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Valuation of the Environmental Services of an Urban Forest - A Case Study of 'Vetal Tekdi' Pune

By Priti Mastakar[*], Atharva Kulkarni[±], Dhruvika Lakhmani[•], Harsh Uttam[◦], Sibani Singh[•], M.K. Darshan[◦], Robia Kshetrimayum[♠], Srushti Pradhan[♥], Swara Bakshi[♦], Swastik Indalkar[♣], Deboleena Nasker[·], Miheer Karandikar[▽], Munib Ahmad[◠], Padmaja Uttawar[◡] & Rupali Sharma[⊃]

Gross Domestic Product (GDP) remains the measurement of growth and development, and while we struggle to find a more accurate rubric than GDP for an economy's progress, Environmental Economics has developed numerous tools to assess this rubric against a criterion of sustainability. Among these tools is the valuation of environmental services (ES) of an ecosystem in monetary terms. When we protect or sacrifice a certain naturally developed ecosystem that has promoted the health of a population, we are able to assess the value of the ecosystem preserved or destroyed using these tools. The present study conducts the valuation of the ES of Vetal Tekdi, a sixty-five-million-year-old extinct volcano that exists as an urban forest right in the midst of a rapidly growing city of Pune in the state of Maharashtra, India. Named after the temple of the malevolent God of demons 'Vetal', (Nalwalla, 2021), this temple has both heritage and cultural value to add to the ES value besides amenity value, carbon sequestration and the like. Field work for the valuation has been done by young environmental scientists and documented by young economists guided by an expert, and has been presented in this research study. Measurement of value of pristine water of ancient aquifers providing water to the city, carbon sequestration, provision of oxygen, biodiversity, heritage, cultural, and amenity value was conducted and then documented to provide a rubric to assess the benefits as well as the costs of the ES lost if the forest is axed in the name of development. Methodology for this research used, existence value and use value, contingent valuation, hedonic pricing method, expert opinion, and travel cost method. Willingness to Pay was used for the amenity valuation. The study monetises the environmental value of

[*]Professor, Gokhale Institute of Politics and Economic, India.
[±]Arachnologist, India.
[•]Associate at S&P Global, India.
[◦]Sustainability Consultant at Intertek, India.
[•]JSW Foundation Fellow, India.
[◦]Herpetologist, India.
[♠]Project Associate at NCBS, Bangalore, India.
[♥]Data Analyst at S&P Global, India.
[♦]Associate Partner at Capparis Eco Solutions, India.
[♣]MIT WPU, Coordinator, TERI, India.
[·]GIPE, Research Analyst, India.
[▽]GIPE, India.
[◠]GIPE, India.
[◡]GIPE, Research Analyst, Pune International Centre, India.
[⊃]SSE, currently Green Transition and Climate Change Intern at NITI Aayog, India.

the ES to understand the contribution of ES to the health of a population, in an area which is not much researched, namely, urban forests and aquifers. This study, based on primary research, will help further the vital valuation of urban forests which are usually undermined and sacrificed to urbanisation.

Keywords: *urban forest, environmental services, valuation, biodiversity, aquifers, amenity value, heritage value, cultural value.*

Introduction

Pune, in the western state of Maharashtra, India, is a city nestled among the Northwest 'Ghats' (mountains) of India, popularly known as the 'City of Hills'. Some of the hills in Pune include - Taljai Hill, Baner Hill, and the focus of the present study, the well-known Vetal Tekdi, tekdi meaning hill**.** Vetal Tekdi is a sixty-five-million-year-old hill, an urban forest, situated in the heart of Pune city.

The site Vetal Tekdi or Vetal Hill, is an urban forest, a part of 'Bhamburda Van Vihar' (forest department), and is a demarcated forest reserve. Located on the western side of Pune Municipal Corporation within the city limits. Vetal Tekdi is prominent and is visible from and surrounded by residential areas of Pashan, Kothrud, Gokhale Nagar, and Bavdhan. The geographical area is 18º 30' to 18º 32' N and 73º 49' to 73º 52' E covering an area of 10.5 square kilometers (4.1 sq mi) and is 800 meters above sea level. The hill shares the same climatic conditions with that of Pune City. The landscape of Vetal Tekdi is predominantly covered by scrubland species of Casia, and Acacia, along with blooms of the invasive Lantana. Vetal Tekdi, is one of the most well-known landmarks of Pune city. Vetal Tekdi is the highest point inside the city limits from where you can see the horizon and the cityscape. It is an excellent area to spend an early morning or late evening. A beautiful natural oasis in the bustling city of Pune, Vetal Tekdi is home to a variety of birds, trees, and plants and is known as the lungs of the city. It is a major groundwater recharge zone, providing clean and safe water to many of the city's residents. Vetal Tekdi is the pride of Pune, lying in the heart of the city and providing a natural refuge.

Urban forests play a crucial role in city environments, providing ecological, recreational, and cultural advantages to local communities. Vetal Tekdi, a significant reserved green area, exemplifies such an essential urban refuge. Renowned for its biodiversity, tranquil atmosphere, and the spiritual importance of the Vetal Baba Mandir, Mandir meaning temple, the Tekdi is cherished by the people of Pune.

These hills are the green lungs of the city acting as an essential oxygen reservoir. The urban forest, Vetal Tekdi, provides a variety of environmental and ecological services that are vital to the city's sustainability and well-being. As urbanisation pressures increase, it becomes crucial to understand and quantify the value of such ecosystems to ensure their preservation and wise management. This study aims to conduct a comprehensive valuation of the environmental services provided by Vetal Tekdi, utilising multiple methods to assess its economic, environmental, and social benefits.

The Vetal Tekdi urban forest provides multiple environmental services of the wetlands, carbon sequestration, biodiversity, aquifer water, cultural value of the temples, and amenity value for all those who benefit from leisure activities here.

The wetlands were formed out of a quarry when stone was extracted to build Pune's historical buildings, residences, colleges, commercial, and infrastructure of the past. Rainwater accumulation in the quarry over many years now sustains diverse flora, fauna, and even methane-eating bacteria, making it a vital ecological habitat. Today, it serves as a serene recreational and research space, symbolic of sustainable urban renewal, enriching both the environment and community well-being. The diverse tree cover supports varied biodiversity, oxygen production and carbon sequestration. Ancient and new aquifers formed between layers of basalt rock store water that recharges the underground streams and one third of the water supply to the Pune city.

Urban green spaces are essential for the ecological balance and survival of ecosystems, which in turn supports the health, both physical and mental, of a population in cities. Vetal Tekdi, is just one such urban forest, known for its peaceful environment, open spaces for physical fitness activities, other leisure activities, presence of diverse ecosystems, and temples that hold cultural and heritage value. A survey was conducted to assess the amenity value of the urban forest, to estimate the value citizens place on the conservation of the amenities of the urban forest. Citizens were interviewed for their willingness to pay for the protection of this ecosystem and their response was recorded.

The following valuations were conducted for each of the environmental services, valuation of the water, biodiversity and carbon sequestration for the wetlands, carbon sequestration and biodiversity of the tree cover outside the wetlands, valuation of water of the aquifers, assessing the willingness to pay, that is contingent valuation for the heritage and amenity values respectively.

Economic valuation of ecosystem services (EVES) acts as one of the quantification of parameters in environmental risk assessment. Environmental risk refers to the potential adverse effects or harm posed to the environment because of human activities or natural phenomena, the ecological damage, pollution, or degradation of natural resources, and the potential consequences for ecosystems, biodiversity, and human well-being. The assessment and management of environmental risks play a crucial role in ensuring sustainable development and safeguarding the well-being of both present and future generations. Any development activity at Vetal Tekdi will increase this environmental risk, hence assessment and management of risks for the Tekdi will have valuation of its services at its core, the objective of this study. Towards protecting this ecosystem, in the past, several initiatives including the Yellow Ribbon, The Chipko Movement, were undertaken to safeguard the Vetal Tekdi (Prasanthi, 2025)

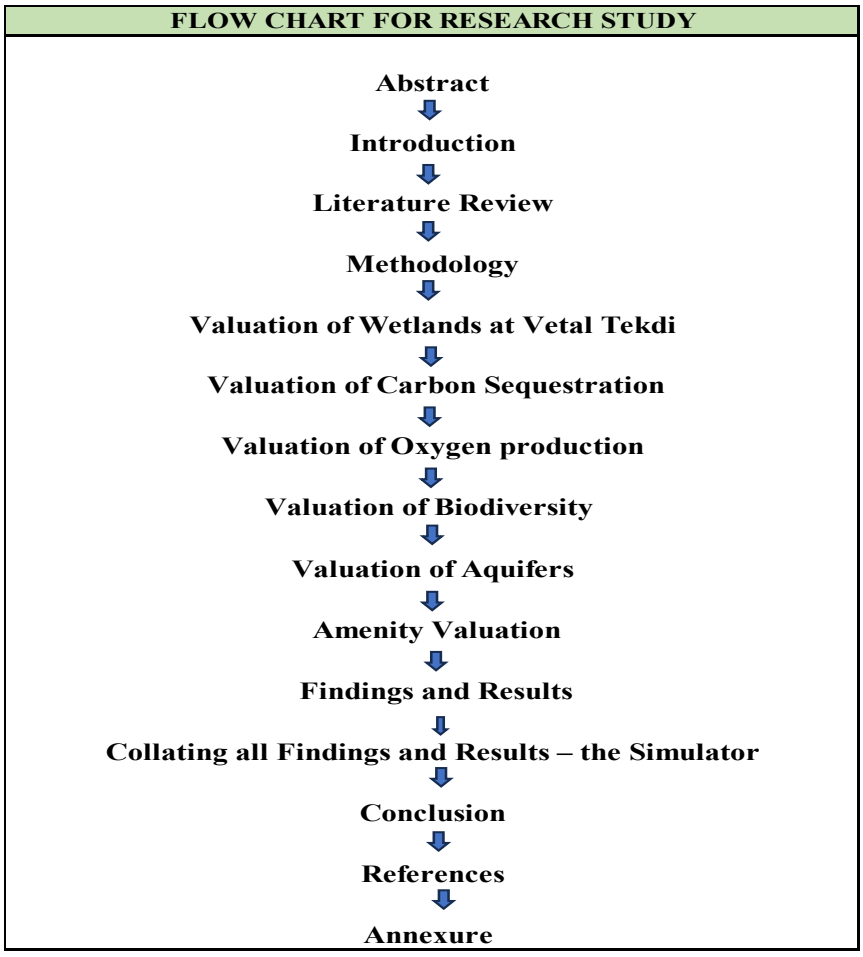
The valuation of environmental and ecological services refers to the process of assigning economic value to the benefits provided by ecosystems. These services are often undervalued because they do not have direct market prices, but they are essential for maintaining environmental health, biodiversity, and the well-being of local communities.

EVES refers to the assessment of the monetary worth of non-market ecosystem benefits, such as those provided by soils, to demonstrate their significance for human well-being and society. The present study on the valuation of the environmental services of the hill aims at using different valuation to derive EVES of the Vetal Tekdi. A simulator integrates all the values to give the total valuation of the urban forest in monetary terms annually.

One of the primary advantages of using EVES in the environmental realm is its ability to consider a wide range of factors and stakeholders. By assigning a monetary value to environmental impacts, such as reduced air pollution or enhanced ecosystem services, EVES allows for more comprehensive and inclusive decision-making (UN, n.d.). Despite being an immensely effective and viable risk management strategy, EVES has certain shortcomings. One of the biggest issues in the analysis is the inability to assign a monetary value to all the benefits identified, the study thus remains conservative in its valuation of the ES of the urban forest.

The research paper first outlines an extensive and recent literature review, followed by the methodology, findings and results, a simulator collating all the valuations gives the final total valuation followed by the conclusion that includes observations and recommendations.

The flow chart for the presentation of the study is presented below:



Literature Review

This literature review covers the various environmental services provided by urban forests and the various types of methodologies and perspectives for the valuation of these environmental services. In this, we emphasise the importance of using different ways of quantifying the economic and non-economic benefits of any environmental/ecological resource to accurately capture the value. First, we begin with a review of the environmental services provided by urban forests and then we move onto the various methodologies that can be used for the valuation of these services.

Ecosystem services (ES) are made up of provisioning, regulating, cultural and supporting services (Meher 2024). Some of these can be directly quantified monetarily, for example, the wood of trees, oxygen production, carbon sequestered can be valued monetarily by using use values, (Callan et al. 2019), however some supporting services like amenity values are difficult to monetise and require to use concepts like willingness to pay, a more abstract concept. Thus, the quantification of the value of the ES is in an area which requires multiple methodologies depending on the nature of the services.

Urban forests provide many provisioning, regulating as well as supporting Ecosystem Services (ES) that contribute to the wellbeing of citizens as well as directly and indirectly to at least nine UN Sustainable Development Goals (SDGs) (Salbitano et. al. 2016). The ES are pollution control, water quality regulation, carbon sequestration, noise reduction, microclimate regulation, recreation, aesthetics and cultural services. People are showing willingness to pay for the associated costs of ecological restoration of natural areas as they realise the direct benefits of urban green spaces (Liu, et al., 2020).

Urban forests provide tree shade that obstructs solar radiation which in turn reduces land and, air temperatures. A 1% increase in tree cover can reduce air temperature by 0.14◦C, and an increase in tree cover from 10% to 25% can bring about a 2.0◦C temperature reduction for 2 meters (Middel et al. 2015).

Urban green spaces can cool land surfaces about two to four times than spaces without tree cover (Schwaab, et al. 2021). Climate change adaptation of local cooling, pollution reduction, and carbon sequestration are other advantages of urban forests and parks (Salbitano et. al. 2016, McPherson et al. 2017, Escobedo et al. 2011, Nowak et al. 2018). Climate regulation through increased tree plantation was observed in California, U.S., (McPherson, et al. 2017).

Cost-benefit Analysis of Urban Forests

Though costs of maintenance of urban forests can be steep, they give more than equal benefits to the population, (Salbitano et. al., 2016). A cost-benefit analysis shows that the benefits to human health far exceed the costs monetarily. For instance, the average annual management cost of USD 19 per tree, gives a benefit of USD 47.83, resulting in a benefit of USD 2.52:1 ratio for 173.2 million trees in California, USA (McPherson et al. 2017).

The regulating services of urban forests include the 'cooling effect' due to shade, interception, and evapotranspiration, cooling the micro-climate, building resilience in the eco system by storing and sequestering carbon thereby mitigating climate change, controlling stormwater runoff, and removing air pollutants (McPherson et al. 2017). Large urban forests can bring a cooling effect of up to 8.4◦ C extending up to 883 m during nighttime vis-à-vis comparative urban sites (Peng et al. 2022). Urban forests help prevent/reduce severe respiratory diseases reportedly, 670,000 and thereby save more than 850 lives annually in the U.S (Novak et al. 2014) through their efficient regulating services of removal of particulate matter (PM10) and ground-level ozone (O_3) air pollutants during summer (Muresan et al. 2022). These climate benefits and avoided expenditures in healthcare are due to urban forests.

Urban forests and its amenities and the interactions therein prevents and restores physical, psychological and emotional health (Taylor et al. 2015). And the restorative benefits associated with regular walking, jogging, strolling, or cycling in urban forest environments with higher tree crown were connected to lesser medicine sales, for cardiovascular problems in people, (Chi et al. 2022). Children get access to green spaces and physical activity thus reducing obesity due to access to urban forests, (Dadvand et al. 2014).

Lessening of clinical depression cases in adults and help with mental health due to urban green spaces was reported, (Frühauf et al. 2016).

There is also evidence of biodiversity of urban forests linkage to mortality rate, (Giacinto et al. 2021). Urban forests with higher levels of biodiversity are associated with a lower mortality rate for heart disease and stroke. Estimates suggest that a 10% increase in urban green space in a community can postpone the average onset of health problems in individuals by up to five years, (Salbitano et. al. 2016).

Increases in urban tree cover and green spaces following extensive tree planting and management that benefits human health and well-being - as well as the spatial expansion of urban settlement - can be better monitored and measured using RS technologies more suitable for larger spatial scales than field survey inventories.

Studies indicate that, (Yang et al. 2024), green viewing, hiking, exercising, biking, and walking, reduced heat due to cooling by shade from tree canopy coverage (74.1%), and, air purification (20.4%), a result of pollution control can extend to a kilometer of the buffer zone.

Urban forests directly and indirectly contribute to the achievement of the UN SDGs by giving many economic benefits, alleviating poverty (SDG 1) of low-income urban residents, improving quality of life and promoting green economies. Food security and nutrition is directly provided through provision of nutritious foods such as fruits and seeds and indirectly by supporting agricultural production by providing wood fuels, high-quality water, and improved soil (SDG2). Forests and other green spaces prevent diseases by removing polluting sources and particulate matter, and ultraviolet radiation and noise pollution, and promoting mental health through amenity value (SDG 3), (Salbitano et al. 2016).

Urban development adversely affects urban forests and associated ecosystem services, these can be minimised with inclusion of urban forests as a non-negotiable part of city planning. ES of urban forests, and access to urban forests are part of

basic services for the health of a population that ensure implementation of UN SDGs (Katila et al. 2019) benefiting city and forest dwellers.

Urban forests offer many economic benefits and boost green economies which can raise the quality of life of low-income urban residents and lift them from poverty (SDG1). Urban forests are also sources of pure water as they filter pollutants from water, and reduce the effects of runoff and flooding in urban areas (SDG 6). Urban forests are also a source of affordable energy due to the replacement of fossil fuel with wood fuel which gives heat and power for low-income people (SDG 7). Entrepreneurship and sustainable employment can be created through investing in urban forests that reduce infrastructure costs and supply ES (SDG 8). Liveable, environmentally sustainable and economically viable cities can be maintained by the presence of urban forests (SDG 11). Carbon sequestration and production of oxygen by trees in urban forests reduce the climate change risk and indirectly save energy and, reduce the effects of urban heat island (SDG 13). Urban forests are sources of biodiversity and, urban wildlife and, they safeguard natural resources (SDG 15), (Ewane et al. 2023).

ES Valuation Methodologies

We first cover some studies that analyse literature on this subject over the years and try to distil findings from them. In (Bockarjova et al., 2020) the authors try to gauge what contingent valuation functions (papers using surveys) look like in different parts of the world to try and create an over-arching function that can be applied everywhere. They then apply it to various cities in Europe. They find decreasing marginal returns based on forest size, income and population density are positively associated. Croci, Lucchitta, and Penati (Croci et al. 2021) define the methods of valuation used for each service and maintain that different types of methods need to be used for valuation to make it more accurate and reflect all the services provided. The study lists the pros and cons of every different valuation methodology for different ecosystem services. In (Söderman et al. 2012), the authors aim to create criteria for measuring, evaluating and assessing various ES in middle-sized urban areas. They use two main databases: the Monitoring System of Spatial Structure (MSSS) and the CORINE Land Cover database. Jim and Chen (Chen et al. 2008) review major studies on ES benefits done in China to evaluate their methodologies and findings. They review the literature on various types of ES across three major cities. They come to a few conclusions and recommendations, mainly on how better studies can be done and how different types of services can be accurately calculated and assessed.

Contingent Valuation (CV) is a method in which surveys are used to find out how much people value a particular environmental resource. (Bernath et al. 2008) do a contingent valuation survey for forests in Zurich using two different methods: bid levels and protest votes for different models of valuation and revenue collection. They integrate a social attitude-behaviour framework because generally, contingent valuation models have large unexplained variation. Messrs del Saz (Salazar et al. 2007) conducted a survey-based study in Valencia to determine the willingness to pay (WTP) for a park replacing a defunct train station. They find that the WTP is

higher in the neighbourhoods close to the park than those away. (Tyrväinen et al. 1998) conducted a study to try and estimate the value of urban forests in a city in Finland. The purpose of evaluating these benefits is to stimulate public awareness regarding the potential of urban forests benefits, to apply the cost-benefit analysis for decision making, and to justify decisions related to urban land use planning and policy making. (Yang et al. 2019) use CV valuations to estimate the relationships between ecosystem services of urban and rural forest areas and the human well-being associated with them. They also attempt to study the differences in this perception between urban and rural areas. (Zegeye et al. 2023) focus on trying to calculate the benefits that citizens would get based on their valuations of urban forest parks (UFP) in the city of Hawassa in Ethiopia. They study the effect of various factors like education level, marital status, number of children, home ownership and others.

Cost-benefit analysis is done by aggregating the monetary value of all the ES in the area based on a central database and the costs of any proposed project to be done on it. (Chen et al. 2008) try to quantify the benefits of a few urban greening projects in Zhuhai City, China. They found that the average perceived benefit would be RMB 161.84 per household per year and evaluated that the greening project would succeed.

Hedonic Pricing Models use market prices of properties differing in access to ES to find out how much people value them. Sander, Polasky, and Haight (Sander et al. 2010) try to estimate the positive externalities caused by afforestation by estimating the changes in house prices as a function of various environmental variables including tree cover. They find that a 10% increase in tree cover within 100 m increases the average home sale price by $1371 (0.48%) and within 250 m increases the sale price by $836 (0.29%). (Tyrväinen 1997) uses the house price values of apartments in a city in Finland to find out the preferences for proximity to green spaces/urban areas are reflected in the prices. The results say that urban forests are an appreciated environmental characteristic, but the specific increases in the city were difficult to find out because of multiple forest areas in the city.

Service Evaluation is the quantification of various ESS based on their biological and ecological functions. These estimates are used in Cost Benefit Analysis. (Aevermann et al. 2015) try and quantify the monetary value of different ecosystem services provided by a park in Munich, Germany. Comparing that to the maintenance costs of the park, they show that the benefits outweigh the costs and that for the select ES (water purification, flood protection) the benefits were €627,586/yr. (Dennis et al. 2016) conducted a study of various types of urban green spaces in the UK to try and estimate the positive impact of complex urban forest systems. They find that collectively managed spaces lead to more impactful urban spaces and that the value of complex natural ecosystems in urban areas is not always accurately captured in assessments of large-scale land. The study concluded that assessments based on landscapes failed to include the provision of a lot of services like microclimate regulation, preservation of genetic diversity and the therapeutic value of engaged community service. (Elmqvist et al. 2015) use the monetary assessments of ecological services from various cities to try and quantify the benefit of restoration of different ES. They then compile the various studies to find out the benefit-cost ratios of

different types of urban green spaces. They conclude that the restoration of any ES leads to massive economic gains and that even cities that don't have massive budgets can gain a lot by doing so. (Langemeyer et al. 2015) assess the monetary and non-monetary benefits of the Montjuïc park in Barcelona. They found that the benefits of a same service differed based on whether it was a monetary or nonmonetary valuation. They also found that people assigned high values to collective experiences and sentiments. Hence, they call for a balanced approach towards valuation techniques and to seriously consider non-monetary benefits as monetary benefits. (Nijhum et al. 2021) use a study of ecosystem services to try and quantify the potential benefits of different scenarios for land use in the future for a lake in Saskatchewan province, Canada. The authors urge the use of land-use assessments in urban land planning and also account for the previous and potential losses of ecosystem services in different types of land use. (Tammi et al. 2017) argue here that there are many different models and perspectives to look at for the valuation of ecosystem services, but there are many discrepancies in the transfer of such frameworks between different types of ecosystems. They recommend using forward-looking surveys to predict land use types and then valuing ecosystems to reflect in urban and land planning.

In a study of valuation of forest services in Himachal Pradesh, India, (Verma 2000), it is found that the total economic value of forests is 2.61 times the value of the growing stock, 980 times the total expenditure incurred by the forestry sector of Himachal Pradesh and 2607 times the revenue realized by the forests annually. This comparison proves gross underestimation of forestry sector's contribution in the economy of the state. When the Gross State Domestic Product (GSDP) of the state is corrected for total economic value calculated through the current study the contribution of the forestry sector increases from 5.26% of GSDP to 92.40% of corrected GSDP.

While reviewing the various literature on valuation of urban forests, the need for an empirical approach using actual use and existence values for monetising the value of urban forests is seen. This study attempts to design an appropriate, empirical methodology for the valuation of each ES listed for the valuation of the ES of the Tekdi, and to suggest appropriate methods of evaluating the efficacy of urban planning projects.

Purpose of the Present Study

Objectives of the research are to primarily carry out a valuation of seven environmental services provided by the Vetal Tekdi, namely: Carbon Sequestration, Oxygen Production, Biodiversity, Aquifers water, Wetland services, Amenity, and Heritage values, this provides a rubric for decision making on projects related to urban forests, whether a development project should be allowed within the urban forest or not, and what would be the loss if such development is allowed.

The novelty of the research study is its empiricity; it is valuing urban forests, aquifers, amenity value, and heritage value on empirical data, all of these services are scarcely researched or assessed.

The research study is based on complete field work and exhaustive, as it encompasses multiple valuations all in a single body of work, viz., valuation of Carbon Sequestration, Oxygen Production, Biodiversity, Aquifers water, Wetland services, Amenity, and Heritage values, and employing all the following methods of valuation of an intangible asset – urban forest: existence value and use value, contingent valuation, hedonic pricing method, expert opinion, travel cost method, Willingness to Pay, and using a simulator that can repeat the valuation every year. The literature review indicates the scarcity of comprehensive empirical research on the valuation of urban forests, aquifers, amenity, through assessing willingness to pay, and heritage value.

Methodology

The site chosen to carry out the valuation of ES is Vetal Tekdi. It is an urban forest of approximately 10 sq kms in size, at the highest point of the city at 800 meters, in the heart of urban Pune. A sample size of approximately one sq km was selected to conduct the field work, and a simulator was created to apply the sample size of one sq km to the valuation of the entire urban forest of ten sq kms. The aquifers were treated separately as one float, that is the aquifers of the entire urban forest were valued together and hence did not have to be converted.

The methodology for this research was to also create a simulator that will assimilate all the values for each parameter automatically to give us the final result, that is the monetary value of the ES of the Urban Forest, Vetal Tekdi, Pune. The forest is surrounded on four sides by residential/commercial sites Gokhalenagar, Pashan, Bavdhan and Kothrud. Land prices were taken for all sites, averaged and added to the simulator, creating a regression. Each ES valuation forms a variable in an equation to which we separately add the land value based on the average values of land surrounding the forest that forms together the regression, viz., Hedonic pricing.

Five environmental services were identified namely:

1. Economic Valuation of Wetland;
2. Economic Valuation of Carbon Sequestration;
3. Valuation of Biodiversity
4. Valuation of Aquifers
5. Valuation of Heritage
6. Amenity Valuation

This study uses five different approaches to value the key services of Vetal Tekdi, each of the services valuation methodology is presented as under:

1. Valuation of Wetlands

Quantification of Economic Values:

Wetlands are crucial ecosystems that provide a range of services, including water filtration, flood control, and habitat for biodiversity. This method involves

estimating the economic worth of these services, considering both direct benefits (e.g., water purification) and indirect benefits (e.g., flood mitigation and recreational value). A second valuation of water by market price, and expert opinion valuation for biodiversity was done.

One of the important roles of wetlands is that they perform functions more cost-effectively than engineering solutions. The economic value of such environmental goods, services, and commodities can be measured by the summation of many individuals' willingness to pay for them. In turn, this willingness-to-pay (WTP) reflects individuals' choice for the goods in question.

The economic value of wetlands includes both tangible and intangible values. Wetland use values are associated with a diverse and complex array of direct and indirect uses. Values provided by the wetland can be derived from outputs consumed directly, such as food, water supply, recreation, or timber; indirect uses arise from the functions occurring within the ecosystem, such as water quality, flood control, future direct or indirect uses such as biodiversity, and conserved habitats. Table 1. below shows the various values and benefits of wetlands:

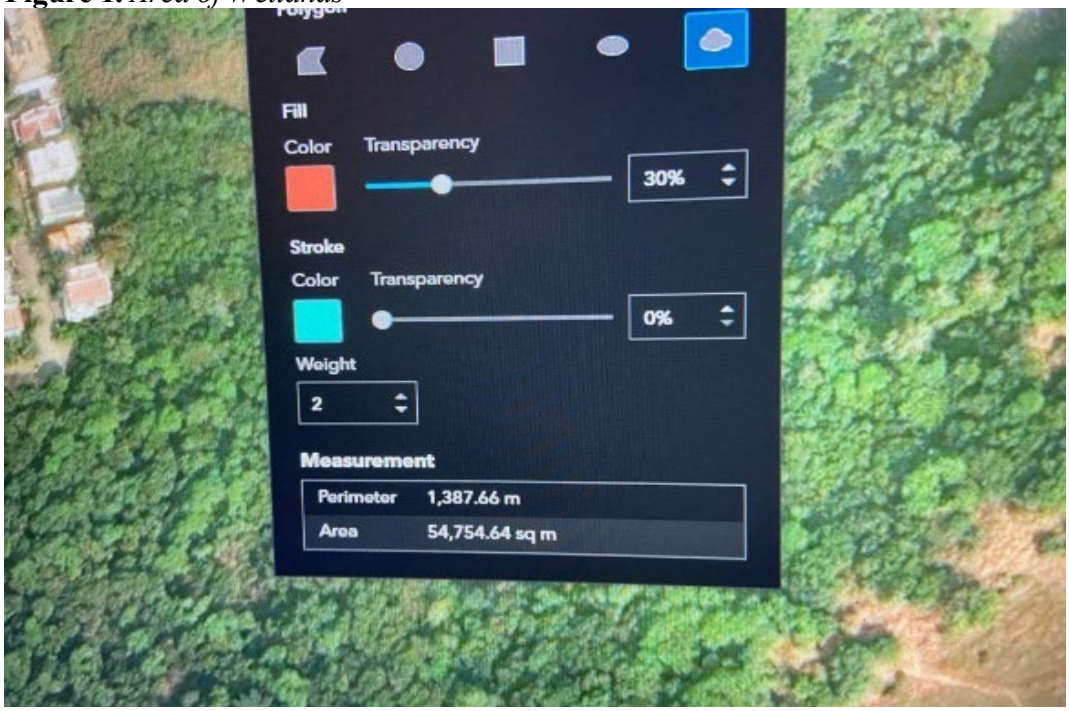
Table 1. *Use and Non-Use Benefits of Wetlands*

Use Value/Benefits			**Non-Use Value/Benefits**
Direct Use Benefits	**Indirect Use Benefits**	**Opinion and Quasi-option Benefits**	**Existence Benefits**
Recreation: • Fauna (Birds, Animals, Reptiles, Amphibians, etc.) • Wildlife • Viewing • Walking • Fishing	• Biodiversity Conservation • Flood Regulation • Ground water recharge • Carbon Sequestration • Water purification	• Potential future uses (as per direct and indirect uses) • Future value of information, eg., pharmaceuticals, education.	• Biodiversity • Culture • Heritage

Source: Authors

Using a Geographic Information System (GIS) tool, we calculated the amount of land covered by wetlands at the Tekdi to be 54,750 sq. m. as shown in Figure 1 below. The perimeter of the wetland area is approximately 1390 m (Figure 1), to estimate the depth of the water, we consulted primarily (Ramchandra et al., 2005) and estimated it at 3 feet. the water quantity will be: Area x Depth, that is 49,140,000 litres. Monetary valuation is presented in findings.

Figure 1. *Area of Wetlands*



Source: Authors

2. Valuation of Carbon Sequestration:

Vetal Tekdi, like other green spaces, plays an important role in carbon sequestration, helping to mitigate climate change by absorbing atmospheric carbon dioxide. This valuation method assesses the economic value of carbon storage and sequestration by estimating the monetary worth of the carbon captured by the vegetation on Vetal Tekdi. Field work measuring the carbon sequestration was conducted.

To ensure unbiased sampling, the study was conducted across three distinct landscape types within Vetal Tekdi:

- Wetland
- Scrubland
- Slope

From each landscape type, five quadrants measuring 10 x 10 meters were selected for sampling. Within each quadrant, all trees were recorded, and their girth at breast height (GBH) was measured. The species name of each tree was also documented. Monetary value calculations are presented in Findings.

3. Valuation of Biodiversity:

Biodiversity within ecosystems like Vetal Tekdi provides a wide range of services, including pollination, genetic diversity, and resilience against environmental change. This method estimates the value of the biodiversity on the hill by considering the intrinsic worth of species preservation, potential medicinal resources, and the ecosystem's ability to maintain a balanced and resilient environment. Experts of

biodiversity were consulted, and their ranking of species in monetary terms was used for the valuation.

Vetal Tekdi hosts a rich biodiversity of Odonates (damselflies and dragonflies), Lepidopterans (butterflies and moths), and avian species (birds). Understanding the perspectives of experts in conservation is crucial for effective management and preservation of these taxa. In this section, we use conservation valuation questionnaires provided by experts for odonates, butterflies, and avian species (Mrs. Monali Shah) to calculate the economic cost of conservation of these taxa.

First, we scoured through existing literature to identify the species of the three taxa previously recorded on Vetal Tekdi. We then selected experts to give their valuation in monetary terms. We identified and selected Mr Arajush Payra for odonates, Mr Narendra Bhagwat for lepidopterans (butterflies), and Mrs. Monali Shah for avians (birds). They were chosen for their experience/expertise in their respective field as well their familiarity with the species diversity of Vetal Tekdi.

Three questionnaires were then drafted, each specialized to one of the above-mentioned groups, consisting questions highlighting their experience and their opinion on what would the monetary value if it could be evaluated based on their experience. Once the response was collected, it was summarised and analysed, and are presented in the findings and results.

Due to the absence of literature, estimates of the number in any species, and an accurate or standardized tool for measuring the value of conservation, we opted to use expert opinion as one of the prescribed methods for monetary valuation of species. Expert opinion is particularly valuable in this context, given the complexities and nuances involved in estimating the worth of ecological contributions that are difficult to quantify through traditional means.

While the more tangible aspects of the species' value, such as their role in carbon sequestration and nutrient cycling, were considered, these estimates are likely negligible as compared to the value provided by the vegetation. Results are presented in the findings.

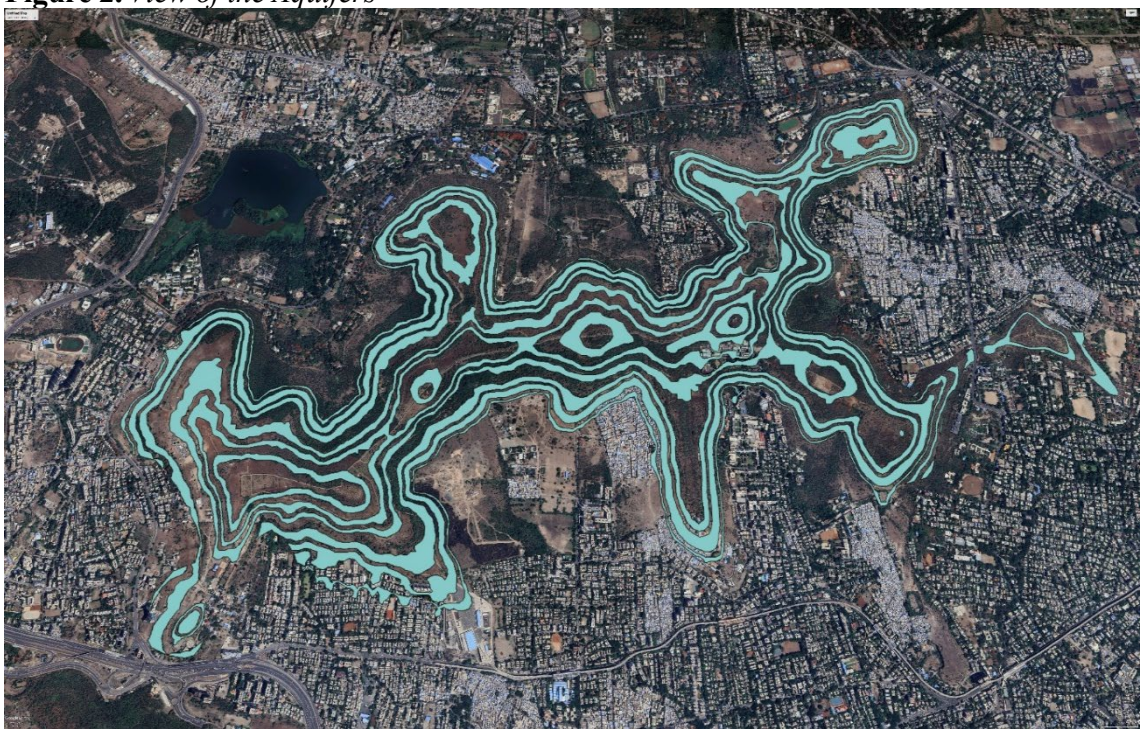
4. Valuation of Aquifers:

The aquifers and groundwater recharge services provided by Vetal Tekdi are essential for sustaining the water supply in the region. This method involves calculating the economic value of the ecosystem's role in replenishing aquifers, ensuring water availability for agriculture, human consumption, and industrial use. Market value of water gave a second valuation of the aquifers.

Visualisation and calculating water quantity

The Advanced Centre for Water Resources Development and Management (ACWADAM) provides valuable data about aquifers. This data includes the identification **(**ID**)**, length, area (in various units), and other details about each aquifer present in Pune, the Vetal Tekdi included. We have imported this data into Google Earth Pro software to create a layer from the shared vector file shown in Fig.2. below. This allows us to visualize the aquifers' locations and sizes in a geospatial context. (WC_95_52.pdf).

Figure 2. *View of the Aquifers*



Source: ACWADAM

Next, we have imported this vector information into Excel to further analyse the data. Through this we calculate the potential storage within the effective thickness for each aquifer by multiplying the given area (in square kilometres) by its respective effective thickness. This gives us the potential aquifer storage over the exposed area. We then multiply this value by a specific yield of 0.04 to get the potential storage within the effective thickness. Finally, we convert this value into cubic millimetres (Mm) to obtain the potential aquifer storage in Mm for each aquifer.

5. Amenity Valuation:

Vetal Tekdi is not only a natural ecosystem but also hosts green spaces for health activities like walking, jogging, and is a cultural and historical landmark. This method focuses on estimating the amenity value, which includes heritage value, recreational, aesthetic, and cultural values. Contingent valuation was used here. It involves assessing how the presence of a green space like Vetal Tekdi enhances property values, provides recreational opportunities, and contributes to the overall physical and mental health of citizens. Hedonic pricing was used for the pricing of the land of the urban forest.

Through these valuation methods, the study seeks to provide a holistic understanding of the contributions Vetal Tekdi makes to the environment, and society. The results will offer insights for policymakers and stakeholders to make informed decisions about the conservation and sustainable management of this critical urban ecosystem, and their environmental value estimated in this study.

Urban green spaces are essential for the ecological balance and survival of ecosystems, which in turn supports the health, both physical and mental, of a

population in cities. Vetal Tekdi, is one such urban forest, known for its peaceful environment, open spaces for physical fitness activities, presence of diverse ecosystems, and temples that hold cultural and heritage value.

A survey was conducted to assess the amenity value of the urban forest, to estimate the value citizens place on the conservation of the amenities of the urban forest. Two hundred and fifty citizens were interviewed while they were engaged in various leisure, fitness and study activities.

In the upcoming section, findings and results for the economic valuation of above mentioned five environmental resources have been presented.

Findings and Results

1. Value of Wetlands:

As mentioned in the methodology, we calculated the perimeter of the wetland area as approximately 1390 m, and estimated the depth of the water at 3 feet, using (Ramchandra et al., 2005), the water quantity was assessed at: Area x Depth, to be 49,140,000 litres.

Multiplying the water quantity with the use value defined by the market price of drinking water at Rs. 20 per litre, we got the final value of Rs. 98,28,00,000.

$Area\ of\ the\ Tekdi = 10{,}50{,}000\ m^2$
$Area\ of\ the\ Quarry\ on\ the\ Tekdi = 54{,}000\ m^2$
$Estimated\ Average\ Depth\ of\ the\ Water\ present = 3\ feet$
$= 0.91\ metres$
Thus, $the\ Volume\ of\ the\ Quarry = 54{,}000\ m^2\ \times\ 0.91\ m$
$= 49{,}140\ m^3$
Since, $1\ cubic\ metre\ of\ Water\ contains\ 1000\ litres\ of\ water,$
$49{,}140 m^3\ of\ water\ will\ have = (49{,}140\ \times\ 1000)\ L$
$= 4{,}91{,}40{,}000\ Litres\ of\ Water$
$According\ to\ the\ current\ market\ rate\ of\ mineral\ water\ at\ INR\ 20\ per\ litre,$
$Price\ of\ the\ total\ water\ present\ in\ the\ Quarry = Rs.\ (20\ \times\ 4914000)$
$= Rs.\ 98{,}28{,}00{,}000$
$= \$\ 11{,}56{,}643.21.\ (Value\ in\ US\$\ as\ of\ 4\ July, 2025)$

2. Valuation of Carbon Sequestration

Determination of Bio-volume:

Bio-volume (b) was calculated using the following equation:

$$b = 0.4 \times (GBH/\pi)^2\ \times\ H$$

Where,

$D =\ (GBH/\pi)$, represents diameter calculated of the tree trunk, assuming the trunk to be cylindrical

$H =$ Height of the tree

1. Estimation of Biomass

Biomass was calculated as:

$$Biomass =\ Specific\ gravity\ of\ wood\ \times\ b$$

The specific gravity (wood density) of each tree species was obtained from publicly available databases:

Bangladesh Forest Information System
World Agroforestry Wood Density Database

2. Carbon Sequestration Rate:
   The carbon sequestration rate was estimated as 1% of the standing biomass.

Results:

Site 1. *Wetland*

Total Carbon Sequestrated (Scrubland):	107434.0095
	118.42 tons

Source: Authors

Figure 3. *Site 2. Grassland*

Source: Authors

Figure 4. *Site 3: Slope*

Source: Authors

Total Carbon Sequestrated (slope):	12551.45508
	13.83 tons

$$Area\ of\ the\ Tekdi = 10{,}50{,}000\ m^2 = 10.50\ Square\ Km \quad (1)$$

$$The\ average\ of\ the\ carbon\ sequestrated\ in\ whole\ Vetal\ Tekdi = 46.86\ ton/Square\ Km \quad (2)$$

$$According\ to\ the\ World\ Bank\ the\ value\ of\ carbon\ is\ \$40/ton \quad (3)$$

$$So, value\ of\ the\ total\ Carbon\ Sequestered = \$\,40 \times 46.86$$
$$= \$1859.2$$
$$= Rs.\,161{,}486.99$$
$$or, Rs.\,161{,}487/year$$
$$or, \$\,1{,}900.52\ \boldsymbol{/year}$$
$$(Value\ as\ of\ US\$\ as\ of\ 4\ July, 2025)$$

3 Oxygen production:

$$Number\ of\ tress\ in\ all\ five\ quandrants = 302$$

Calculation of oxygen production in tress is as follows:

$$Oxygen\ production\ ability\ of\ prtective\ tress = Number\ of\ tress \times 1.2\ kg/day$$
$$or, 438\ kgs\ per\ year$$

(Kusminingrum, 2008).

$$302 \times 1.2 = 362.4\ kgs/day\ for\ 5m \times 5m\ quadrant/day$$

or,

$$302 \times 438\ kgs$$
$$= 132{,}276\ kgs/year\ for\ a\ 5m^2\ quadrant$$
$$\times 194\ m^2\ for\ the\ entire\ tekdi\ of\ 0.97\ sq\ km$$
$$= 25{,}2661.544/year\ for\ tekdi\ area$$
$$25{,}661.544 \times \$3 = \$\ 76{,}984.632/year$$
$$= Rs.\ 6{,}694{,}583.59872$$
$$= approximately\ Rs.\ 66{,}94{,}584/year$$
$$= about\ \$\ 78{,}787.62/year\ (Value\ as\ of\ US\$\ as\ of\ 4\ July, 2025)$$

3. Valuation of Biodiversity

Results of the Biodiversity Expert Opinion survey are presented in Table 2 below.

Table 2. *Expert Valuation of Biodiversity*

Category	Odonates	Butterflies	Birds	Observation
Willingness to Spend on Conservation	₹2000 (damselflies & dragonflies)	₹1000 (butterflies & moths)	More than ₹4000 annually	Variability across taxa; birds have the highest value, indicating differences in perceived value or ecological importance.
Expenditure on Surveys	₹50 on average for surveying	₹200 on average for Lepidopterans	₹250 per visit for bird surveying	Variation in surveying costs; birds and butterflies have higher costs compared to odonates.
Ecosystem Benefits	Habitat quality indicator	Pollination, food chain	Aesthetic value, pollination, seed dispersal, negative economic impact with forest loss	All taxa contribute to ecosystem services; birds are valued aesthetically, while butterflies and odonates are emphasised for ecological roles.
Service Charge for Ecological Services	₹1,000	₹1,000	More than ₹600	Consistency in willingness to charge; birds show a higher threshold for service charges.
Monetary Value for Conservation	Not specified	Not specified	>₹20,000 for a significant bird; ₹1000 for	Birds have a significant monetary value for conservation, highlighting their perceived importance.

			migratory species	
Perception of Climate and Habitat Change	Not addressed explicitly	Not addressed explicitly	Negative impact on economic value with forest loss	Only the bird questionnaire explicitly mentions climate and habitat change, indicating variations in how taxa are perceived to be affected.

Source: Authors

We can see from the table that the willingness to spend on conservation varies across taxa, with birds being considered of the highest value. Surveying costs also vary, reflecting the differing methodologies and complexities of studying each taxon. Ecosystem benefits are recognized for all taxa, emphasizing their unique roles in the ecosystem. Service charges for ecological services are generally consistent, showing a recognition of the value of these services. Birds show a higher emphasis on the monetary value of conservation, possibly skewed by a few species. They also are the most prone to habitat damage due to climate change.

Value of Biodiversity: each species valuation was calculated for one representative quadrant, there were ten such quadrants:

a. Odonates & Dragonflies: ₹ 54,000 X 10 = ₹ 5,40,000 (one quadrant multiplied by10)
b. Invertebrates: ₹ 2,46,000 X 10 = ₹ 24,60,000 (one quadrant multiplied by10)
c. Butterflies: ₹ 87,000 X 10 = ₹ 8,70,000 (one quadrant multiplied by10)
d. Birds: ₹10,96,000 X 10 = ₹ 1,09,60,000 (one quadrant multiplied by10)
TOTAL = ₹ 14,830,000 or approximately US $ 173,207 annually.

Valuation of Aquifers

Valuation of Aquifers by Water Treatment Cost

Considering the total water demand for Pune in 2020, (PMC,2014)) which is 1,906,260 cubic meters per day (or 1906.26 MLD, million litres per day). The operation and maintenance cost of the water treatment plant in 2020 is Rs. 2,833,600,000 (or Rs. 283.36 crores).

The cost per cubic meter of water treatment is calculated as follows:

$$\begin{aligned} Cost\ per\ cubic\ metre &= \ Total\ Demand\ /Total\ Cost \\ &= 1{,}906{,}260\ m^3/day/Rs.\,2{,}833{,}600{,}000 \\ &\approx Rs.\,1486.34\ INR/m^3 \end{aligned}$$

This means that the cost of treating one cubic meter of water is approximately Rs. 1486.34.

Here, we considered the monetary/commercial value of this water. It provides a different perspective on the way we see aquifers as it not only saves the Pune Municipal corporation the water treatment cost. However, it also represents a monetary/commercial value of itself (which we have assumed to be 20rs per litre)

Valuation of Aquifers by Water Market Value

Estimating water quantity in the aquifers:

Table 3. *Water Storage in Aquifers*

Aquifer	Area (Sq. Km)	Area (Sq. m)	Aquifer thickness (m)	Effective thickness at 70% of the mapped thickness (m)	Potential aquifer storage within effective aquifer thickness over exposed area and with a specific yield of 0.04 (Cubic m)	Potential aquifer storage (Cubic mm)
Aquifer-16	0.02435	24,350	11	7.7	7499.8	$7.4998*10^{12}$
Aquifer-17	0.215	2,15,000	6	4.2	36120	$3.6120*10^{16}$
Aquifer-18	0.39686	3,96,860	4	2.8	44448.32	$4.444832*10^{16}$
Aquifer-19	0.6851	6,85,100	4	2.8	76731.2	$7.67312*10^{16}$
Aquifer-20	0.71865	7,18,650	9	6.3	181099.8	$1.810998*10^{17}$
Aquifer-21	0.88302	8,83,020	14	9.8	346143.84	$3.4614384*10^{17}$
Aquifer-22	0.2714	2,71,400	3	2.1	22797.6	$2.27976*10^{16}$
Aquifer-23	0.043	43,000	6	4.2	7224	$7.224*10^{15}$
Aquifer-24	0.00798	7,890	7	4.9	1564.08	$1.56408*10^{15}$
Aquifer-25	0.02324	23,240	12	8.4	7808.64	$7.80864*10^{15}$
Total	**3.2686**	**32,68,600**			**731437.28**	**$7.3143728 *10^{17}$**

Source: Authors, derived from ACWADAM report

Where, Potential Aquifer storage = Effective thickness x Area x Specific yield
So, Table 3,

$$\begin{aligned} &Converting\ the\ total\ Potential\ Aquifer\ Storage\ to\ Litres \\ &= (7.3143728 \times 10^{17}\ cubic\ millimetres) \times 10^{-6} \\ &= 7.3143728 \times 10^{11}\ Litres \end{aligned}$$

$$= 7{,}31{,}43{,}72{,}80{,}000\ Litres$$
$$or, 73{,}143.728\ Crore\ Litres$$

Thus, since the value of a bottle of mineral water is Rs 20 per Litre, the value of potential aquifer storage in Rupees (Rs.) is

$$= 7{,}31{,}43{,}72{,}80{,}000 \times Rs.20$$
$$= Rs.1.4628746 \times 10^{13}$$
$$= 1{,}46{,}28{,}74{,}60{,}00{,}000$$
$$0r, Rs.14{,}62{,}874.6\ Crores\ or, \$\ 172{,}163{,}657{,}762$$

Results-Discussion

Between 2011 and 2021, Pune's Urban Agglomeration grew by approximately 30%, reaching an estimated total of around 6.57 million residents from 5.05 million (as per the last census data). As of 2025, it is expected to be around 7.4 million. As the population grows, the demand for domestic and non-domestic water usage increases proportionally, so does the total water demand, (PMC 2014).

Hence, aquifers play a key role as they are a natural source of clean water. Expressing the water in terms of litres makes it easier to comprehend their amounts. We then use *table 3*, where we see area, thickness and potential storage within each and every aquifer. We convert the total amount of water present in all aquifers, reaching 7,31,43,72,80,000 Litres or 73,143.728 Crore Litres.

To express this quantity of water in monetary terms, we used the market value of a one litre of drinking water, that is, multiplied the quantity (in litres) with the rate/price of mineral water per litre i.e. Rs 20. Doing that gave us the resultant amount Rs. 1,46,28,74,60,00,000 or Rs. 14,62,874.6 Crores.

The Pune Municipal Corporation receives an annual water supply of 12.8 TMC (Thousand Million Cubic feet) which is around 36,24,55,636,378 Litres (3624 Crore Litres), while they need around 21 TMC to keep up with the demand. 21 TMC equates to 5,94,65,37,78,432 Litres or 59,465 Crore Litres of water, (PMC 2014). This puts into context not only the demand for water but also how indispensable the water storage of the Aquifers in the Vetal Tekdi of Pune truly is.

Data taken from:

- WATER SUPPLY SYSTEM FOR PUNE CITY DETAILED PROJECT REPORT FEBRUARY, 2014
- An economic analysis of groundwater markets and water use efficiency in hard rock area of Hosur union Krishnagiri district of Tamil Nadu.

Data Analysis - Amenity Valuation

Introduction

Urban green spaces are essential for the ecological balance and survival of ecosystems, which in turn supports the health, both physical and mental, of a population in cities. Vetal Tekdi, is one such urban forest, known for its peaceful environment, open spaces for physical fitness activities, presence of diverse ecosystems, and temples that hold cultural and heritage value.

A survey was conducted to assess the amenity value of the urban forest, to estimate the value citizens place on the conservation of the amenities of the urban forest. Two hundred and fifty citizens were interviewed while they were engaged in various leisure, fitness and study activities.

The analysis of the survey is presented in this section, it is divided into four parts: A. demographics, B. the significance of Vetal Tekdi, C. cultural value of Vetal Baba Mandir, and D. access and transportation logistics.

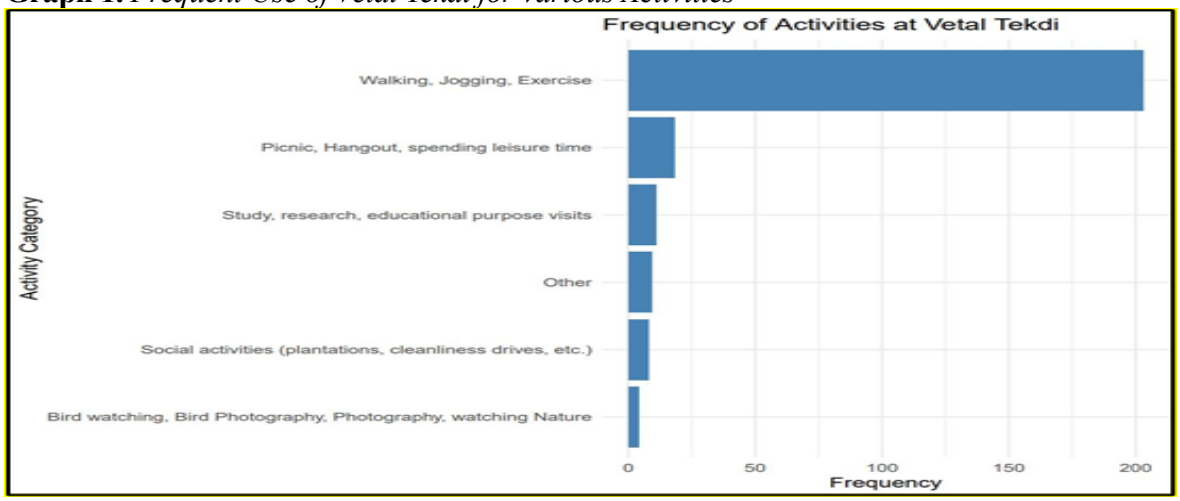
Section A

This section briefly outlines the demographic profile of the survey, majority of respondents were in the 20–50 age group, with limited representation from those over 70. Around 58% of participants identified as male and 41% as female. Most respondents reside in neighbourhoods near Vetal Tekdi, such as Kothrud, Panchavati, and Bavdhan. Income-wise, a large share of respondents reported annual earnings above ₹12 lakhs, indicating a middle- class income group (graphs in annexure 1).

Section B

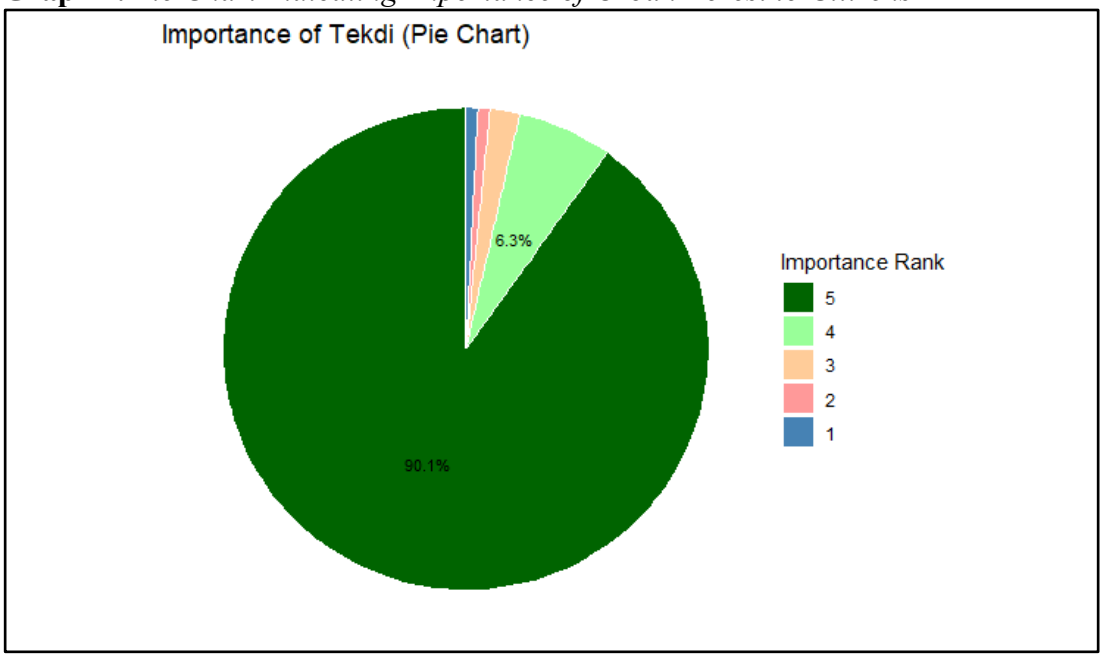
Section B highlights the diverse significance of Vetal Tekdi, focusing on its recreational use, public benefits, and support for conservation.

Graph 1. *Frequent Use of Vetal Tekdi for various Activities*



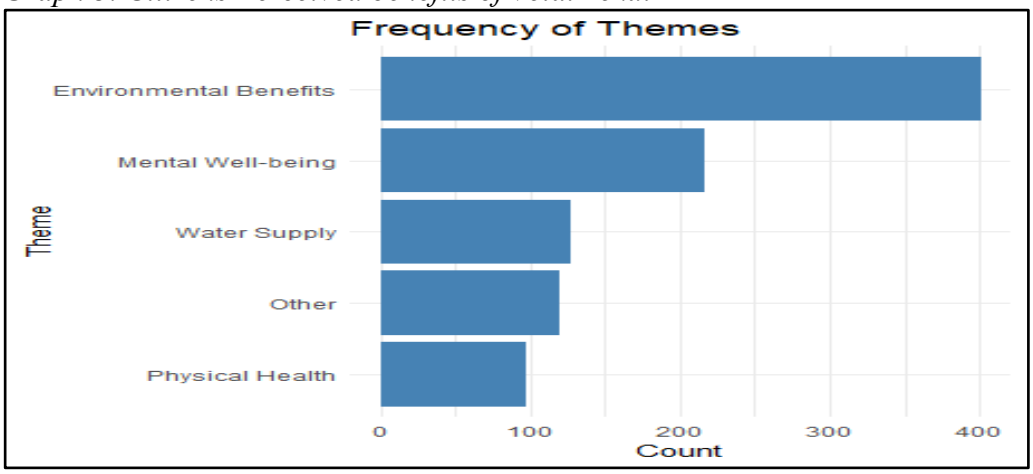
Survey data shows that walking, jogging, and exercising are the most common activities, making the Tekdi a key space for physical fitness. Less frequent uses include various leisure, study, and nature-based visits, indicating that while the Tekdi serves various purposes, its primary role is promoting health and well-being, (Graph.1). Survey shows that a vast majority of respondents, approximately 95% reported visiting Vetal Tekdi indicating a broad public engagement with the Tekdi.

Graph 2. *Pie Chart Indicating Importance of Urban Forest to Citizens*



The pie chart (Graph 2) alongside shows that 90.1% of respondents rated Vetal Tekdi as highly important (5 on a 5-point scale), reflecting strong public support for its preservation and consensus on the Tekdi's significance.

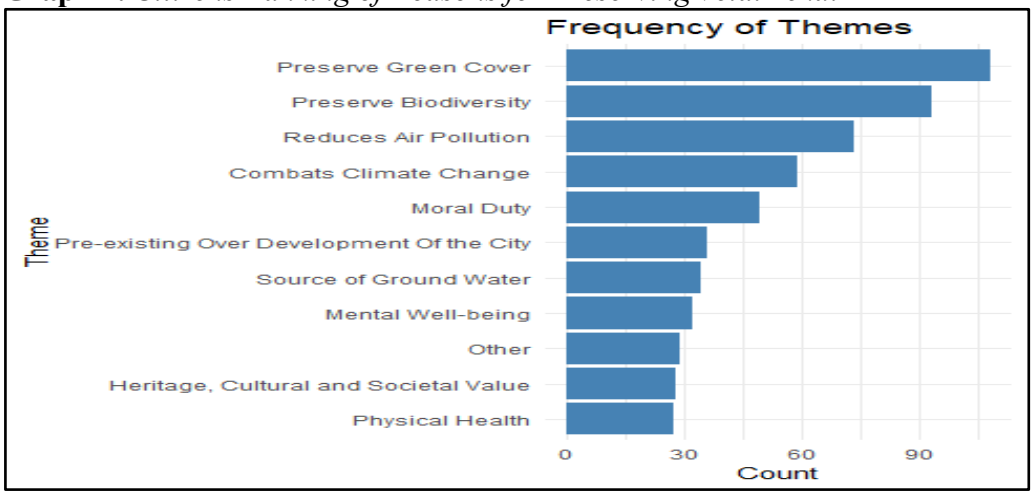
Graph 3. Citizens Perceived benefits of Vetal Tekdi



Graph 3 presents citizens perceived benefits of the urban forest - Vetal Tekdi. Grouped into five categories. "Environmental Benefits" was ranked the highest (401 times), followed by "Mental Well-being" (216 times), and "Water Supply" (127). "Others" and "Physical Health" were mentioned less preferred. It was interesting to note that citizens placed more value on environmental benefits and mental well-being, underscoring the Tekdi's ecological and emotional significance to the public.

Graph 4., the bar chart alongside categorises respondents' reasons for supporting the preservation of Vetal Tekdi into 11 themes. The most cited reasons include preserving green cover and biodiversity, followed by reducing air pollution and combating climate change. Mid-tier concerns involve moral duty, overdevelopment, and groundwater preservation, while fewer mentions were made of mental well-being, heritage, and physical health. Overall, the data highlights a strong ecological and environmental motivation behind the public's overwhelming support for preservation. These findings suggest that citizens view the Vetal Tekdi as a vital natural asset integral to the city's environmental health and sustainability.

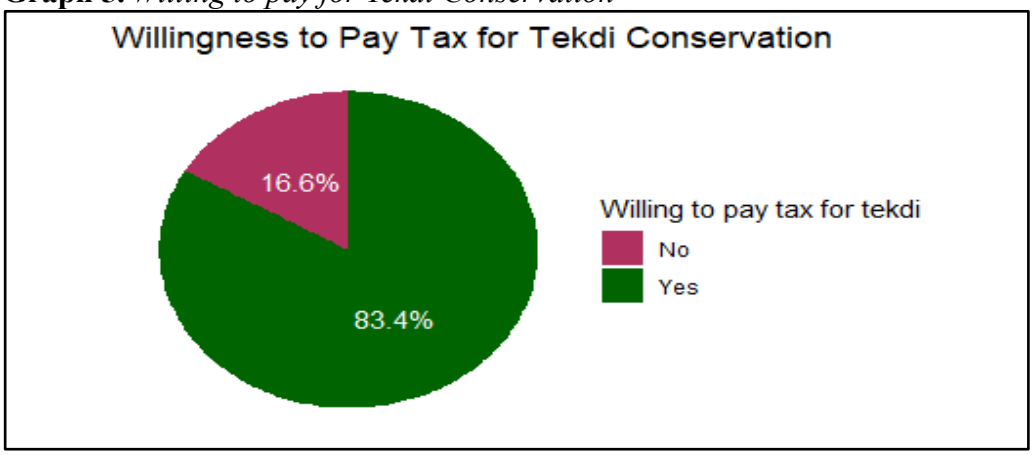
Graph 4. *Citizens Ranking of Reasons for Preserving Vetal Tekdi*



Willingness to pay for Tekdi Conservation

The "willingness to pay" can be considered as the demand price, the value or benefit a consumer expects to receive from consumption of the commodity, it is considered a measure of the marginal benefit, the increase in benefit associated with consuming another unit of the good, (Callan, 2019).

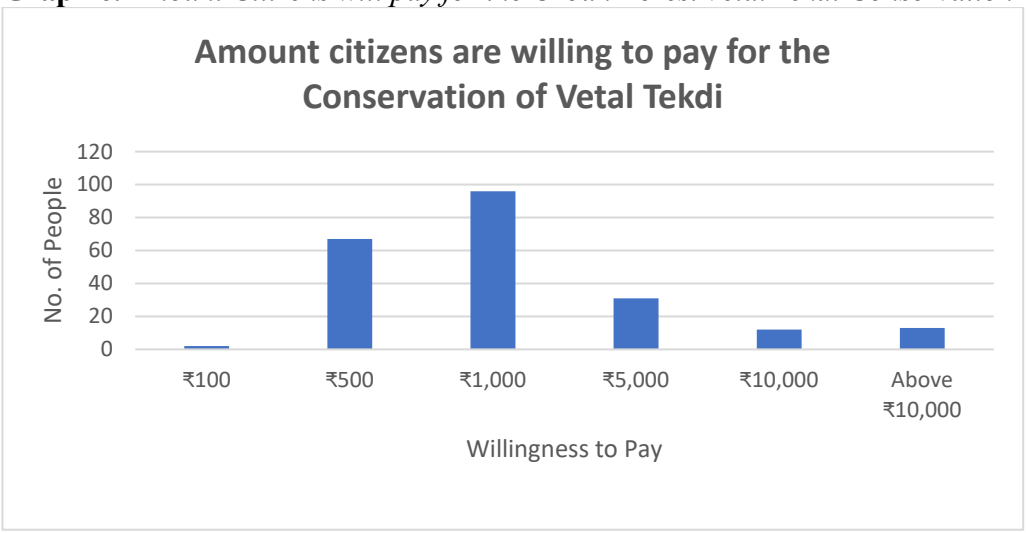
Graph 5. *Willing to pay for Tekdi Conservation*



The survey collected data on how much citizens were ready to pay for the conservation of the Urban Forest – Vetal Tekdi. The result is shown in Graph 5.

In Graph 5, 83.4% of the citizens are willing to pay a tax to support the conservation of Vetal Tekdi. This indicates that citizens know they benefit from the presence of the urban forest and are ready to contribute financially to the Tekdi's preservation.

Graph 6. *Amount Citizens will pay for the Urban Forest Vetal Tekdi Conservation*



Graph 6 shows the amount citizens are ready to pay for conserving Vetal Tekdi, with most willing to contribute ₹1000 and then ₹ 500, indicating a higher willingness to pay for the conservation of the urban forest. Considering the respondents are from the middle-income group, it is notable that they are ready to pay higher for the conservation of resources. Willingness declines sharply for amounts above ₹1,000 and below ₹500, with very few selecting other amounts. For the purpose of calculation, the average willingness to pay comes to ₹ 3230.435. The willingness to pay increases sharply initially, and then tapers down more gradually at higher amounts indicating a sharp increase in utility of this environmental service, and a decrease in

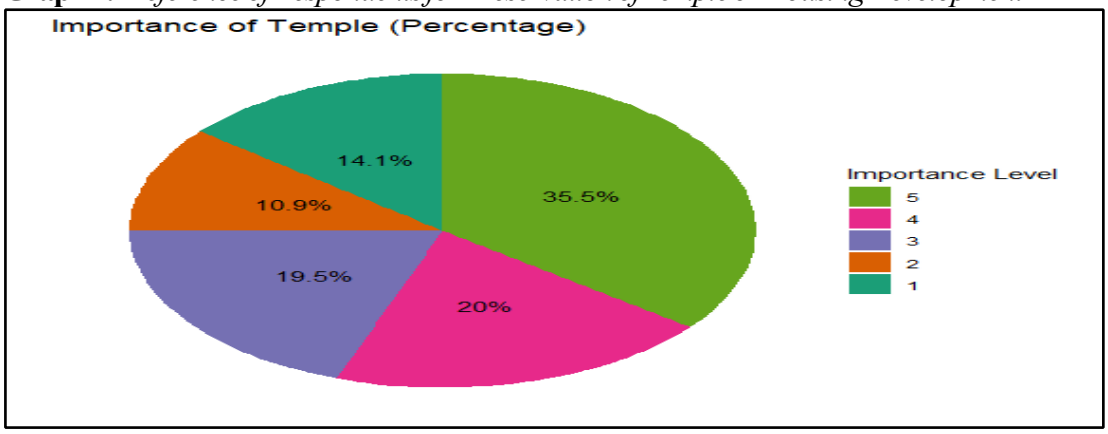
the utility which can be interpreted as a wide range over which the urban forest has high utility. These insights are useful for designing entry fees for the use of the urban forest, or for realistic fundraising strategies, suggesting that ₹500–₹1,000 is the most acceptable contribution range for the majority.

Section C

Section C focuses on the Vetal Baba Mandir (Temple), analysing its community significance based on visit frequency, perceived importance, preference for preservation over development, and willingness to contribute financially. It combines quantitative and qualitative insights to assess the temple's role in citizens' lives. Further the results show that 69% of respondents reported visiting Vetal Baba Temple, while only 16 respondents said they never visited the site. This indicates a fairly large public engagement with the Mandir, however in varying capacity.

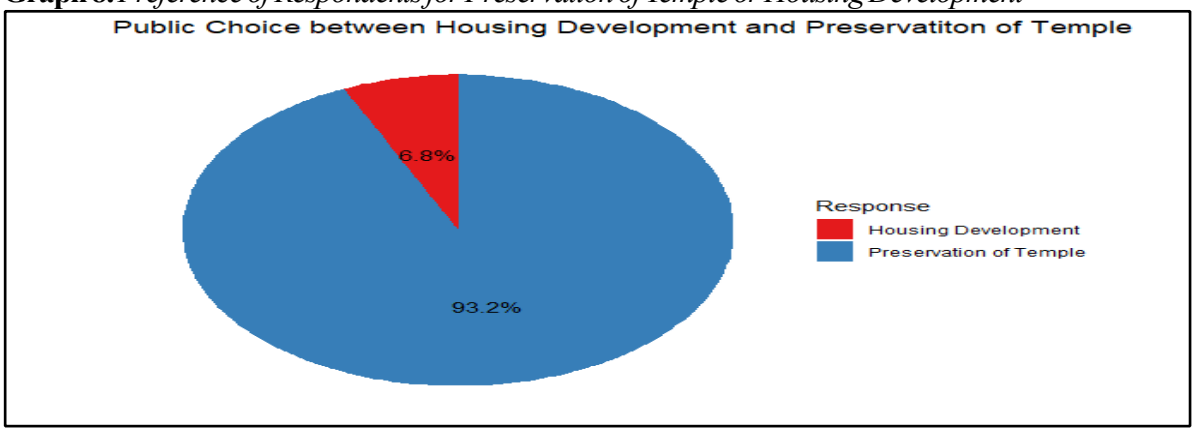
Graph 7 shows that 35.5% of respondents rated the temple as highly important (5), followed by 20% rating it a 4. About 30% gave moderate scores (2 or 3), and 14.1% rated it as least important (1). Overall, most respondents view the temple as important, though opinions vary.

Graph 7. *Preference of Respondents for Preservation of Temple or Housing Development*



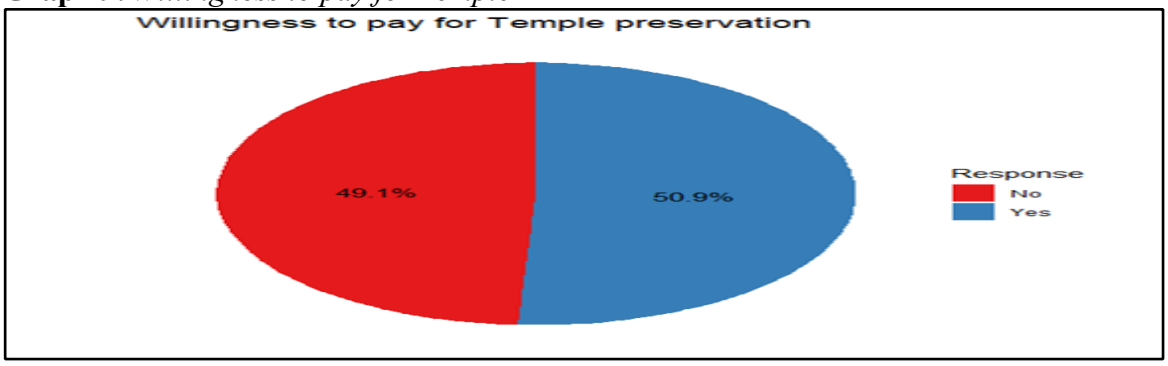
Graph 8 shows that 93.2% of respondents prefer preserving the temple, while only 6.8% support housing development. This reflects strong public consensus for temple preservation.

Graph 8. *Preference of Respondents for Preservation of Temple or Housing Development*

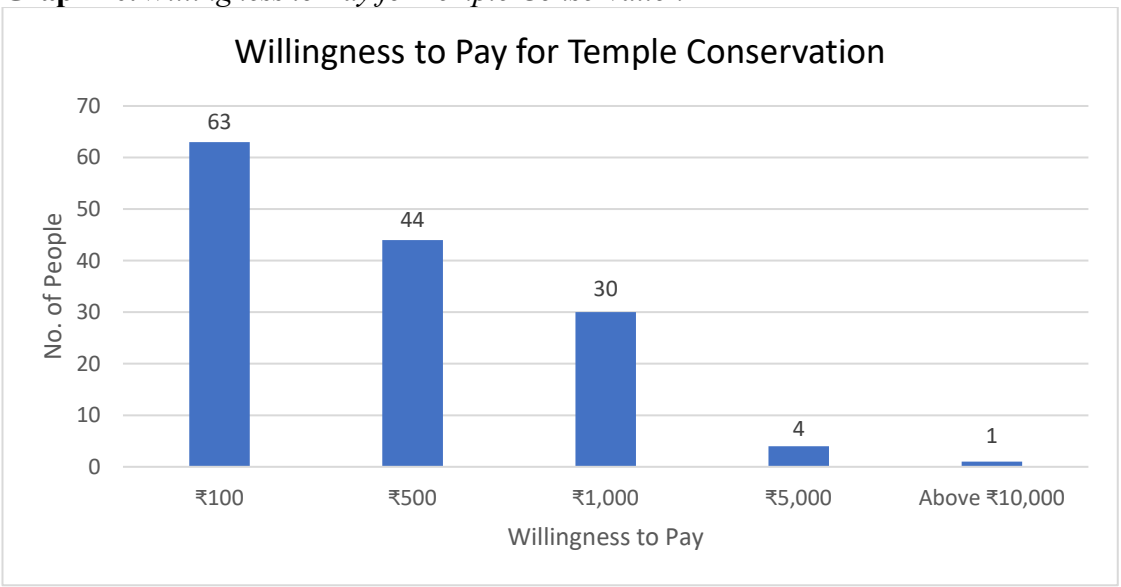


Graph 9 shows a nearly even split in public opinion on financially contributing to temple preservation, with 50.9% willing to pay and 49.1% unwilling. Citizens seem to be divided on their opinion of preserving the temple.

Graph 9. *Willingness to pay for Temple*



Graph 10. *Willingness to Pay for Temple Conservation*



Graph 10 shows respondents' willingness to pay for temple improvement, with most (over 60) preferring to contribute ₹100. The number drops for ₹500 (40–50) and ₹1,000 (30), and significantly fewer opt for ₹5,000 or ₹10,000.

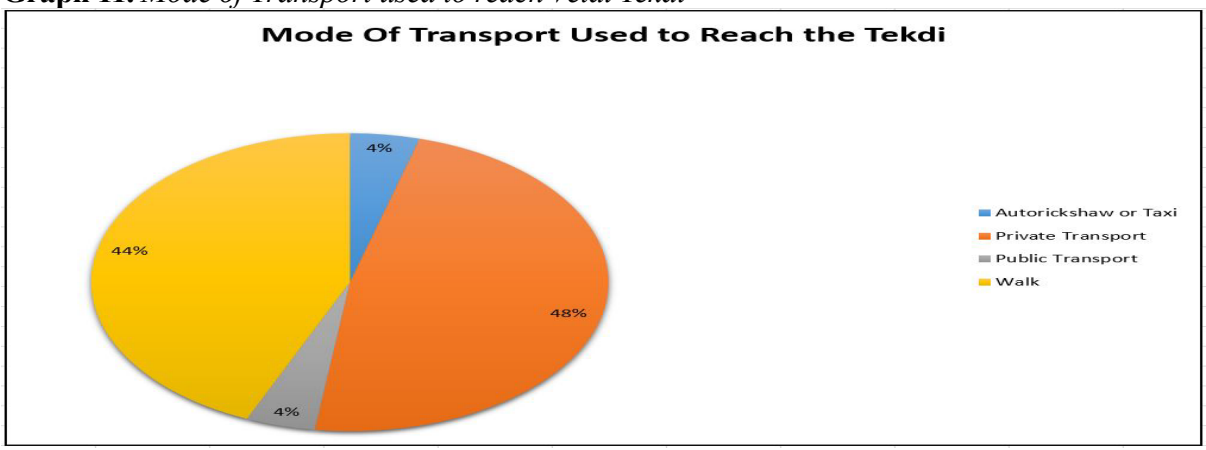
This pattern reflects a typical demand curve—willingness to pay declines as cost increases, indicating diminishing marginal utility. The sharp drop at higher amounts suggests price sensitivity, emphasizing the need to target lower contributions for effective fundraising.

The analysis confirms that perceived importance strongly influences willingness to contribute financially. Understanding public sentiment toward cultural landmarks can help policymakers design more effective, community-aligned conservation strategies.

Section D

This section uses the Travel Cost method to arrive at the Willingness to Pay for the Vetal Tekdi environmental services. It delves into the logistical dynamics of accessing Vetal Tekdi, focusing on the modes of transportation, distances travelled, and associated costs. The section examines the preferences of respondents regarding their choice of transportation, the type of private vehicles used, and the financial implications of using public transport, taxis, or auto-rickshaws.

Graph 11. *Mode of Transport used to reach Vetal Tekdi*



Examining the mode of transport used by citizens to reach Vetal Tekdi shows the following results in the pie chart in Graph11. About 48% of the respondents use private vehicles and 44% walk, highlighting a strong reliance on personal transport or close proximity while only 4% each use public transport or autos/taxis. Among private vehicle users, two-wheelers (50%) are far more common than four-wheelers (20%), indicating that citizens prefer environmentally friendly and less costly modes of reaching the urban forest. Most private vehicle users (20%) live within 1–3 km of the Tekdi, with numbers declining as distance increases, suggesting that proximity influences travel mode.

Graph 12 shows the distribution of bus travel costs to Vetal Tekdi. A majority (143 respondents) reported zero cost, suggesting they either live nearby or use

passes/subsidies. Costs between ₹10–50 were reported by fewer respondents, with only 6 people each in the ₹40–50 and >₹50 categories, indicating limited higher-cost travel. Table 4 shows the total bus travel cost was ₹1,570, with an average cost of ₹24.53 per person. This indicates that while some incur moderate costs, many access Vetal Tekdi at little or no expense.

Graph12. *Total Cost of traveling to the Tekdi via Bus (Public Transportation)*

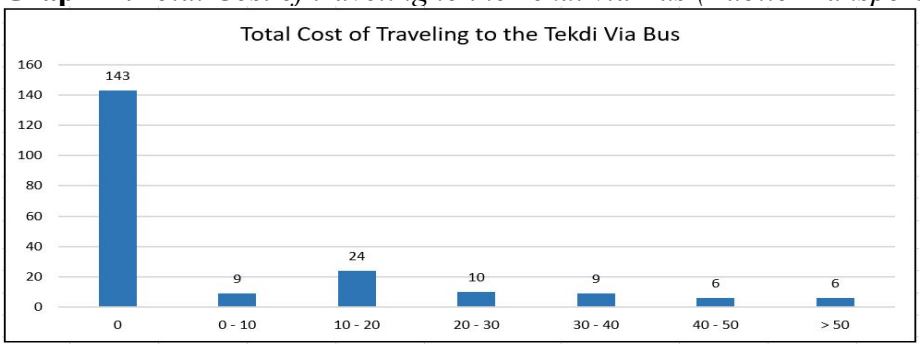


Table 4. *Average Cost of taking Public Transport to the Tekdi*

People who take the Bus	
TC	1570
AC	24.53125

Graph 13. *Total Cost of traveling to the Tekdi via Taxi or Auto*

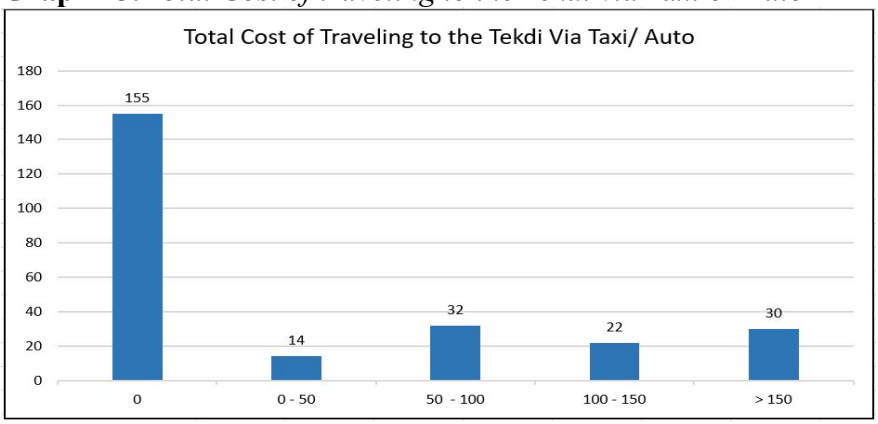


Table 5. *Average Cost of taking Taxi or Auto to Vetal Tekdi*

People Who Take a Taxi/ Auto	
TC	10750
AC	109.6938776

Graph 13 displays the distribution of travel costs for respondents using taxis or auto-rickshaws to reach Vetal Tekdi. About 60% respondents reported zero cost, indicating many live nearby or used free/subsidised transport. As cost increases, the number of respondents declines sharply, with the highest cost category (>₹150) having only 12% respondents. The accompanying table 5 shows the total cost

incurred by all users of this transport mode, about ₹10,750, with an average cost of ₹109.69 per person. This shows higher provides a clear snapshot of the typical financial burden for those using taxis or auto-rickshaws.

It is clear that the travel Cost method used here is more indicative of willingness to use physical exercise to reach and use this urban forest, it is also indicative of the environmental nature of the citizens participating in the survey.

Conclusion

The analysis affirms Vetal Tekdi's vital role as an ecological, recreational, and cultural asset. Urban green spaces like the Tekdi enhance sustainability, mental well-being, and quality of life, with survey findings revealing a strong community connection and overwhelming support for its preservation over urban development.

Final Findings and Results: The Simulator

The methodology for this research was to create a simulator that will assimilate all the values for each parameter automatically to give us the final result, that is the monetary value of the ES of the Urban Forest, Vetal Tekdi, Pune. Table 6 below is one such simulator that can automatically assess the annual value of the urban forest with differing data input each year.

There are seven parameters recorded here, value of the water in the wetlands, value of the carbon sequestration of the different types of trees, value of the oxygen produced, value of the biodiversity of the urban forest including the wetlands, value of the water in the aquifers, heritage value of the Vetal Temple, and the Hanuman temple, the latter part is a part of the amenity value. The biodiversity value covers the value of the following species, namely, odonates, dragonflies, butterflies, invertebrates, and birds. Together these form the valuation of the urban forest, the trees through carbon sequestration and production of oxygen, biodiversity, wetlands, water from the aquifers, and the amenity valuation. We have also added the use value of the land of the urban forest, namely, its market value, this valuation is treated additionally at the end in the simulator.

Willingness to Pay has been treated separately due to lack of data on the number of citizens visiting the urban forest daily/annually, and hence is not a part of the valuation, and will thus reduce the valuation by that extent.

Another important point to note is that this is a very conservative valuation as nature’s services are very intricate, one cannot fathom how each creature, big or small contributes to the efficient functioning of an ecosystem. Willingness to Pay, contingent valuation also could not be added due to lack of data, hence the valuation of the urban forest is a conservative one.

Valuation of the Urban Forest Vetal Tekdi

The annual value of the Environmental Services of the Urban Forest, namely, Vetal Tekdi is presented below in table 6 and is **$ 171.35 Billion**. The value of the water in the aquifers is the highest, a steep Rs. 14.62 trillion, or, $170 billion approximately. Followed by the water in the quarry, Rs. 98,28,00,000, or US $ 11 million approximately. The biodiversity valuation is Rs 1,537,000 or $453,774, carbon sequestration Rs.1,614,870, Oxygen, Rs. 66,945,840, heritage value of Vetal Temple, Rs. 74,368,869, heritage value of Hanuman Temple, is Rs. 10,665,430. Additionally, after we use the market price of the land of the urban forest, the total value goes up to, Rs. 16.5 trillion, or US $ 194.29 billion.

Table 6. *Annual Valuation of the ES of the Urban Forest, Vetal Tekdi, Pune*

Annual Valuation of the Environmental Services of the Urban Forest - Vetal Tekdi, Pune 2024 – 2025				
Parameters for Valuation	**Valuation in Sample Area**	**No. of Samples**	**Valuation of Entire Urban Forest**	
i. Value of Water Present in the Quarry	₹ 98,28,00,000	1	₹ 98,28,00,000	
ii. Value of Carbon Sequestration	₹ 1,61,487	10	₹ 16,14,870	
iii. Value of Oxygen Production	₹ 66,94,584	10	₹ 6,69,45,840	
iv. Value of Biodiversity				
iv.a. Odonates & Dragonflies	₹ 54,000	10	₹ 5,40,000	
iv.b. Invertebrates	₹ 2,46,000	10	₹ 24,60,000	
iv.d. Butterfly	₹ 87,000	10	₹ 8,70,000	
iv.c. Birds	₹ 10,96,000	10	₹ 1,09,60,000	
v. Value of Water in Aquifers	₹ 1,46,28,74,60,00,000	1	₹ 1,46,28,74,60,00,000	
vi. Heritage Value of Vetal Temple	₹ 7,43,68,868.89	1	₹ 7,43,68,869	
vii. Heritage Value of Hanuman Temple	₹ 1,06,65,430.13	1	₹ 1,06,65,430	
Sub-Total Value of Urban Forest			**₹ 1,46,29,89,72,25,009**	**~ ₹ 14.6 Trillion**
			$ 1,71,35,04,00,855*	**~ $ 171.35 Billion**
viii. Value of the Tekdi Land (Use Value)	₹ 19,58,65,89,55,939		₹ 19,58,65,89,55,939	
Total Value of Urban Forest			**₹ 1,65,88,55,61,80,948**	**~ ₹ 16.5 Trillion**
			$ 1,94,29,08,89,915 *	**~ $ 194.29 Billion**

*US Dollar to Rupee conversion rate of 4 July 2025 was used.

A second valuation of the ES of the Urban Forest was worked out by substituting the India's Supreme valuation of trees in the simulator, the result was approximately the same, proving our tree valuation was accurate. All other valuations remain the same.

Table 7. *Valuation According to Supreme Court of India*

Annual Valuation of the Environmental Services of the Urban Forest - Vetal Tekdi, Pune 2024 – 2025				
Parameters for Valuation	**Valuation of Sample Area**	**No. of Samples**	**Valuation of Entire Urban Forest**	
i. Value of Water Present in the Quarry	₹ 98,28,00,000	1	₹ 98,28,00,000	
ii. Value of Trees (Supreme Court of India**)	₹ 2,24,99,000	10	₹ 22,49,90,000	
iii. Biodiversity				
iii.a. Odonates & Dragonflies	₹ 54,000	10	₹ 5,40,000	
iii.b. Invertebrates	₹ 2,46,000	10	₹ 24,60,000	
iii.c. Birds	₹ 10,96,000	10	₹ 1,09,60,000	
iii.d. Butterfly	₹ 87,000	10	₹ 8,70,000	
iv. Value of Water in Aquifers	₹ 1,46,28,74,60,00,000	1	₹ 1,46,28,74,60,00,000	
v. Heritage Value of Vetal Mandir	₹ 7,43,68,869	1	₹ 7,43,68,869	
vi. Heritage Value of Hanuman Mandir	₹ 1,06,65,430	1	₹ 1,06,65,430	
Sub-Total Value of Urban Forest			**₹ 1,46,30,05,36,54,299**	**~ ₹ 14.6 Trillion**
			$ 1,71,35,22,33,009 *	**~ $ 171.35 Billion**
vii. Value of Tekdi Land (Use Value)	₹ 19,58,65,89,55,939		₹ 19,58,65,89,55,939	
Total Value of Urban Forest			**₹ 1,65,88,71,26,10,238**	**~ ₹ 16.5 Trillion**
			$ 1,94,29,27,22,069 *	**~ $ 194.29 Billion**

*US Dollar to Rupee conversion rate of 4 July 2025 was used.
**Supreme Court has given the value of 1 tree. Is equal to ₹ 74,500.

The annual value of the Environmental Services of the Urban Forest, namely, Vetal Tekdi is presented above in table 6 and is **$ 171.35 Billion**. The value of the water in the aquifers is the highest, a steep Rs. 14.62 trillion, or, $170 billion approximately. Followed by the water in the quarry, Rs. 98,28,00,000, or US $11 million approximately. The biodiversity valuation is Rs 1,537,000 or $453,774, carbon sequestration Rs.1,614,870, Oxygen, Rs. 66,945,840, heritage value of Vetal Temple, Rs. 74,368,869, heritage

value of Hanuman Temple, is Rs. 10,665,430. Additionally, after we use the market price of the land of the urban forest, the total value goes up to, Rs. 16.5 trillion, or US $ 194.29

Conclusion

Urban forests provide crucial environmental services, ecological, recreational, cultural, and the urban forest - Vetal Tekdi, Pune has additionally pristine, ancient aquifers, alongside new wetlands formed from previous stone quarries, and very old temples that have cultural and heritage value. The urban forest is part of very old mountain ranges, these mountains are hotspots of biodiversity, there are multiple species of flora and fauna that contribute to the health of the ecosystem. In turn, all these services facilitate good health of the population of the city, both mental and physical, besides providing a robust environment for the flourishing of biodiversity. The aquifers here are the source of clean water to the intricate underground network of streams and ground water. For the aquifers, the rapid population growth in Pune underscores the critical importance of sustainable water management. The aquifers, a gift of nature, emerge as an invaluable resource, holding a staggering 73,143.728 crore litres of water, with a very high monetary value. Protecting and optimizing the utilization of aquifers is not merely a matter of convenience but a necessity to bridge the gap between supply and demand, ensuring Pune's water security for its growing population.

The analysis affirms Vetal Tekdi's vital role as an ecological, recreational, and cultural asset. Urban green spaces like the Tekdi enhance sustainability, mental well-being, and quality of life, with survey findings revealing a strong community connection and overwhelming support for its preservation over urban development. When such urban spaces are protected, they support the health of the population ensuring a healthy and happy life of the citizens while also improving productivity as a result of good health.

This study aimed to do the valuation of the all the services of the Vetal Tekdi, the urban forest at the centre of the city. Multiple valuation methods were used for the purpose, use value, existence value, market value, travel cost method, amenity valuation, expert opinion for the biodiversity, contingent valuation, and hedonic pricing to suit the diverse services of the richly endowed urban forest.

Value of the Wetlands was immense as was that of aquifers, the rain water stored in these newly formed wetlands nestled on top of the hill is not touched by any pollution as it is not exposed to any industrial/commercial human activity. The value of Carbon Sequestration was ₹ 61,487 and of Oxygen Production ₹ 66,94,584. Biodiversity was valued annually at Rs 1,537,000 or $ 453,774, and covered insects, odonates, dragonflies, butterflies and birds. Experts from the field were consulted for their view on the value of these essential species, the species covered were however not exhaustive, hence the valuation is very conservative.

The amenity valuation by citizens in the form of recreational, physical and study activities highlighted near-unanimous support (90.1%) for Tekdi's conservation. It was valued for its environmental benefits and as a space for mental and physical

health. A significant majority (83.4%) were willing to contribute financially, especially in the ₹500–₹1,000 range, to note here, the willingness to pay was driven more by values and awareness than by income levels.

The heritage value revealed a nuanced view of the Vetal Baba Temple. While visit frequency was low, 35.5% of respondents rated its importance at the highest level. A dominant 93.2% support preserving the temple over housing development. Again, perceived importance, not income, was the key factor influencing willingness to pay, indicating the need for value-based fundraising.

The Travel Cost method outlined transportation trends. Walking followed closely behind private vehicles, especially two-wheelers, reflecting a trend for physical fitness and proximity to the urban forest, hence many incurred no travel costs, promoting sustainable, low-cost transport.

The simulator that collated all the resulting values for the various services showed an annual value of the Environmental Services of the Urban Forest, namely, Vetal Tekdi at: $ 171.35 Billion. This included the value of the water in the aquifers, at Rs. 14.62 trillion, or, $170 billion approximately, the water in the quarry at, Rs. 98,28,00,000, or US $ 11 million approximately, the biodiversity valuation at Rs 1,537,000 or $453,774, carbon sequestration at Rs.1,614,870, oxygen at, Rs. 66,945,840, heritage value of Vetal Temple at, Rs. 74,368,869, heritage value of Hanuman Temple, at Rs. 10,665,430, adding the market value of the land at ₹ 19,58,65,89,55,939, gave a total value of Rs. 16.5 trillion, or US $ 194.29 billion to the urban forest Vetal Tekdi.

In conclusion, the six billion old urban forest, Vetal Tekdi is abundantly endowed with multiple environmental services as it is part of a biodiversity hotspot, and while we can conduct only a conservative assessment of its services, it's annual value monetised stands at a huge Rs. 14.6 trillion, or US $ 171.35 Billion. If we add the market value of the land the valuation is Rs. 16.5 trillion, or US $ 194.29 billion annually.

Limitations of the study are that the biodiversity valuation is not exhaustive, the biodiversity valuation is limited to the species of fauna; flora is not considered, the value of the pristine waters of the aquifers is far higher than the market value per litre of drinking water chosen. Also, the Willingness to Pay for the urban forest's services could not be included in the valuation due to the lack of data regarding the number of people using the urban forest. Hence the overall valuation is limited by these shortcomings.

Data paints a clear picture of Vetal Tekdi as an invaluable urban green space that provides wide-ranging benefits extending beyond mere recreation to ecological preservation, community health, and cultural heritage. While urbanization pressures persist, the strong public preference for conservation signals the need for policymakers to prioritize sustainable development strategies. By balancing urban growth with environmental preservation, stakeholders can ensure that essential spaces like Vetal Tekdi remain integral to the city's environmental and cultural fabric. The insights from this report should guide stakeholders in devising informed, community-driven solutions that respect both environmental imperatives and urban development needs. Policy recommendations of this study are that decision makers should use the valuation tools while evaluating projects for implementation.

Selection of projects should be on this basis. A cost benefit analysis based on environmental valuation should be used for such decision making.

Strong recommendations of this study are to conduct more such valuations of aquifers and urban forests as both are undermined in their value and often sacrificed in the name of development, hence, both require protection and strong support from empirical research.

More than a green space, the urban forest is a vital part of Pune's ecological, cultural, and community landscape. Strong public support for its conservation calls for sustainable urban planning that protects such spaces. Policymakers must leverage community values and accessibility insights to craft inclusive, eco-conscious development strategies. This invaluable natural endowment will compromise sustainability and deprive future generations of its valuable services if sacrificed to urbanisation.

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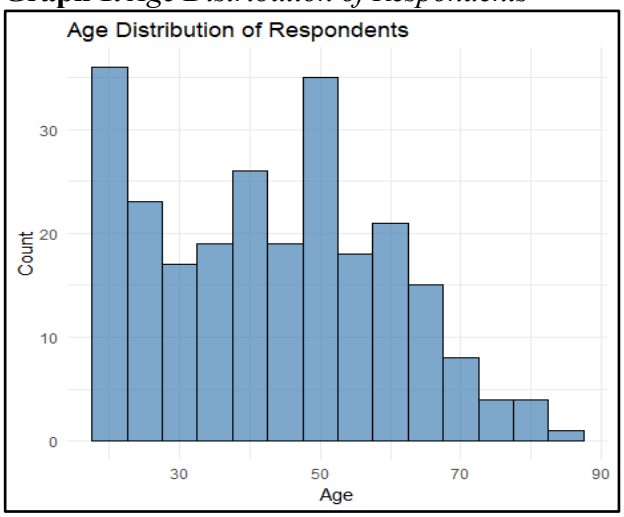
Appendix

Graph 1. *Age Distribution of Respondents*



Graph 2. *Gender Distribution of Respondents*