuments.

5. Guidelines and Standardisation Framework for Digital Documentation of Water Heritage

The digital documentation of water heritage structures, particularly stepwells, requires a nuanced, context-sensitive, and standardised approach due to their diverse architectural typologies, varying states of preservation, environmental conditions, and social contexts. The proposed framework aims to establish a set of comprehensive guidelines that practitioners, institutions, and communities can adopt for effective, ethical, and meaningful documentation.

The overall framework can be structured in the following divisions:

Pre-documentation planning and assessment: Survey the environmental, structural, and accessibility conditions, prior to planning the documentation strategies. Identify potential challenges, such as water retention, vegetation growth, debris, and public movement. Additionally, securing the necessary permission from heritage authorities, local governance bodies and other stakeholders is crucial. Initiate conversations with the local community to ensure informed participation and consent.

Documentation methodologies and techniques: A multi-scale, multi-tool and inclusive approach should be adopted to achieve results with greater accuracy and information. Employ a combination of handheld DSLR or mirrorless cameras, UAVs (drones), and 3D laser scanners, along with photogrammetry-based software for capturing large sites. The choice of technique should be tailored to the specific site conditions. For example, drones shall be used for inaccessible areas and handheld cameras for detailed elements. Consistent photographic standards must be maintained, ensuring appropriate lighting, exposure settings, and overlap (typically 60–80%) for photogrammetric stitching. Image metadata, including time, location, and device details, should be standardized. Conduct ground surveys for sections, profiles, and elevations using traditional tools like tapes and total stations, where possible, to supplement digital data. Record the environmental conditions, such as humidity, water levels, and vegetation cover, at the time of documentation to contextualize the captured data.

Community engagement and local knowledge: Document oral histories, rituals, and intangible associations with the water structure alongside technical data. Conduct awareness initiatives, workshops, exhibitions, or VR demonstrations post-documentation to return the knowledge to the community.

Post-Documentation use, preservation, and knowledge dissemination: The documentation outputs should be directly integrated into conservation strategies, helping damage assessments, repair planning, and monitoring frameworks. In addition, create monitoring mechanisms for periodic re-documentation and updating records, especially for water bodies that are active or exposed to seasonal and environmental changes.

The key principles to be followed while documenting these water heritage structures include accuracy and integrity of the digital representations, ethical responsibility respecting the community and religious practices, adaptability allowing flexible methods based on site-specific challenges, transparent documentation recording the complete processes, and sustainable efforts that involves conservation and connections, apart from academic record-keeping.

6. Future Scope

Building upon the insights and outcomes of this research, several directions for future work emerge:

- Integration of intangible layers: Future documentation projects can explore the incorporation of oral histories, ritual practices, seasonal use patterns, and memory-mapping techniques into digital models, enhancing the interpretive value of photogrammetric outputs.
- Expanded regional coverage: While this paper focuses on selected sites in India, future efforts can target under-documented regions such as the Northeast, Eastern Gangetic Plains, and tribal areas, where vernacular water systems exist but remain largely unrecorded.
- Longitudinal documentation: Establishing protocols for periodic re-documentation of active or threatened water structures can help monitor degradation, seasonal changes, and post-conservation effects over time.
- Policy and curriculum integration: The proposed standardised framework can inform heritage documentation guidelines by state agencies and be embedded into architecture, conservation, and planning curriculums to build capacity among young professionals.

In summary, the documentation of India’s water heritage is an evolving discipline. By fostering interdisciplinary collaboration, embracing emerging technologies, and centering local narratives, future efforts can ensure that these remarkable structures continue to inform, inspire, and sustain generations to come.

7. Conclusion

The digital documentation of India's water heritage, comprising stepwells, tanks, canals, and reservoirs, is not merely a technical undertaking but a cultural and ecological imperative. These structures are embedded within the environmental, social, and spiritual fabric of the subcontinent. As illustrated through five geographically diverse case studies, the process of documentation is both complex and deeply contextual, shaped by site conditions, stakeholder engagement, and the integration of new technologies with traditional knowledge systems; the journey of documenting water structures is layered, demanding, and immensely rewarding.

This study has demonstrated how photogrammetry and allied digital methods can record physical attributes with high fidelity, enabling the creation of reliable archives that can support conservation, education, and public engagement. Yet, the act of documentation goes beyond capturing form, it becomes a medium for community dialogue, a method for safeguarding intangible heritage, and a tool for advocacy in the face of neglect or development pressures.

By addressing technical, logistical, and ethical challenges across varied contexts, the paper proposes a framework that balances methodological rigour with local adaptability. The integration of citizen science, local stewardship, and hybrid documentation techniques highlights a shift toward democratized heritage practices.

In an era of increasing environmental vulnerability and loss of cultural memory, digitally documenting traditional water systems offers not just preservation but continuity—a way to reconnect contemporary audiences with centuries of ecological wisdom and community resilience. This documentation must not be seen as an end, but as a beginning—catalyzing renewed use, further research, and sustainable management of India's vernacular water heritage.

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