SAVi Sustainable Asset Valuation

Lake Dal in Srinagar, India:

Application of the Sustainable Asset Valuation (SAVi) methodology for the analysis of conservation options

IISD International Institute for Sustainable Development

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Lake Dal in Srinagar, India

About SAVi

Sustainable infrastructure holds enormous potential for alleviating poverty, improving access to basic services, creating employment and businesses, and ultimately contributing to the well-being of people and the planet.

IISD's Sustainable Asset Valuation tool (SAVi) assesses the extent to which environmental, social and economic risks and externalities affect the financial performance of infrastructure assets. It also calculates the societal and economic benefits of sustainable infrastructure, such as employment, productivity, income and contributions to GDP.

SAVi puts a financial value on risks and externalities that are not well understood and therefore ignored in traditional investment assessments. These can include legal and environmental risks, resource and revenue risks, and climate-change related risks. SAVi assesses the impact of these risks on the financial performance of an infrastructure project or portfolio.

SAVi combines the outputs of system dynamics simulation and project finance models. SAVi can currently be applied to several asset types: energy, roads, buildings, irrigation, sewerage treatment and nature-based infrastructure. Models on railways and waste management are in the pipeline.

We customize SAVi to the needs of our clients, whether they are looking at a single project, a portfolio of projects, or an economic or industrial policy. We identify externalities and risks on a case-by-case basis in collaboration with the client.

For more information on SAVi:
https://www.iisd.org/project/SAVi-sustainable-asset-valuation-tool

Glossary

Causal loop diagram: A schematic representation of key indicators and variables of the system under evaluation that shows the causal connections between them and contributes to the identification of feedback loops and policy entry points.

Chlorophyll-*a* concentration: The concentration of planktonic algal chlorophyll per litre of lake water, typically measured in microgram per litre. The higher the chlorophyll concentration per litre of water, the lower the water clarity. Chlorophyll concentration is often used as a proxy for eutrophication.

Feedback loop: "Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself" (Roberts, Andersen, Deal, Garet, & Shaffer, 1983).

Grey Infrastructure: Engineered assets that provide one or multiple services required by society, such as access to water, wastewater treatment and mobility.

Indicator: An instrument that provides an indication, generally used to describe and/or give an order of magnitude to a given condition.

Johkasou Sewage Treatment Plant: Highly advanced on-site wastewater treatment system that can be applied to individual homes or clusters of houses in the Dal catchment.

Methodology: The underlying body of knowledge for the creation of different types of simulation models. It includes theoretical foundations for the approach, and often encompasses both qualitative and quantitative analyzes and instruments.

Model transparency: A transparent model is one for which equations are available and easily accessible and it is possible to directly relate structure to behaviour (i.e., numerical results).

Model validation: The process of deciding whether the structure (i.e., equations) and behaviour (i.e., numerical results) are acceptable as descriptions of the underlying functioning mechanisms of the system and data.

Natural infrastructure: Networks of land or ecosystems that provide infrastructure through services that are inherent to such geographical areas, while also perpetuating active conservation efforts and the enhancement of those environments.

Net benefits: The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by intervention scenario.

Nitrogen (N) concentration: Refers to the amount of organic and anorganic nitrogen per litre of lake water. It can contribute to eutrophication if N loadings exceed a critical threshold. This assessment uses N concentration to determine the growth of algae chlorophyll as relevant N loadings and lake water recharge can be determined with relative certainty.

Nitrogen (N) loadings: The total annual amount of nitrogen from anthropogenic wastewater and fertilizers that reaches the lake. N loadings serve to determine the N concentration in the lake water.

Optimization: Simulation that aims at identifying the best solution (with regard to some criteria) from some set of available alternatives.

Policy cycle: The process of policy-making, generally including issue identification, policy formulation, policy assessment, decision making, policy implementation and policy monitoring and evaluation.

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Secchi depth: A Secchi disk is a round plate that is painted black and white. The disk is attached to a rope and lowered into the lake water until it is at a depth where it can no longer be seen. Secchi depth helps to measure the clarity of the water and the general "health" of the lake.

Sewage treatment plant: Grey infrastructure component used for treating domestic sewage and other wastewater.

Simulation model: A model is a simplification of reality, a representation of how the system works, and an analysis of (system) structure and data. A quantitative model is built using one or more specific methodologies, with their strengths and weaknesses.

Social costs of carbon: The economic cost caused by an additional ton of carbon dioxide emission or its equivalent through the carbon cycle (Nordhaus, 2017).

Stock and flow variables: A *stock* variable represents accumulation and is measured at one specific time. A *flow* variable is the rate of change of the stock and is measured over an interval of time.

System Dynamics: A methodology to create descriptive models that focus on the identification of causal relations influencing the creation and evolution of the issues being investigated. Its main pillars are feedback loops, delays and non-linearity through the explicit representation of stocks and flows.

Vertical/horizontal disaggregation of models: Vertically disaggregated models represent a high degree of sectoral detail; horizontal models instead include several sectors and the linkages existing among them (with a lesser degree of detail for each of the sectors represented).

Executive Summary

Located in the Indian state of Jammu & Kashmir, Lake Dal has suffered from anthropogenic pressures over the past few decades, including encroachment, water extraction and pollution, solid waste pollution and runoff from fertilizer use. This has led to a sharp decrease in water quality, eutrophication and further cascading effects such as decreasing fish stocks and negative impacts on the lake's recreational attractiveness.

The Tourism Directorate and the Lake and Waterways Development Authority (LAWDA) of the Jammu & Kashmir State Government approached the International Institute for Sustainable Development (IISD) to conduct an assessment of the effectiveness and investment attractiveness of various ongoing and potential conservation options for Lake Dal. A systemic assessment employing the Sustainable Asset Valuation (SAVi) methodology was conducted to identify to what extent various conservation options contribute to the social, economic and environmental sustainability of Lake Dal and the surrounding region. Several SAVi models were combined for the systemic assessment:

- The SAVi Wastewater model was applied to assess options to treat domestic sewage.
- The SAVi Energy model was used to estimate the impact of installing solar PV to provide electricity to sewage treatment plants (STPs) and pumping stations.
- The SAVi Natural Infrastructure model was used to forecast the outcomes of investing in the construction of an artificial wetland.
- The SAVi Roads model was employed to determine the impact of a newly constructed road along the lake.

Diverse scenarios were tested with these interconnected SAVi models:

Table ES1. Scenarios under different SAVi models

Scenario	Polluters covered	Interventions considered and implemented by 2025
1.) Business-as-usual	None	• 75 per cent of periphery connected to sewage network • Sewage of lake dwellers is not treated • Sewage of houseboats is not treated
2.1) Improved sewage treatment for all polluter groups	• Periphery population • Lake dwellers • Houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all lake dwellers and houseboats
2.2) Improved sewage treatment for all polluter groups + installation of solar PV	• Periphery population • Lake dwellers • Houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all lake dwellers and houseboats • Solar PV is used to power all sewage treatment
2.3) Improved sewage treatment of periphery population + installation of solar PV	• Periphery population	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Solar PV is used to power all sewage treatment
2.4) Improved sewage treatment of lake dwellers	• Lake dwellers	• Johkasou STPs for all lake dwellers
2.5) Improved sewage treatment of houseboats	• Houseboats	• Johkasou STPs for all houseboats
3.1) Artificial wetland construction	None directly	• Construction of 500 ha of artificial wetland
3.2) Artificial wetland construction + improved sewage treatment for all polluter groups + installation of solar PV	• Periphery population • Lake dwellers • Houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all lake dwellers and houseboats • Solar PV is used to power all sewage treatment • Construction of 500 ha artificial wetland

Scenario	Polluters covered	Interventions considered and implemented by 2025
4.1) Relocation of lake dwellers	• Lake dwellers	• Relocation of dwellers to Rakh-e-Arth • Construction of housing for lake dwellers • Compensation payments to dwellers for plot and structure
5.1) Road construction	None	• Construction of 20km Western Foreshore Road
5.2) Road construction + artificial wetland construction + improved sewage treatment for all polluter groups + installation of solar PV	• Periphery population • Lake dwellers • Houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all lake dwellers and houseboats • Solar PV is used to power all sewage treatment • Construction of 500 ha artificial wetland • Construction of 20km Western Foreshore Road

The SAVi assessment applied to examine treatment options for the conservation of Lake Dal reveals a range of key insights. More effective and systemic measures for reducing pressures on the lake need to be implemented urgently instead of treating only the symptoms of pollution such as algae growth. The assessment highlights that neither business as usual nor the incautious construction of the Western Foreshore Road are viable options at Srinagar if the ecological collapse of Lake Dal is to be prevented and fishing activities maintained over time. Neither will it be sufficient to address only sewage pressures caused by lake dwellers or houseboats.

The hybrid infrastructure approach deployed in Scenario 3.2 is most cost-effective for reducing nitrogen loading to the lake, removing nitrogen from the lake and for generating economic benefits in the region. The scenario envisions the simultaneous implementation of four interventions. First, establishing sewage network connectivity and STP capacity for treating sewage from inhabitants living in the periphery of the lake. Second, installing solar PV to provide reliable and emission-free electricity to STPs and pumping stations to avoid accidental discharge during power cuts. Third, implementing on-site sewage treatment for lake dwellers and houseboats, and fourth the construction of an artificial wetland. Through analyzing the projections of Scenario 5.2, the assessment further reveals that the resulting pressures from construction of the Western Foreshore Road will be mitigated if sewage treatment capacity is expanded, but this could come at the cost of the ecological health of Lake Dal. Still, the road project would create additional runoff and encroachment pressures on the lake and significantly reduce overall net benefits associated with sewage treatment interventions compared to Scenario 3.2.

When budget priorities need to be made, it remains most important to treat sewage from the lake's periphery effectively (Scenario 2.3) as this represents by far the biggest population group among remaining polluters. Treating the sewage from houseboats (Scenario 2.5), by contrast, has hardly any significance for the rehabilitation of the lake. Given the political difficulty of permanently relocating lake dwellers (Scenario 4.1) and prevent them from returning to their old habitats, as well as the high costs associated with their relocation, it is recommended to explore on-site sewage treatment for lake dwellers at their current locations.

Abbreviations

BAU	business-as-usual
CBA	cost–benefit analysis
CLD	causal loop diagram
ha	hectare
IISD	International Institute for Sustainable Development
LAWDA	Lake and Waterways Development Authority, Jammu & Kashmir
N	nitrogen
O&M	operation and maintenance
INR	Indian rupee
SAVi	Sustainable Asset Valuation methodology
Solar PV	solar photovoltaic
STP	sewage treatment plant

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PART I: Introduction

Historically, Lake Dal and the surrounding area were visited by maharajahs and tourists alike, due to its beauty. The city of Srinagar, the summer capital of Jammu & Kashmir, has grown around the lake.

Over the centuries Lake Dal has served recreational purposes, sustained livelihoods and allowed the surrounding area to flourish economically. During the last decades, however, anthropogenic pressures such as water extraction, water pollution, solid waste pollution, runoff from fertilizer use and encroachment on the lake have exceeded its carrying capacity. This has led to a shrinking size of the lake from 31 to 24 km2 between 1859 and 2014 and a sharp decrease in water quality, increased eutrophication and further cascading effects such as declining fish stocks and negative impacts on the lake's recreational attractiveness.

In light of these developments, public authorities in Jammu & Kashmir as well as stakeholders depending directly on the lake began to recognize the need for conservation efforts. Among others, the high court of Jammu & Kashmir got involved to ensure progress in implementing conservation measures, setting up a monitoring committee and scientific advisory committee. Despite these steps, ongoing monitoring of the lake's water quality and rather erratic conservation measures, no substantial improvements of the lake's water quality have been achieved, and the negative trends in such things as eutrophication and algae growth continue.

The Tourism Directorate and the Lake and Waterways Development Authority (LAWDA) of the Jammu & Kashmir State Government, India approached the International Institute for Sustainable Development (IISD) to conduct a systemic assessment of the effectiveness and investment attractiveness of various ongoing and potential conservation options for Lake Dal. There is a need for prioritizing interventions according to their effectiveness and identifying viable structures for financing the prioritized strategies. A systemic assessment applying the Sustainable Asset Valuation (SAVi) methodology is well suited to address the complexity of various pollution sources, the need to define long-term, sustainable conservation options as opposed to treating only the symptoms of pollution, and to pay attention to interlinkages between social, economic and environmental drivers for development around Lake Dal.

Application of the Sustainable Asset Valuation (SAVi) Methodology

IISD used the SAVi methodology to conduct the requested assessment and identify to what extent various conservation options contribute to the social, economic and environmental sustainability of Lake Dal and the surrounding region. Several components of SAVi were combined for the systemic assessment:

- The SAVi Wastewater model was applied to assess options to treat domestic sewage.
- The SAVi Energy model was used to estimate the impact of installing solar PV to provide electricity to sewage treatment plants (STPs) and pumping stations.
- The SAVi Natural Infrastructure model was used to forecast the outcomes of investing in the construction of an artificial wetland.
- The SAVi Roads model was employed to determine the impact of a newly constructed road along the lake.

Several scenarios were tested with these interconnected SAVi models. The scenarios are presented in Part IV.

Part II: Local Context in Srinagar, Jammu & Kashmir

Lake Dal is located in Jammu & Kashmir, India's northernmost state.

Figure 1. Location of Lake Dal

Source: atrocitiesonindians.wordpress.com

Local conditions at Lake Dal are presented below. These outline pollution sources and provide more context about challenges for implementing conservation measures.

Value of the lake: Lake Dal is an important economic and cultural asset for Srinagar and the region. The lake has been utilized over the years for its environmental and infrastructure services. This includes tourism, fisheries and agriculture.

Adverse environmental impacts: The development seen in the last decades has started impacting the lake's health. Due to urban infrastructure development, agricultural expansion and lake encroachment, a lot of forest land, natural wetlands and natural springs were lost. These developments led to a reduced lake size, an increasing amount of pollutants reaching the lake without natural filtration, a reduction of freshwater volume in the lake as well as less water circulation. Rehabilitation measures such as the construction of artificial wetlands could support the natural filtration capacity of the lake's ecosystem.

Sewage treatment network: Only 75 per cent of the population whose sewage is channelled toward Lake Dal is connected to sewage treatment plants (STPs). The technology of several STPs is outdated and there are not enough pumping stations. Additionally, STPs and pumping stations suffer from frequent power cuts from the grid, resulting in sewage flowing into the lake without treatment. So far, on-site diesel generators are in place as backup capacity at some STPs. Investments into the upgrade of the sewage network are hence required.

Lake dwellers: Over the years, encroachment of the lake occurred. An increasing amount of people brought land mass to the lakefront and into the lake to build their homes. The inhabitants are called lake dwellers in Srinagar. At the present time, some of their homes are connected to the city's electricity grid but there is no sewage network in place. The government has periodically worked to relocate the lake dwellers to another location that can be connected to an STP. Relocation activities had been implemented and compensation payments have been made to the effected communities.

The issue remains, however, that relocated families accept the compensation and then migrate back to their former dwellings on the lake periphery.

Houseboats: These are a traditional cultural element of Lake Dal and primarily serve for accommodating tourists. The houseboats are not connected to any STPs, and their sewage is directly released into the lake. Relocation of the houseboats and other measures will be further discussed in this report. The cultural and economic value of houseboats for the region must be considered when suggesting interventions.

Lake pollution: Due to these developments, parts of the lake are currently characterized by high water pollution, leading to excessive algal blooms and negative impacts on the fish stock. If above issues are not addressed in a systemic and preventive manner, environmental degradation of the lake's ecosystem will lead to increasing costs to society.

Part III: SAVi Analysis

Systems Thinking and System Dynamics

The main drivers of change for Lake Dal were analyzed (periphery, houseboats, lake dwellers) and summarized in the causal loop diagrams (CLDs) displayed in Figure 2. The CLD includes the main indicators analyzed, their interconnections with other relevant variables in the sector and the feedback loops they form. It was developed in a collaboration between the IISD team and local stakeholders during several meetings in Srinagar. The CLD is the starting point for the development of the mathematical stock and flow models. Model results are instead presented in Section IV.

The creation of a CLD has several purposes: first, it combines the team's ideas, knowledge and opinions; second, it highlights the boundaries of the analysis; third, it allows all stakeholders to achieve basic-to-advanced knowledge of the analyzed issues and their systemic properties. Having a shared understanding is crucial for solving problems that influence several sectors or areas of influence, which are common in complex systems. Since the creation of a CLD touches upon and relies on cross-dimensional knowledge, it supports developing a shared understanding of the factors that generate the problem and those that could lead to a solution among all the parties involved in the decision-making process and implementation, and to effectively implement successful private–public partnerships. As such, the solution should not be imposed on the system, but should emerge from it. In other words, interventions should be designed to make the system start working in our favour (i.e., of decision-makers and relevant stakeholders) to solve the problem, rather than amplifying it.

In this context, the role of feedback is crucial. It is often the very system we have created that generates the problem, due to external interference, or to a faulty design, which shows its limitations as the system grows in size and complexity. In other words, the causes of a problem are often found within the feedback structures of the system. The indicators alone are not sufficient to identify these causes and explain the events that led to the creation of the problem. We are too often prone to analyzing the current state of the system, or to extending our investigation to a linear chain of causes and effects, which does not link back to itself, thus limiting our understanding of open loops and linear thinking.

Causal loop diagrams include variables and arrows (called causal links), with the latter linking the variables together with a sign (either + or –) on each link, indicating a positive or negative causal relation (see Table 1):

- A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction.

Table 1. Causal relations and polarity

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	-
↓	↑	-

Circular causal relations between variables form causal, or feedback, loops. These can be positive or negative. A negative feedback loop tends toward a goal or equilibrium, balancing the forces in the system (Forrester, 1961). A positive feedback loop can be found when an intervention triggers other changes that amplify the effect of that initial intervention, thus reinforcing it (Forrester, 1961). CLDs also capture delays and non-linearity.

Causal Loop Diagram Lake Dal

Figure 2 and Figure 3 display the causal loop diagram (CLD) that was developed for the Lake Dal analysis, in simplified and full form. The diagram was developed and validated with local experts and represents the key factors at play concerning the pollution of Lake Dal. It contains both grey infrastructure (e.g., wastewater treatment) and natural infrastructure (e.g., wetlands), which allows for an analysis of individual and combined treatment options. The feedback loops are numbered, and a description of the feedback loops and their dynamics is provided below.

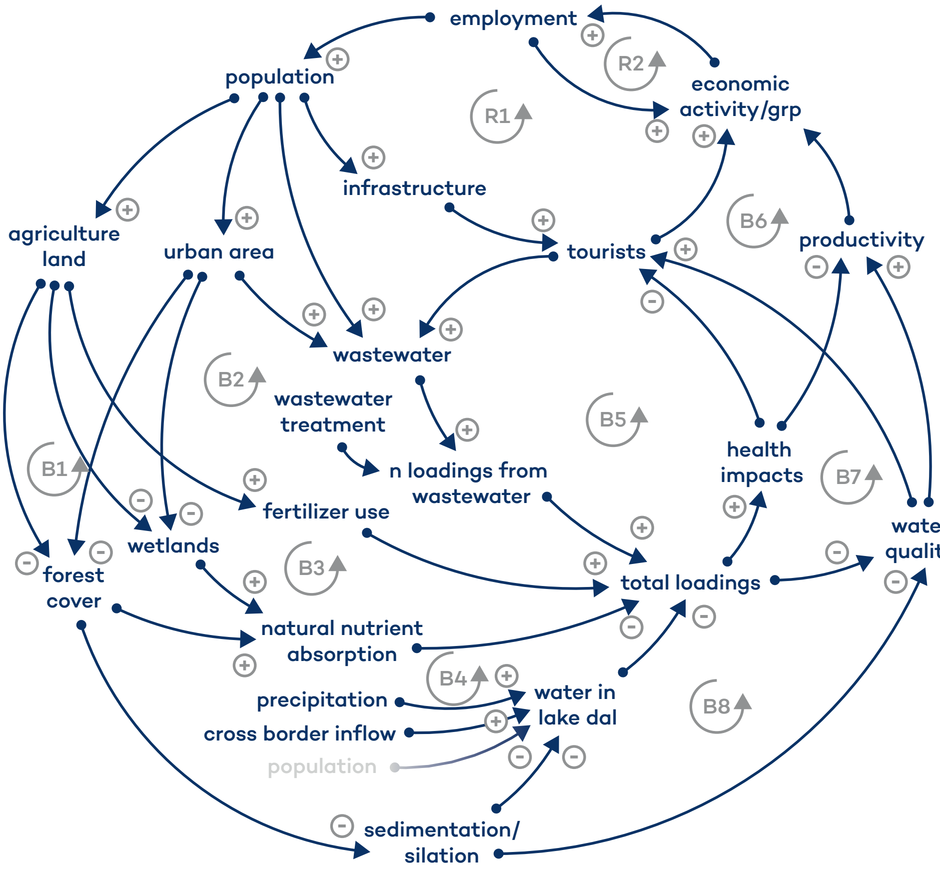


Figure 2. Simplified CLD Lake Dal

People have lived around Lake Dal for centuries. As the city grew its population required additional agriculture land to provide food and shelter, and infrastructure to maintain and increase productivity. The expansion of infrastructure supported the development of the tourism sector, and Srinagar became known as the home of the "Jewel of Kashmir," Lake Dal. The feedback loops (R1) and (R2) capture the economic development of and around Lake Dal.

The loop (R1) captures how population growth affects infrastructure development and its beneficial impacts on tourism. As the number of tourists increases, economic opportunity around the lake increases. Employment opportunities trigger work-related migration from poorer rural areas into the city and increases its total population. The income generated from economic activity benefits Srinagar's economy by facilitating local consumption (R2).

Over time, the development of Srinagar has outgrown the carrying capacity of the lake. The growth of the city caused continuous encroachment on the lake, which caused it to shrink considerably over the last two decades. Increasing wastewater loads from the population living in the periphery and lake dwellers are increasingly reducing water quality and threaten ecosystem integrity and tourism sector profitability in the future.

The conversion of land cover and the change in land use have led to increasing pressures on the lake's ecosystem, which are captured through the balancing loops (B1) – (B7).

The loop (B1) and (B3) captures the conversion of forests and wetlands, which has reduced the natural nutrient buffers between polluter sources such as farmers and the lake. The conversion of forests and wetlands to urban areas reduces the capacity of the natural environment to absorb nutrients. This increases the amount of nutrient loads that reaches the lake. The increase in loads has caused the water to be undrinkable and reduced water quality, causing declines in tourist visits in recent years. This in turn curbs economic development of the city and reduces work-related migration toward the city.

Balancing loop (B2) captures the impacts of agriculture land on water quality. The population-driven increase in agricultural land leads to an increase in the total quantity of fertilizers used in the watershed. This causes rainwater runoff from fields to carry higher nutrient loads as agriculture land expands, which leads to higher nutrient loads reaching the lake. Higher loads cause health impacts and reduce water quality, which leads to reduced economic development and lower tourism numbers int the future.

Loops (B4) to (B7) are related to direct anthropogenic pressures on the lake. The loop (B4) captures the use of the lake for drinking water extraction. The more the population grows, the more potable water is extracted from the lake. The extraction of water reduces the total water in the lake, while nutrient loadings remain unchanged. This leads to an increase in the N concentration in the water body and causes water quality to decrease.

Loop (B5) captures the impacts of sewage discharge on water quality and subsequent effects on tourism. As part of the sewage is released into the lake untreated, the N loads reaching the lake reduce water quality and cause the water to be undrinkable. The increase in loadings leads to the growth of aquatic plants and a decrease in water quality. This reduces the lake's attractiveness for tourists and hence curbs the economic development of Srinagar. These health effects are also captured by loops (B6) and (B7), which capture water quality-related impacts on economic productivity.

Loop (B8) captures increasing sedimentation resulting from land use and land cover changes. The conversion of densely vegetated areas for agriculture purposes such as crop production and livestock grazing has increased the area's vulnerability to soil erosion. The removal of soil cover increases soil erosion during precipitation events, which leads to increasing sediment loads in the streams feeding the lake. Sediment is filling up the lake and reduce its total capacity, which reduces the total quantity of water in the lake over time and leads to increasing nitrogen concentrations.

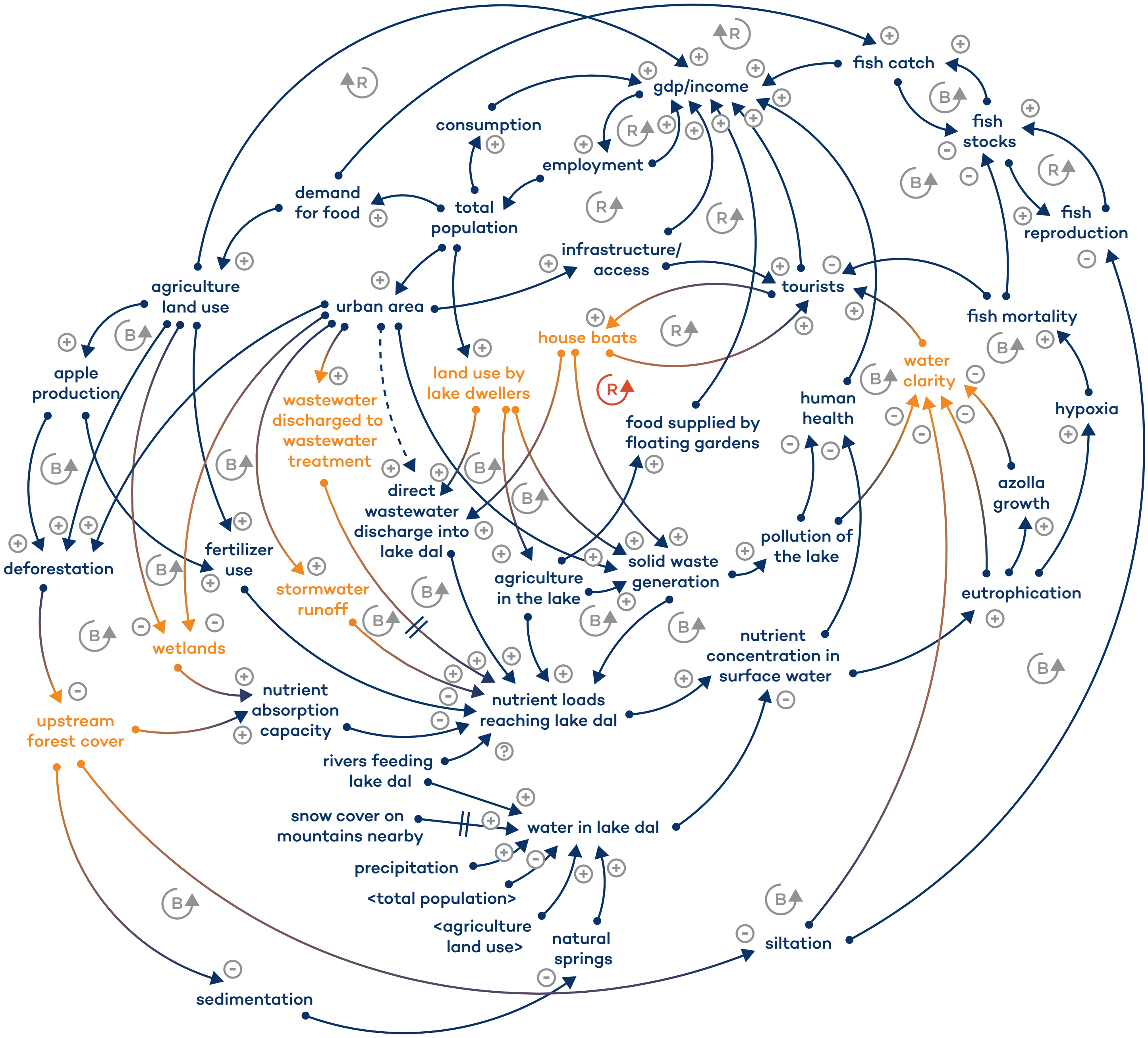


Figure 3. **Full CLD Lake Dal**

Part IV: Intervention Scenarios and Assessment Results for Lake Dal Conservation

The following scenarios have been defined for a SAVi assessment based on extensive research about the local context, on-site exchange with local stakeholders and feedback from responsible policy-makers. Results of these scenarios are presented and compared in Part V. In total, 11 scenarios were simulated, each looking at different interventions and combinations of interventions.

The business-as-usual scenario (BAU) represents the baseline scenario and assumes no intervention to implement mitigation measures. It serves as the baseline for comparison to analyze the net impact of intervention methods.

The first set of alternative scenarios (Grey infrastructure interventions) focuses on the implementation of conventional treatment options for selected polluters (see Table 1). It further assesses the net impacts of using solar power for sewage treatment.

The second set of alternative scenarios (Hybrid interventions) analyzes the feasibility of supporting conventional sewage treatment with artificial wetlands. Wetlands serve as buffer zone between the outlet of STPs and the open lake. This set of scenarios focuses on the impacts of wetlands on the nitrogen (N) concentration in the lake.

The third alternative scenario (Relocation of lake dwellers) assumes the relocation of lake dwellers to the development site Rakh-e-arth. Dwellers are compensated, moved to a new location (including housing) and provided with new opportunities for livelihood development (4.1).

The fourth set of scenarios (Road construction) focuses on the impacts on the dynamics of the lake of constructing the Western Foreshore Road. It analyzes the net impacts of road construction on lake encroachment and additional stormwater loadings. This assessment is conducted for road construction in isolation (5.1) and combined implementation (5.2) of sewage network expansion (as in Scenario 3.2) and the construction of the road.

The assumptions on polluter groups covered, interventions implemented and time horizon of implementation for all scenarios are summarized in Table 2.

Table 2. Overview of scenarios and interventions

Scenario	Polluters covered	Interventions considered and implemented by 2025
1.) Business-as-usual	None	• 75 per cent of periphery connected to sewage network • Sewage of lake dwellers is not treated • Sewage of houseboats is not treated
2.1) Improved sewage treatment for all polluter groups	• Periphery population • Lake dwellers • Houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all lake dwellers and houseboats

Scenario	Polluters covered	Interventions considered and implemented by 2025
2.2) Improved sewage treatment for all polluter groups + installation of solar PV	• Periphery population • Lake dwellers • Houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all lake dwellers and houseboats • Solar PV is used to power all sewage treatment
2.3) Improved sewage treatment of periphery population + installation of solar PV	• Periphery population	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Solar PV is used to power all sewage treatment
2.4) Improved sewage treatment of lake dwellers	• Lake dwellers	• Johkasou STPs for all lake dwellers
2.5) Improved sewage treatment of houseboats	• Houseboats	• Johkasou STPs for all houseboats
3.1) Artificial wetland construction	None directly	• Construction of 500 ha of artificial wetland
3.2) Artificial wetland construction + improved sewage treatment for all polluter groups + installation of solar PV	• Periphery population • Lake dwellers • Houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all lake dwellers and houseboats • Solar PV is used to power all sewage treatment • Construction of 500 ha artificial wetland
4.1) Relocation of lake dwellers	• Lake dwellers	• Relocation of dwellers to Rakh-e-Arth • Construction of housing for lake dwellers • Compensation payments to dwellers for plot and structure
5.1) Road construction	None	• Construction of 20km Western Foreshore Road
5.2) Road construction + artificial wetland construction + improved sewage treatment for all polluter groups + installation of solar PV	• Periphery population • Lake dwellers • Houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all lake dwellers and houseboats • Solar PV is used to power all sewage treatment • Construction of 500 ha artificial wetland • Construction of 20km Western Foreshore Road

Table 3 summarizes all references that served as data sources for variables included in the modelling work and the assessment of different scenarios.

Table 3. Overview of variables and data sources

Variable	Sources
Population	India Population, 2018 Indian Institute of Technology (ITR), 2017 Nengroo, Bhat, & Kuchay, 2017 J&K Urban Environmental Engineering Department, 2017
Land use	Amin, Fazal, Mujtaba, & Singh, 2013 Shah, Teli, & Bhat, 2014 Rashid, Amin, Khanday, & Chauhan, 2017
Water level and flows	ITR, 2017 J&K Lakes and Waterways Authority, 2018
Water quality	Wani & Kumar, 2017 ITR, 2017 Amin, Fazal, Mujtaba, & Singh, 2013 Filstrup & Downing, 2017 Lee, Jones-Lee, & Rast, 1995
Wastewater treatment	ITR, 2017; UEED, 2017 Government of Jammu & Kashmir, n.d. Kim, Jung, & Park, 2008 Central Pollution Control Board (CPCB), 2015 Al-Shididi, Henze, & Ujang, 2003 Krishna Reddy, Adamala, Levlin, & Reddy, 2017
Revenues generated through the lake	Wani, Baba, Yousuf, Mir, & Shaheen, 2013
Fisheries	Qureshi, et al., 2013 Qureshi & Krishnan, 2015 Qureshi, Krishnan, & Chandrasekaran, 2016
Tourism	Wani, Baba, Yousuf, Mir, & Shaheen, 2013 Directorate of Tourism, 2018

1. Business as Usual

SCENARIO DEFINITIONS

This section presents the assessment results of the business-as-usual (BAU) scenario. In this scenario a continuation of current trends is assumed, and it serves as a baseline to compare the effectiveness of intervention scenarios that will be presented in subsequent sections. An overview of the assumptions for the BAU scenario and its description is provided below.

Table 4. Scenario assumptions BAU scenario

Scenario	Description
Scenario 1: Business-as-usual (BAU)	The BAU scenario represents the baseline scenario for the assessment. It assumes a continuation of current trends and pressures and assumes no interventions or remediation measures. Specific assumptions are: • 75 per cent of the lake periphery's sewage is treated. • Sewage of lake dwellers and houseboats flows directly into the lake without treatment. • Frequent overflow of STPs and pumping stations during heavy rainfall events as well as during electricity cuts causes the discharge of additional untreated sewage into the lake. • Grid electricity for STPs and pumping stations is provided by diesel generators.

SUMMARY OF RESULTS

Table 5 presents the development of key variables and drivers in the BAU scenario over time. In the BAU scenario, the combination of population growth and lack of mitigation measures leads to increasing pressures on the lake and worsening water quality. Although migration slows down due to the lack of economic opportunity provided by the lake, these developments threaten tourism and fishery-dependent livelihoods. The growth of aquatic plants changes the scenic landscape around the lake and causes tourism numbers to decline. Furthermore, worsening water quality affects the reproduction of fish and potentially leads to the depletion of local fish stocks within the next 20 years.

Table 5. Summary of key indicators BAU scenario

Variable	Unit	2016	2020	2025	2030	2040	2050	2060
Population								
Population Srinagar	People	1,533,622	1,728,397	1,940,868	2,126,033	2,447,984	2,691,297	2,837,592
Population in the periphery	People	199,371	224,692	252,313	276,384	318,238	349,869	368,887
Lake dwellers	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804
N loadings								
Total N loadings	kg N/year	398,764	403,795	456,672	475,449	489,717	572,597	587,020
N loadings from population	kg N/year	338,966	345,174	399,487	419,664	436,632	522,074	538,717
Residual (non-sewage) N loadings	kg N/year	59,798	58,621	57,185	55,785	53,085	50,523	48,303
Water quality								
N Concentration	mg N/litre	0.91	0.93	1.08	1.18	1.21	1.45	1.53
Secchi depth	Metre	1.28	1.28	1.09	1.07	1.05	0.74	0.75
Chlorophyll-a concentration	Ug/litre	26.22	25.57	39.40	40.47	41.99	71.28	71.10
Economic impacts								
Tourism revenues	INR million/ year	7,533	7,120	6,880	7,028	5,742	5,986	5,443
Fisheries revenues	INR million/ year	1,076	1,209	1,354	1,481	1,082	173	25
Total revenues	INR million/ year	8,609	8,329	8,234	8,508	6,824	6,159	5,468

DESCRIPTION OF RESULTS

In the BAU scenario, Srinagar's population is projected to reach 2.8 million people by 2060. This represents an increase of approximately 1.3 million people, and is 85 per cent higher compared to 2016. The change in population is driven by migration and natural population growth. Population growth naturally increases the population in the periphery of the lake, increasing from 199,400 people in 2016 to 368,900 people in 2060. The number of lake dwellers is projected to increase from around 59,900 people in 2016 to 66,800 people in 2060. The development of total population and population in the periphery of the lake (left) and the lake dwellers in the BAU scenario is displayed in Figure 4.

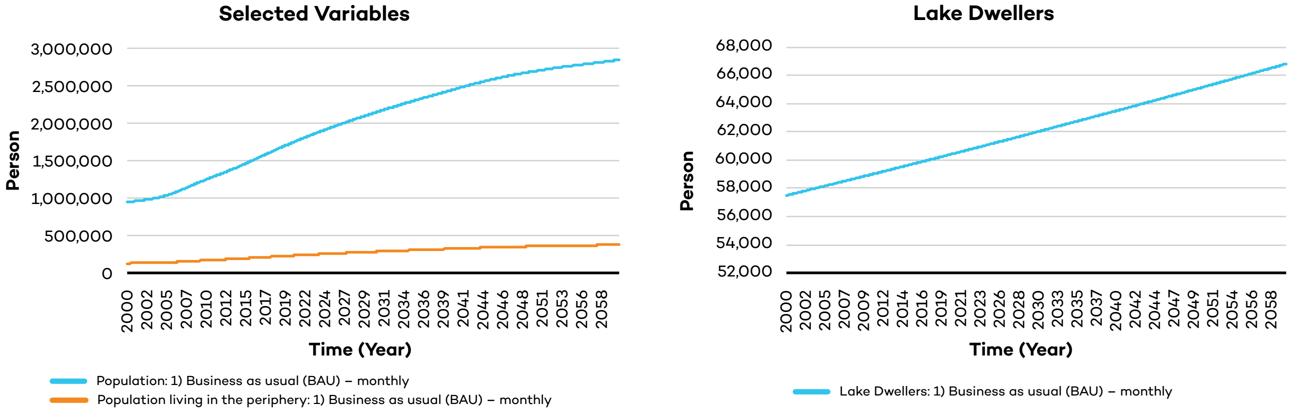


Figure 4. Baseline population, population in the periphery of the lake and lake dwellers

At the same time, there is no intervention to upgrade the city's sewage network or treatment capacity. The combination of outdated sewage treatment plants (STPs) and a growing population worsens the pressure on the lake's ecosystem. Total N loadings in the BAU scenario are projected to increase to 587 tons by 2060, which is a 47.2 per cent increase compared to the roughly 400 tons of N loadings in 2016. Higher N loadings cause the concentration of nutrients in the BAU scenario to increase to 1.53 mg N per litre by 2060, compared to 0.91 mg N per litre in 2016. Total annual N loadings and the concentration of N in the water of Lake Dal are depicted in Figure 5.

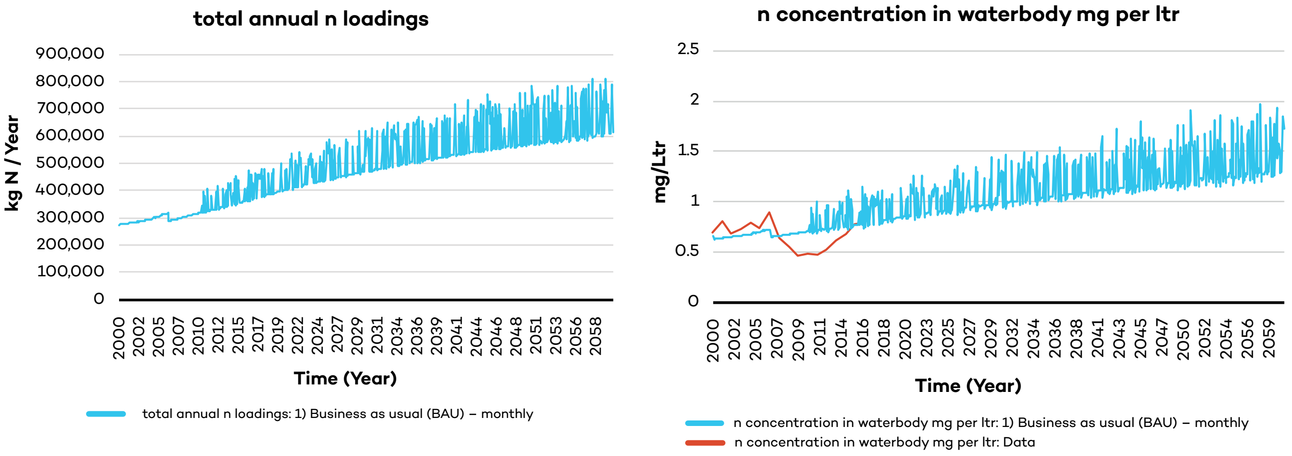
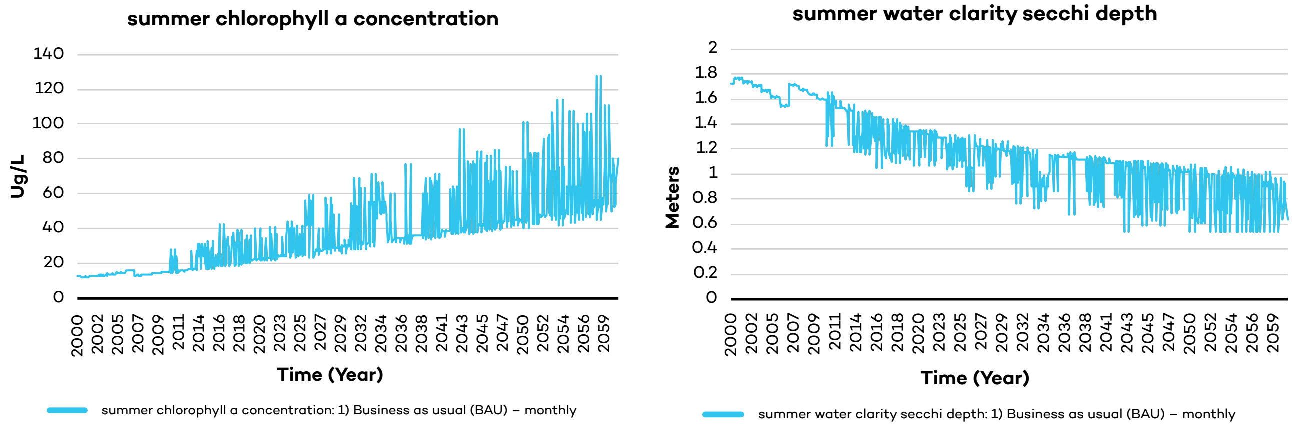


Figure 5. Baseline annual N loadings and N concentration in Lake Dal

Higher nutrient concentrations provide beneficial environment for algae and other aquatic plants to grow. The chlorophyll-a concentration in the BAU scenario almost triples from 26.2 ug per litre in 2016 to approximately 71.1 ug per litre in 2060. Between 2030 and 2060, the average concentration of chlorophyll-a is 53.7 ug per litre. Values that high provide beneficial conditions for the growth of aquatic plants and put the lake at high risk of being classified as "eutrified." The high nutrient concentration causes the growth of aquatic plants and leads to a decrease in water clarity and water quality.

A commonly used measure for water clarity is the "Secchi depth." A "Secchi disk" is a white plastic disk that is used to determine the clarity of the water. The Secchi depth is the depth at which the disk is still visible when held under water. In the BAU scenario, the average Secchi depth is projected to decrease from 1.36 m in 2016 to 0.75 m by 2060. The average Secchi depth between 2030 and 2060 is 0.94 m. The development of chlorophyll-a concentration and Secchi depth in the BAU scenario is illustrated in Figure 6, compared to historical data.

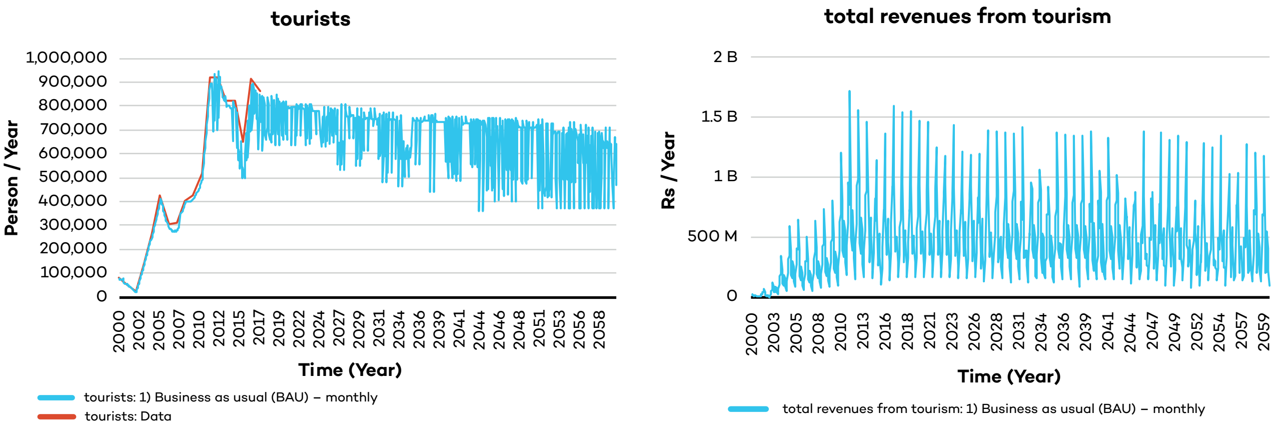


summer chlorophyll a concentration

summer water clarity secchi depth

Figure 6. Baseline chlorophyll-a concentration and Secchi depth

The decrease in environmental quality of the lake reduces its attractiveness for tourists and affects the annual number of visitors. In the BAU scenario, declining water clarity levels reduce the number of tourists over time. By 2060, the annual number of visitors is projected at 600,400 visitors, compared to approximately 900,000 in the year 2016. This is equivalent to a 33.3 per cent reduction in tourists over the next 40 years. This leads to a proportional decline in tourism-related spending and overall tourism revenues. Revenues from tourism shrink by 27.7 per cent from INR 7.5 billion in 2016 to INR 5.4 billion in 2060. Due to the area's high dependence on tourism, this reduction in visitors poses a threat to many lake-dependent livelihoods. The development of tourists and tourism revenues is presented in Figure 7, compared to historical data.



tourists

total revenues from tourism

Figure 7. Baseline projections on number of tourists and tourism revenues

Next to tourism, fisheries are a livelihood for many people living in and around the lake. The reproduction rate of fish highly depends on water quality, as fish depend on oxygen levels in the water to survive. The increase in nutrients and aquatic plants leads to a depletion of oxygen in the lake and reduces the fish reproduction rate over time. Figure 8 illustrates the development of fish catch and reproduction (left), and total revenues from fisheries (right). In the BAU scenario, the reproduction rate of fish (blue line) falls below the catching rate (green line) around the year 2024, which indicates that a net depletion of the fish stock takes place. The stocks are able to maintain the desired catching rates until approximately 2038, before the catching rate itself is affected by fish scarcity. In conclusion, if current trends continue, the lake's water quality declines to a point where it no longer sufficiently serves to maintain the required fish reproduction necessary for sustaining the projected catch. This poses a threat for the livelihood of people that depend economically on the local fishery industry.

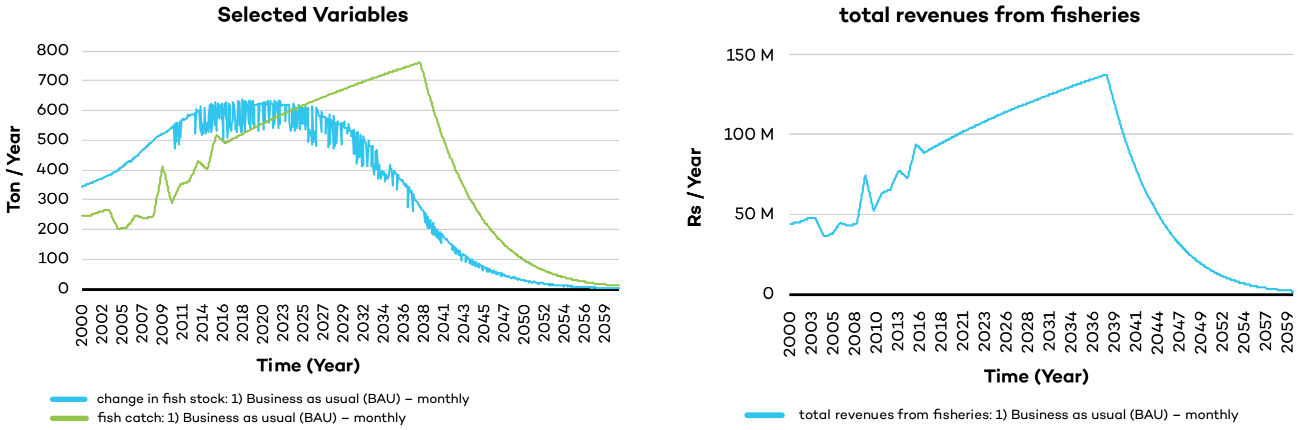


Figure 8. Baseline fish catch and fish stock (left) and revenues from fisheries (right)

2. Grey Infrastructure Interventions: Sewage treatment upgrades using traditional technologies

SCENARIO DEFINITIONS

This section presents assessment results with regard to the effectiveness of different treatment options and their impacts on key development indicators at Lake Dal. An overview of scenarios with name and description is provided below.

Table 6. Overview and description of traditional treatment scenarios

Scenario	Description
Scenario 2.1: Traditional technology upgrades for all polluters	The sewage of all lake polluters is treated, including lake periphery population, lake dwellers and houseboats. Deployment of the following technologies used at STPs: activated sludge process, sequencing batch reactor and moving bed biofilm reactor. STPs are supported by diesel generators as backup. For treating the sewage of lake dwellers and houseboats on site, Johkasou treatment technology is used.
Scenario 2.2: Traditional technology upgrades for all polluters + solar PV	The sewage of all lake polluters is treated, including lake periphery population, lake inhabitants and houseboats. Deployment of the following technologies used at STPs: activated sludge process, sequencing batch reactor and moving bed biofilm reactor. The STPs are powered entirely by solar PV. For treating the sewage of lake dwellers and houseboats on site, Johkasou treatment technology is used.
Scenario 2.3: Traditional technology upgrade for periphery + solar PV	All people of the lake periphery are connected to STPs and 100 per cent of their sewage is treated by 2025. Deployment of the following technologies used at STPs: activated sludge process, sequencing batch reactor and moving bed biofilm reactor. The STPs are powered entirely by solar PV. Sewage of lake dwellers and houseboats will not be treated.

Scenario	Description
Scenario 2.4: Traditional technology upgrade for lake dwellers	Sewage of lake dwellers is treated on site, using Johkasou treatment technology. Other business-as-usual conditions are maintained.
Scenario 2.5: Traditional technology upgrade for houseboats	Sewage of houseboats is treated on site, using Johkasou treatment technology. Other business-as-usual conditions are maintained.

Different (sets of) interventions are assumed for the scenarios. Scenarios 2.1 and 2.2 analyze the combined implementation of treatment options across all polluters, with solar PV installation at STPs (2.1) and without (2.2). The remaining scenarios analyze the impacts of implementing treatment options for the periphery (2.3), lake dwellers (2.4) and houseboats (2.5) in isolation. Polluters treated and interventions considered for the traditional treatment scenarios are summarized in Table 7.

Table 7. Scenario assumptions traditional treatment scenarios

Scenario	Polluters covered	Interventions considered	Implementation completed by:
1.) Business-as-usual	None	None	N/A
2.1) Improved sewage treatment for all polluter groups	Periphery, dwellers & houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for dwellers and houseboats	2025
2.2) Improved sewage treatment for all polluter groups + installation of solar PV	Periphery, dwellers & houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for dwellers and houseboats • Solar PV is used to power all sewage treatment	2025
2.3) Improved sewage treatment of periphery population + installation of solar PV	Periphery	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Solar PV is used to power all sewage treatment	2025
2.4) Improved sewage treatment of lake dwellers	Lake Dwellers	• Johkasou STPs for dwellers	2025
2.5) Improved sewage treatment of houseboats	Houseboats	• Johkasou STPs for houseboats	2025

SUMMARY OF RESULTS

The implementation of sewage treatment technologies improves the lake's ecosystem health by reducing the discharge of annual N loadings into the lake. The combined implementation of treatment technologies for all polluters powered by solar PV (Scenario 2.2) yields the highest reductions in N loadings and improvements in water quality among all traditional treatment scenarios. N loadings are reduced by 56 per cent, which is equivalent to reductions of 326.6 tons per year in 2060. The expansion of sewage network and STP capacity leads to the highest reduction in N loadings across Scenarios 2.3 to 2.5. The projected reduction in loadings is approximately 236.8 tons per year, which is 40 per cent lower compared to the baseline. The treatment of lake dwellers yields a reduction in N loadings of around 11 per cent. Table A2.1 in Appendix I presents the results of key indicators in the traditional treatment scenario compared to the BAU scenario.

- The analysis indicates that expanding sewage network connectivity and STP capacity, and the treatment of lake dwellers are the effective interventions for reducing N loadings. Treating the periphery and avoiding power cuts through the use of renewable energy has the potential to reduce N loadings by 40.3 per cent.
- Using solar PV at STPs and pumping will avoid sewage overflow and accidental discharge of untreated wastewater into the lake currently caused by power cuts. The implementation of treatment for the periphery of the lake supported by solar PV yields higher reductions of N loadings (40.3 per cent) by 2060 than the implementation of treatment for all polluters without solar PV (35.4 per cent). Details are displayed in Table A2.1 in Appendix I.
- Realizing the outlined interventions of LAWDA and UEED provides full coverage for the periphery of the lake. The planned actions are sufficient to reliably treat wastewater loads over the next decades, given the supply of electricity and the installation of effective sewage treatment technologies.
- Establishing sewage network connectivity and STP capacity is necessary for maintaining the fishery industry at Lake Dal. The sole treatment of dwellers and/or houseboat sewage is insufficient and would lead to a collapse of the fish stock in the long run, as indicated by decreasing fishery revenues for Scenarios 1, 2.4 and 2.5 at the bottom of Table A2.1 in Appendix II.

DESCRIPTION OF RESULTS

a. Population Development

In the traditional treatment scenarios, population is expected to increase by between 4 per cent and 13 per cent compared to the baseline. Only Scenario 2.5 yields no population growth. The increase in population for the other scenarios is mainly driven by work-related migration resulting from increasing economic activity as the quality of the lake improves. The increase in population produces additional pressures on the sewage treatment system, but the expansion of sewage network coverage and STP capacity would be sufficient to mitigate these pressures (see discussion below). Projections about Srinagar's population in 2060 range from 2.84 million people to 3.25 million people, where the latter one represents a 13 per cent increase compared to the BAU scenario. Population developments of all scenarios are presented in Table 8. The table distinguishes between total population in Srinagar and share of the population living in the periphery of the lake.

Table 8. Population trends traditional treatment scenarios

	Population Srinagar			Population in the periphery		
2016 value	**1,530,000**			**199,450**		
Scenario	**Total (2060)**	**Net difference**	**% vs BAU**	**Total (2060)**	**Net difference**	**% vs BAU**
1.) BAU	2,837,592	—	—	368,887	—	—
2.1) All polluters	3,179,374	341,783	12%	413,319	44,432	12%
2.2) All polluters + solar PV	3,248,298	410,706	13%	422,279	53,392	14%
2.3) Periphery + solar	3,148,230	310,639	10%	409,270	40,383	11%
2.4) Lake dwellers	2,958,565	120,973	4%	384,613	15,727	4%
2.5) Houseboats	2,837,839	248	0%	368,919	32	0%

b. Nitrogen Loadings

Scenarios 2.1 and 2.2 both imply the expansion of sewage treatment options to provide full coverage for all polluter groups. Both scenarios include the expansion of the sewage network to cover 100 per cent of the periphery population, constructing the STP Noor-Bagh and constructing sewage treatment technologies for lake dwellers and houseboats. Scenario 2.1 yields reductions of 40.9 per cent in total N loadings compared to the baseline. If solar PV for powering STPs is additionally installed (Scenario 2.2), this yields the best results: 54.7 per cent reduction of N loadings compared to the BAU scenario. Scenario 2.3 assumes the treatment of only the sewage of the periphery and installation solar PV at STPs, which reduces N loadings by 37.3 per cent. Treating only the sewage of lake dwellers as assumed in Scenario 2.4, yields a reduction of 15.4 per cent in N loadings. Scenario 2.5 yields little reduction in N loadings compared to the other scenarios because a relatively low share of the population lives on houseboats, their tourism-related use is only seasonal and tourists spend only part of their stays on the houseboats. Hence, the treatment of relatively low sewage volumes decreases N loadings by only 0.02 per cent. Table 9 provides an overview of N loadings across all traditional treatment scenarios.

Table 9. N loadings in traditional treatment scenarios

	Total N loadings (kg/year)				N loadings from population (kg/year)				Residual (non-sewage) N loadings (kg/year)			
2016 value	**361,867**				**302,069**				**59,798**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	587,020	511,222	—	—	538,717	459,267	—	—	48,303	51,955	—	—
2.1) All polluters	379,439	302,141	-209,081	-40.9%	327,716	249,833	-209,434	-45.6%	51,723	52,308	353	0.7%
2.2) All polluters + solar PV	260,402	231,660	-279,562	-54.7%	207,725	179,211	-280,056	-61.0%	52,677	52,450	495	1.0%
2.3) Periphery + solar PV	350,225	320,728	-190,494	-37.3%	299,167	268,549	-190,718	-41.5%	51,058	52,179	224	0.4%
2.4) Lake dwellers	524,861	432,397	-78,825	-15.4%	476,362	380,435	-78,832	-17.2%	48,499	51,962	7	0.0%
2.5) Houseboats	586,975	511,123	-99	-0.02%	538,672	459,168	-99	-0.02%	48,303	51,955	0	0.01%

c. Water Quality

Reducing N loadings that reach the lake has a positive effect on water quality. It leads to a reduction of N concentration in the lake, a lower chlorophyll-a concentration and better water clarity. Across all these analyzed water quality indicators, Scenario 2.2 attains the highest water quality improvements, while implementing interventions of Scenario 2.5 would yield hardly any water quality improvements. N concentration in the lake is reduced by 0.02 per cent and up to 54.7 per cent. Chlorophyll-a levels in analyzed scenarios are reduced by 0.05 per cent and up to 81.4 per cent compared to the BAU scenario. Water clarity improvements range between 0.18 and 1.02 metres, which is respectively 0.03 per cent and 108.8 per cent higher compared to the baseline. Water quality indicators for all treatments scenarios are presented in Table 10.

Table 10. Water quality indicators traditional treatment scenarios

	N Concentration (mg N/litre)				Secchi depth (metre)				Chlorophyll-a concentration (Ug/litre)			
2016 value	**0.83**				**1.36**				**21.28**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	1.526	1.282	—	—	0.754	0.936	—	—	71.1	53.7	—	—
2.1) All polluters	0.986	0.759	-0.523	-40.8%	1.324	1.693	0.757	80.8%	27.6	20.3	-33.4	-62.2%
2.2) All polluters + solar PV	0.677	0.581	-0.702	-54.7%	1.668	1.955	1.019	108.8%	13.7	10.0	-43.7	-81.4%
2.3) Periphery + solar PV	0.911	0.804	-0.479	-37.3%	1.267	1.410	0.474	50.6%	25.4	19.7	-34.0	-63.3%
2.4) Lake dwellers	1.365	1.085	-0.197	-15.4%	0.901	1.116	0.180	19.2%	56.0	38.6	-15.1	-28.2%
2.5) Houseboats	1.526	1.282	0.000	-0.02%	0.754	0.937	0.000	0.03%	71.1	53.7	0.0	-0.05%

d. Economic Impacts

In terms of economic impacts, the analysis confirms that improvements in water quality are beneficial for the tourism and fishery sector. Improving water quality draws more tourists to Srinagar and contributes to healthy fish stocks that can sustain the desired catch levels. Projections indicate an increase in tourism revenues between 0.03 per cent and 107.9 per cent, and an increase in fishery revenues between 0.06 per cent and 164.6 per cent compared to the baseline. Total revenues from fisheries and tourism are between 0.03 per cent and 108.4 per cent higher than in the BAU scenario, which is equivalent to INR 895.9 million and INR 6.5 billion respectively. In line with the assessment of indicators in previous sections, combined interventions of Scenario 2.2 yield the highest economic gains while interventions of Scenario 2.5 imply hardly any economic impacts. Revenues of analyzed sectors are summarized for each scenario in Table 11.

Table 11. Economic impacts traditional treatment scenarios

	Tourism revenues (INR million/year)				Fisheries revenues (INR million/year)				Total revenues (INR million/year)			
2016 value	7,628				1,076				8,704			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	5,443	5,940	—	—	25	719	—	—	5,468	6,660	—	—
2.1) All polluters	9,908	10,813	4,873	82.0%	318	1,516	797	110.7%	10,226	12,329	5,670	85.1%
2.2) All polluters + solar PV	10,947	12,348	6,408	107.9%	2,236	1,904	1,184	164.6%	13,183	14,252	7,592	114.0%
2.3) Periphery + solar PV	8,285	8,886	2,946	49.6%	2,167	1,851	1,132	157.3%	10,451	10,737	4,077	61.2%
2.4) Lake dwellers	6,296	7,091	1,151	19.4%	68	1,043	323	44.9%	6,364	8,134	1,474	22.1%
2.5) Houseboats	5,444	5,942	1.857	0.03%	25	720	0.4	0.06%	5,470	6,662	2	0.03%

e. Integrated Cost–Benefit Analysis

Table 12 presents the results of the integrated cost–benefit analysis (CBA) for the traditional treatment scenarios. The integrated CBA compares the results of Scenarios 2.1–2.5 with the baseline and lists required investments, added benefits and avoided costs of interventions across social, economic and environmental indicators.

The highest additional capital and operational expenditures are required in Scenario 2.1, which assumes sewage treatment interventions for all polluter groups without installing solar PV. The projections in Scenario 2.2 indicate that using solar energy to provide electricty to STPs and to pumping stations yields reductions in electricity costs compared to Scenario 2.1. Cumulative investments of INR 310 million for installing solar PV are required to cover STPs and pumping station with solar energy. The implementation yields savings of INR 593 million in electricity costs for wastewater treatment by avoiding high fuel expenses for frequently using diesel generators in cases of power cuts from the grid. The implementation of individual treatment options requires expenses of INR 13.42 billion for treating sewage from the periphery (Scenario 2.3), 4.37 billion for treating the sewage of lake dwellers (Scenario 2.4) and INR 768 million for treating the sewage generated on houseboats (Scenario 2.5).

Scenario 2.2 yields the highest added benefits in form of revenues from tourism and fisheries. The projections indicate total added benefits of INR 237.7 billion between 2019 and 2060 for the full treatment of all polluter groups and the installation of solar PV (Scenario 2.2) and INR 179.8 billion for the same interventions but without installing solar PV (Scenario 2.1). Positive impacts of individual interventions are lower compared to combining interventions. The projections indicate added benefits of INR 109.1 billion for Scenario 2.3, INR 44.5 billion for Scenario 2.4, and INR 74 million for Scenario 2.5.

External costs included in the CBA are the social costs of carbon, which represent health costs caused by emissions associated with the energy generation process based on fossil fuel energy sources. Since these health costs do not occur in cases where solar power is used, they are treated as "avoided costs" in the CBA. The scenarios in which solar power is used avoid social costs equivalent to INR 75.2 million (Scenario 2.2) and INR 76 million (Scenario 2.3). These costs are avoided since diesel generators are replaced by solar PV to provide electricity to STPs and pumping stations. Scenarios 2.1, 2.4 and 2.5 show social costs of carbon of INR 126 million, INR 26 million and INR 40,000 respectively. The underlying reason for the occurrence of social costs of carbon in these scenarios is the increase in emissions due to energy provided by diesel generators for wastewater treatment. The population in Srinagar is projected to grow in all presented scenarios, which indicates increasing volumes of wastewater that need to be treated. The treatment of the additional wastewater requires energy, which is provided by diesel generators in Scenarios 2.1, 2.4, and 2.5, as indicated in Table 12.

Overall, Scenario 2.2 yields the highest net benefits for the Lake Dal area, with approximately INR 222.6 billion in net benefits between 2019 and 2060. Improved sewage treatment of all polluter groups without using solar PV yields cumulative benefits of INR 163.9 billion, which is 26.4 per cent lower compared to Scenario 2.2. The implementation of individual interventions for treating the sewage of the population living in the periphery, lake dwellers and houseboats yields INR 98.8 billion, INR 40.1 billion, and INR 694 million respectively. The negative net benefits of treatment interventions for houseboats indicate that the reductions of N loadings obtained from treating the sewage generated on houseboats alone are insufficient to achieve substantial water quality improvements that would cause positive economic impacts. Hence, the costs for implementing interventions of this scenario outweigh the monetary benefits.

Table 12. Integrated CBA traditional treatment scenarios

Scenario	2.1 Improved treatment all polluters	2.2 Improved treatment all polluters + solar PV	2.3 Improved treatment periphery + solar PV	2.4 Improved treatment lake dwellers	2.5 Improved treatment houseboats
EXPENDITURES (in INR million)					
Upgrade sewage treatment network	**10,894**	**10,301**	**10,110**	**208**	**0**
Investment in STPs	6,750	6,750	6,750	0	0
O&M costs STPs	3,141	3,141	3,141	0	0
Electricity costs nitrogen removal	1,003	410	219	208	0
Sewage treatment of lake population	**4,933**	**4,933**	**0**	**4,165**	**768**
Houseboat sewage treatment	768	768	0	0	768
Lake dwellervs sewage treatment	4,165	4,165	0	4,165	0
Costs of solar energy capacity	**0**	**391**	**310**	**0**	**0**
Total costs	**15,826**	**15,625**	**10,420**	**4,373**	**768**
ADDED BENEFITS (in INR million)					
Revenues for benefiting sectors					
Revenues from tourism	177,822	234,743	106,305	43,670	73
Revenues from fisheries	2,002	2,975	2,840	812	1
Total added benefits (in INR million)	179,823	237,718	109,144	44,482	74
AVOIDED COSTS (in INR million)					
Social costs of carbon	-126	75.2	76	-26	-0.04

Scenario	2.1 Improved treatment all polluters	2.2 Improved treatment all polluters + solar PV	2.3 Improved treatment periphery + solar PV	2.4 Improved treatment lake dwellers	2.5 Improved treatment houseboats
Net results	163,871	222,168	98,800	40,083	-694
Benefit to cost ratio	**11.4**	**15.2**	**-10.5**	**10.2**	**0.1**
Rehabilitation Benefit for the lake					
Additional tons of nitrogen removed	10,027	14,206	10,432	2,079	3
Net benefits (in INR million) per ton of nitrogen avoided	**16**	**16**	**9**	**19**	**-227**
Costs per ton of nitrogen avoided	1.58	1.07	1.00	2.10	250.83

3. Hybrid Interventions: Artificial wetland as a natural infrastructure component

This section presents the assessment results of establishing an artificial wetland and its impacts on key development indicators at Lake Dal. An overview of scenarios, including the name and a description of the scenarios, is provided below.

Table 13. Overview and description of artificial wetland scenarios

Scenario	Description
Scenario 3.1: Artificial wetlands	A 500 ha artificial wetland is constructed in shallow waters of the lake. Wetlands provide ecosystem services of water filtration and nitrogen absorption. These natural infrastructure services reduce the N concentration in the lake by filtering some of the sewage and wastewater flowing into the lake. Aside from that, all business-as-usual conditions are maintained in this scenario: • Only 75 per cent of the lake periphery's sewage is treated. • Sewage of lake dwellers and houseboats flows directly into the lake without treatment. • Overflow of STPs during heavy rainfalls as well as during power cuts is assumed.
Scenario 3.2: Artificial wetlands + traditional technology upgrades + solar PV	A 500 ha artificial wetland is constructed in shallow waters of the lake to provide water filtration and nitrogen absorption services. These natural infrastructure elements are constructed to complement grey infrastructure measures used in Scenario 2.2: • Sewage of all lake polluters is treated, including lake periphery population, lake dwellers and houseboats. • All STPs are powered entirely by solar PV The treatment of the periphery is achieved by expanding sewage network coverage and using the following STP technologies: activated sludge process, sequencing batch reactor and moving bed biofilm reactor. For the treatment of sewage from lake dwellers and houseboats the implementation of Johkasou treatment technology is assumed.

The two scenarios are designed to analyze the impact of wetlands in isolation (3.1) and the added value of artificial wetlands when used to supplement the expansion of traditional sewage treatment options for all polluter groups (3.2). The wetlands are constructed to serve as a nitrogen-absorbing buffer zone between STP outlets and the open lake. Polluters treated and interventions considered for the traditional treatment scenarios are summarized in Table 14.

Table 14. Scenario assumptions artificial wetland scenarios

Scenario	Polluters covered	Interventions considered	Implementation completed by:
1.) Business-as-usual	None	None	N/A
3.1) Artificial wetland construction	None directly	• Construction of 500 ha of artificial wetland	2025
3.2) Artificial wetland construction + improved sewage treatment for all polluter groups + installation of solar PV	Periphery, lake dwellers & houseboats	• Construction of 500 ha artificial wetland • Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for lake dwellers and houseboats • Solar PV is used to power all sewage treatment	2025

Summary of Results

The analysis reveals that constructing an artificial wetland alone (see Scenario 3.1) is not sufficient to mitigate nutrient loadings from wastewater. While it contributes to reducing the N concentration in the lake by 19.7 per cent, this represents only a small improvement compared to the 66.4 per cent reduction achieved by combining the artificial wetland with an expansion of the sewage network and providing treatment capacity directly to all polluter groups (see Scenario 3.2). Both the use of a wetland in isolation and the use of a hybrid approach for sewage treatment improve the water quality in the lake. Reducing the N concentration of the lake's water contributes to reducing chlorophyll-a levels to 45.12 ug per litre (Scenario 3.1) and 7.66 ug per litre (Scenario 3.2). This reduces the potential for the growth of algae and other aquatic plants and increases water clarity by 0.27 m (Scenario 3.1) and 1.44 m (Scenario 3.2) respectively. Table A3.1 in Appendix II summarizes the results for the two hybrid treatment scenarios and shows the developments of key indicators over time.

- Using an artificial wetland in isolation, without any grey infrastructure measures, yields a reduction in nitrogen concentration in the lake water. It slightly improves water quality, but is insufficient to reduce N loadings and N concentration to sustainable levels.
- Constructing an artificial wetland to supplement conventional wastewater treatment (Scenario 3.2) significantly reduces the N concentration in the lake. The results of this scenario demonstrate the lowest N concentration in the lake in the year 2060 out of all simulated scenarios (0.513 mg per litre).

Description of Results

a. Population Development

In the hybrid treatment scenarios, population is expected to increase by between 6 per cent and 13.3 per cent compared to the baseline. Projections about Srinagar's population in 2060 range from 3.01 million people (3.1) to 3.24 million people (3.2), which is 6 per cent and 13.3 per cent higher compared to the baseline. Indicators related to population are presented in Table 15. The increase in population is mainly driven by work-related migration resulting from increasing economic activity as the quality of the lake improves. In both scenarios, an increase in population produces additional pressures on the sewage treatment systems. In Scenario 3.1, establishing an artificial wetland serves as a buffer zone that absorbs N and other nutrients from the wastewater before they reach the lake. Compared to the baseline, this improves water quality and increases N loads from population as more people migrate to the area. In Scenario 3.2, the expansion of sewage network coverage and STP capacity is sufficient to mitigate the additional pressures, and the wetland reduces the N concentration of wastewater even further before it reaches the lake. Scenario 3.2 shows the lowest N concentration by 2060 out of all simulated scenarios.

Table 15. Population trends artificial wetland scenarios

	Population Srinagar			Population in the periphery			Lake dwellers		
2016 value	1,530,000			199,450			59,850		
Scenario	Total (2060)	Net difference	% vs BAU	Total (2060)	Net difference	% vs BAU	Total (2060)	Net difference	% vs BAU
1.) BAU	2,837,592	—	—	368,887	—	—	66,804	—	—
3.1) Wetland	3,009,077	171,485	6.0%	391,180	22,293	6.0%	66,804	0	0.0%
3.2) Wetland + treatment all + solar PV	3,237,943	400,352	13.3%	420,933	52,046	14.1%	66,804	0	0.0%

b. Nitrogen Loadings

The construction of a 500 ha artificial wetland, while not extending the targeted sewage treatment of polluter groups (3.1), results in a 3.8 per cent increase in N loadings. This projected increase is caused by several factors. The projections are estimated in average values per year during a time period between 2030 and 2060. The construction of artificial wetlands will at first lead to an improvement of the water quality and over time enhance economic activities around the lake. This will attract more people to Srinagar, which will increase sewage pressures on the lake and hence increase N loadings reaching the lake. On the other hand, wetlands are created within shallow parts of the lake and hence are not targeted to decrease the N loadings reaching the lake. The positive filtration and absorption services of wetlands only take effect once the wastewater flows into the lake. These factors cause an increase of the average N loadings during the assessed time period in Scenario 3.1. Scenario 3.2 combines the construction of a 500 ha artificial wetland and the expansion of targeted sewage treatment options for all polluter groups as well as the installation of solar PV to provide electricity to STPs and pumping stations. These combined interventions yield a reduction in N loadings by 53.9 per cent compared to the baseline.[1] Indicators related to N loadings are presented in Table 15.

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[1] Described effects that cause an increase of N loadings in Scenario 3.1 also hold true for Scenario 3.2. The overall decrease of N loadings in Scenario 3.2 is attained by traditional sewage treatment options but the construction of the wetland triggers a rebound effect on N loadings. This is confirmed by the fact that Scenario 3.1 only decreases N loadings by 53.9 per cent while Scenario 2.2 of the previous section (identical interventions but no construction of an artificial wetland) reduces N loadings by 54.7 per cent.

Table 16. N loadings in artificial wetland scenarios

	Total N loadings (kg/year)				N loadings from population (kg/year)				Residual N loadings (kg/year)			
2016 value	**361,867**				**302,069**				**59,798**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	587,020	511,222	—	—	538,717	459,267	—	—	48,303	51,955	—	—
3.1) Wetland	637,085	530,776	19,554	3.8%	587,938	478,778	19,511	4.2%	49,147	51,998	43	0.1%
3.2) Wetland + treatment all + solar PV	266,667	235,425	-275,796	-53.9%	212,661	182,690	-276,577	-60.2%	54,006	52,735	780	1.5%

c. Water Quality

Despite an increase in N loadings in Scenario 3.1, both scenarios contribute to reducing the N concentration in the lake water due to the positive filtration and absorption services of wetlands. The average N concentration declines by 22.2 per cent in Scenario 3.1 and 65.5 per cent in Scenario 3.2[2] respectively. This improves the water quality of the lake and results in lower chlorophyll-a concentrations and improved water clarity. Chlorophyll-a levels in the treatment scenarios are on average 40.6 per cent (Scenario 3.1) and 89.5 per cent (Scenario 3.2) lower compared to the BAU scenario. Water clarity improvements range between 0.26 m and 1.63 m for Scenario 3.1 and 3.2 respectively. Water quality indicators for the treatments scenarios are presented in Table 17.

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[2] The additional value of artificial wetlands for the decrease of N concentration in the lake is evidenced when comparing Scenario 3.2 with Scenario 2.2. Both scenarios include the same traditional sewage treatment measures and installation of solar PV. While Scenario 3.2 additionally includes the construction of a wetland and decreases N concentration by 65.5 per cent, Scenario 2.2 reduced the N concentration by only 54.7 per cent.

Table 17. Water quality indicators artificial wetland scenarios

	N Concentration (mg N/litre)				Secchi depth (metre)				Chlorophyll-a concentration (Ug/litre)			
2016 value	**0.83**				**1.36**				**21.28**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	1.526	1.282	—	—	0.754	0.936	—	—	71.1	53.7	—	—
3.1) Wetland	1.226	0.998	-0.284	-22.2%	1.02	1.20	0.26	28.1%	45.1	31.9	-21.8	-40.6%
3.2) Wetland + treatment all + solar PV	0.513	0.442	-0.840	-65.5%	2.19	2.57	1.63	174.2%	7.7	5.7	-48.0	-89.5%

d. Economic Impacts

In terms of economic impacts, the assessment confirms that improvements in water quality due to the construction of artificial wetlands are beneficial for the tourism and fishery sector. In comparison to the BAU scenario, the construction of artificial wetlands without extending the targeted sewage treatment for polluter groups (3.1) contributes to better water quality, which attracts more tourists, causes an increase in tourism revenues of 27.9 per cent and likewise increases fishery revenues by 60.6 per cent. However, solely constructing a wetland is insufficient to prevent water quality from worsening to a point where fish reproduction is impacted. This leads to a depletion of the fish stocks over the next decades, causing a reduction of fishery revenues in year 2060 by more than 90 per cent compared to 2016. In the hybrid treatment Scenario 3.2, improved water quality draws more tourists to Srinagar, increases tourism revenues by 173 per cent and contributes to healthy fish stocks that sustain the desired catch levels, with fishery revenues increasing by 170.2 per cent. Total revenues are 28.2 per cent (Scenario 3.1) and 172.9 per cent (Scenario 3.2) higher than in the BAU scenario, which is equivalent to INR 1.51 billion and INR 11.21 billion respectively. Indicators on total and sectoral revenues are summarized in Table 18.

Table 18. Economic impacts artificial wetland scenarios

	Tourism revenues (INR million/year)				Fisheries revenues (INR million/year)				Total revenues (INR million/year)			
2016 value	**7,628**				**1,076**				**8,704**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	5,443	5,940	—	—	25	719	—	—	5,468	6,660	—	—
3.1) Wetland	6,879	7,595	1,655	27.9%	100	1,155.48	436	60.6%	6,979	8,751	2,091	31.4%
3.2) Wetland + treatment all + solar PV	14,387	16,214	10,274	173.0%	2,293	1,943.48	1,224	170.2%	16,680	18,157	11,498	172.7%

e. Integrated Cost–Benefit Analysis

Table 19 presents the results of the integrated CBA for the artificial wetland and hybrid intervention scenario. The integrated CBA compares the results of Scenarios 3.1 and 3.2 against the BAU scenario and lists required investments, added benefits induced by the interventions and avoided costs across social, economic and environmental indicators.

Scenario 3.2 requires high capital and operational expenditures as it includes all intervention expenditures of Scenario 2.2 (sewage treatment for all polluter groups and solar PV installation) and expenditures for constructing and maintaining an artificial wetland. Cumulatively, INR 19 billion additional expenditures are required by 2060 to implement this intervention. The construction and maintenance of the artificial wetland alone in Scenario 3.1 requires cumulative additional expenditures of INR 1.3 billion.

Despite high capital and operational expenditures, Scenario 3.2 is very cost-effective when considering the amount of N removed from the lake—approximately INR 1 million needs to be invested to remove 1 ton of nitrogen. Due to this nitrogen removal capacity, Scenario 3.2 yields by far the highest added benefits among all assessed scenarios in this study, with cumulative added benefits of INR 360 billion between 2018 and 2060, compared to INR 271.5 billion in Scenario 5.2 and INR 222.2 billion in Scenario 2.2. Those added benefits stem from additional revenues generated in the tourism and fishery industries and result from higher water quality that leads to higher tourism numbers and better fishing opportunities.

Scenario 3.2 also yields significant amounts of avoided costs due to the installation of solar energy capacity. This intervention reduces the social costs of carbon by INR 75 million as energy is generated by solar PV as opposed to fossil fuel based generation in the BAU scenario. The resulting reduction in emissions reduces emission-related health impacts and treatment costs. Scenario 3.1 slightly reduces emissions compared to the BAU scenario and hence also avoids respective health costs.

In this study, Scenario 3.2 yields the highest net benefits for the Lake Dal area. If interventions of this scenario are implemented, Lake Dal will sustain productivity over time. The construction of the artificial wetland in isolation in Scenario 3.1 attains net benefits of INR 59.5 billion. However, this intervention scenario is insufficient to maintain the water quality in Lake Dal at desirable levels.

Table 19. Integrated CBA artificial wetland scenarios

Scenario	3.1 Artificial wetland	3.2 Artificial wetland + treatment all + solar
EXPENDITURES (in INR million)		
Upgrade sewage treatment network	**0**	**10,321**
Investment in STPs	0	6,750
O&M costs STPs	0	3,141
Electricity costs nitrogen removal	0	430

Scenario	3.1 Artificial wetland	3.2 Artificial wetland + treatment all + solar
Artificial wetland construction	**1,321**	**1,321**
Investment in artificial wetlands	336	336
O&M cost artificial wetlands	985	985
Sewage treatment of lake population	**0**	**4,933**
Houseboat sewage treatment	0	768
Lake dwellervs sewage treatment	0	4,165
Costs of solar energy capacity	**0**	**393**
Total costs	**1,321**	**16,968**
ADDED BENEFITS (in INR million)		
Revenues for benefiting sectors		
Revenues from tourism	59,740	373,863
Revenues from fisheries	1,095	3,077
Total added benefits (in INR million)	60,835	376,940
AVOIDED COSTS (in INR million)		
Social costs of carbon	0.08	75
Net results	59,515	360,047
Benefit to cost ratio	**45.1**	**22.2**
Rehabilitation Benefit for the lake		
Additional tons of nitrogen removed	4,743	16,767
Net benefits (in INR million) per ton of nitrogen avoided	**13**	**21**
Costs per ton of nitrogen avoided	0.28	1.01

4. Policy Intervention: Relocation of lake dwellers

This section presents the assessment results of the intervention to relocate lake dwellers to the remediation site Rakh-e-Arth. To reduce the discharge of untreated sewage into Lake Dal, it is assumed that all dwellers are relocated by 2025. This section assesses whether relocating the dwellers is sufficient for reducing current and future N loadings to acceptable levels. This option is being considered by the local government in Srinagar and first reocation efforts have started. Polluters treated and interventions considered for the dweller relocation scenario are summarized below.

Table 20. Overview and description of lake dweller relocation scenario

Scenario	Description
Scenario 4.1: Relocation of lake dwellers	All lake dwellers living on the shore and inside of Lake Dal are relocated permanently to Rakh-e-Arth. Their sewage is treated at the new location. Measures are taken to prevent new people from settling at the lake and former lake dwellers from returning to their old habitats. No other interventions are implemented, and business-as-usual conditions are maintained: • 75 per cent of the lake periphery's sewage is treated. • Sewage of lake dwellers and houseboats flows directly into the lake without treatment. • Overflow of STPs during heavy rainfalls as well as during electricity blackouts is assumed.

The simulated scenario is used to analyze the impacts of relocating lake dwellers to Rakh-e-Arth. The assumptions used for the simulation of the scenario are mentioned in Table 21.

Table 21. Scenario assumptions lake dweller relocation scenario

Scenario	Polluters covered	Interventions considered	Implementation completed by:
1.) Business-as-usual	None	None	N/A
4.1) Relocation of lake dwellers	Lake Dwellers	• Relocation of dwellers to new site • Construction of housing for dwellers • Compensation payments to dwellers for plot and structure	2025

Summary of Results

The relocation of lake dwellers reduces the number of polluters discharging sewage directly into the lake. The resulting 12 per cent reduction in average N loadings leads to lower N concentrations in the lake water, which improves water clarity by 0.17 m by 2060 compared to the baseline. Improving lake quality attracts more tourists and leads to additional economic activity around the lake. This causes people from rural areas to migrate to Srinagar. A total population increase of 4.9 per cent and an increase of the population living at the periphery of the lake by 5.6 per cent compared to the BAU scenario is the result. Table A4.1 in Appendix IV summarizes the impacts for the dweller relocation scenario and shows the developments of key indicators over time.

- The relocation of lake dwellers reduces the pressures on the lake's ecosystem by removing one polluter group that directly discharges wastewater into the lake. Total N loadings are projected to be 12 per cent lower compared to the BAU scenario.
- However, the relocation of lake dwellers alone is insufficient to prevent impacts on fish reproduction, which leads to a depletion of the lake's fish stocks during the next decades. While fishery revenues are INR 119 million higher than in the BAU scenario, they are far below the revenue projections for scenarios in which fish stocks do not collapse (see Scenarios 2.2, 2.3 & 3.2 in Table 35).
- Relocating lake dwellers would allow LAWDA and the local government of Srinagar to improve water circulation. Removing structures and artificial islands from the lake would prevent water from stagnating and counteract eutrophication.

Description of Results

a. Population Development

In the lake dweller relocation scenario, Srinagar's population is projected to increase by 4.9 per cent compared to the baseline, which is equivalent to approximately 159,400 people. The total population in 2060 reaches around 3 million people. The increase in population is mainly driven by work-related migration resulting from increasing economic activity as the quality of the lake improves. The increase in population yields additional pressures on the sewage treatment systems. Since the only reduction in N loadings in this scenario is caused by the relocation of lake dwellers, the projections indicate that future loads will exceed the city's wastewater treatment system. Indicators related to population are presented in Table 22.

Table 22. Population trends lake dweller relocation scenario

	Population Srinagar			Population in the periphery			Lake dwellers		
2016 value	1,530,000			199,450			59,850		
Scenario	Total (2060)	Net difference	% vs BAU	Total (2060)	Net difference	% vs BAU	Total (2060)	Net difference	% vs BAU
1.) BAU	2,837,592	—	—	368,887	—	—	66,804	—	—
4.1) Relocate dwellers	2,997,010	159,419	4.9%	389,611	20,724	5.6%	0	-66,804	-100.0%

b. Nitrogen Loadings

Concerning nitrogen loadings, the relocation of lake dwellers yields a 18.3 per cent decrease in total N loadings. By 2060, total N loadings are 516.5 tons per year, which is 70.5 tons per year lower compared to the baseline. Indicators related to N loadings in the BAU and the dweller relocation scenario are presented in Table 23.

Table 23. **N loadings in lake dweller relocation scenario**

	Total N loadings (kg/year)				N loadings from population (kg/year)				Residual N loadings (kg/year)			
2016 value	**361,867**				**302,069**				**59,798**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	587,020	511,222	—	—	538,717	459,267	—	—	48,303	51,955	—	—
4.1) Relocate dwellers	516,496	417,832	-93,390	-18.3%	467,503	365,844	-93,422	-20.3%	48,994	51,988	33	0.1%

c. Water Quality

The reduction in N loadings from relocating lake dwellers contributes to a reduced N concentration in the lake water. The average N concentration declines by 18.2 per cent for the period between 2030 and 2060. This improves the water quality of the lake by reducing the chlorophyll-a concentration, which again improves water clarity. Chlorophyll-a levels in the dweller relocation scenario are on average 32.8 per cent lower compared to the BAU scenario. Water clarity improvements on average compared to the baseline are projected at 0.17 m by 2060. Water quality indicators for baseline and relocation scenario are presented in Table 23.

Table 24. Water quality indicators lake dweller relocation scenario

	N Concentration (mg N/litre)				Secchi depth (metre)				Chlorophyll-a concentration (Ug/litre)			
2016 value	**0.83**				**1.36**				**21.28**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	1.526	1.282	—	—	0.754	0.936	—	—	71.1	53.7	—	—
4.1) Relocate dwellers	1.343	1.049	-0.233	-18.2%	0.92	1.16	0.22	23.4%	54.1	36.1	-17.6	-32.8%

d. Economic Impacts

The improvements in water quality are beneficial for the tourism and fishery sector. The relocation of lake dwellers contributes to better water quality, which attracts more tourists compared to the baseline. However, this intervention is insufficient to prevent water quality from reaching a critical level that will disturb fish reproduction rates. This leads to a depletion of fish stocks over the next decades. Projections indicate an average increase in tourism revenues between 2030 and 2060 of 23.8 per cent, and an increase in fishery revenues of 77.1 per cent compared to the BAU scenario. This is equivalent to an increase of INR 966 million and INR 119 million respectively. However, tourism revenues show a decreasing trend after 2030 and fishery revenues a very strong decline from peak values after 2037. The tourism revenues in year 2060 are approximately 16 per cent lower than in 2016 and fishery revenues in 2060 are approximately 87 per cent lower than in year 2016. These values indicate that the relocation of lake dwellers is not expected to have long lasting postive economic impacts if no other remediations measures are implemented. Indicators on total and sectoral revenues are summarized in Table 25.

Table 25. Economic impacts lake dweller relocation scenario

	Tourism revenues (INR million/year)				Fisheries revenues (INR million/year)				Total revenues (INR million/year)			
2016 value	**7,628**				**1,076**				**8,704**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	5,443	5,940	—	—	25	719	—	—	5,468	6,660	—	—
4.1) Relocate dwellers	6,409	7,351	1,411	23.8%	144	1,274	554	77.1%	6,553	8,625	1,966	29.5%

e. Integrated Cost–Benefit Analysis

Table 25 presents the results of the integrated CBA for the relocation of lake dwellers. The integrated CBA compares the results of Scenario 4.1 with the BAU scenario and lists required investments, added benefits induced by the intervention and costs avoided across social, economic and environmental indicators.

The relocation of lake dwellers is very capital intensive because of land acquisition costs and compensation payments to lake dwellers as well as expenditures for the development of the relocation site at Rakh-e-Arth. Total expenditures add up to INR 9.5 billion by 2060. Successfully relocating lake dwellers will improve the water quality of the lake and contribute to reducing total N loadings by 2,600 tons between 2019 and 2060. The improved water quality contributes to attaining a cumulative INR 59.7 billion of additional revenues in the tourism and fishery sector. On the other hand, improved water quality and economic opportunities attract more people to Srinagar, which leads to additional volumes of sewage that need to be treated by STPs. Since Scenario 4.1 assumes no installation of solar PV, the additional electricity is provided by diesel generators. Associated emissions translate into INR 32 million in additional social costs of carbon by 2060. The positive net result of Scenario 4.1 amounts to approximately INR 50 billion.

Table 26. Integrated CBA lake dweller relocation scenario

Scenario	4.1 Relocation of lake dwellers
EXPENDITURES (in INR million)	
Upgrade sewage treatment network	**259**
Investment in STPs	0
O&M costs STPs	0
Electricity costs nitrogen removal	259
Costs of land acquisition	**5,037**
Development of relocation site (Rakh-e-Arth)	**4,212**
Total costs	**9,508**
ADDED BENEFITS (in INR million)	
Revenues for benefiting sectors	
Revenues from tourism	58,270
Revenues from fisheries	1,394
Total added benefits (in INR million)	59,664
AVOIDED COSTS (in INR million)	
Social costs of carbon	-32

Scenario	4.1 Relocation of lake dwellers
Net results	50,124
Benefit to cost ratio	**6.3**
Rehabilitation Benefit for the lake	
Additional tons of nitrogen removed	2,591
Net benefits (in INR million) per ton of nitrogen avoided	**19**
Costs per ton of nitrogen avoided	3.67

5. Road Infrastructure Intervention

This section presents the results of road construction scenario assessment. The construction of the Western Foreshore Road along Lake Dal is currently under consideration in Srinagar. An overview of scenarios, including names and scenario description, is provided below.

Table 27. Overview and description of road construction scenarios

Scenario	Description
Scenario 5.1: Road construction	As outlined in the LADWA Western Foreshore Road proposal, a 20 km road is to be constructed close to the lake. The rationale is to relieve traffic on the main boulevard. Based on historic evidence, it is assumed that encroachment of 100 m on both sides of the road will occur. All business-as-usual conditions are maintained: • Only 75 per cent of the lake periphery's sewage is treated. • Sewage of lake dwellers and houseboats flows directly into the lake without treatment. • Overflow of STPs during heavy rainfalls as well as during electricity blackouts is assumed.
Scenario 5.2: Road construction + artificial wetlands + traditional technology upgrades + solar PV	As outlined in the LADWA Western Foreshore Road proposal, a 20 km road is constructed close to the lake. The rationale is to relieve traffic on the main boulevard. Based on historic evidence, it is assumed that encroachment of 100 m on both sides of the road will occur. All interventions of Scenario 3.2 are implemented: Artificial wetlands are constructed in shallow parts of Lake Dal to provide infrastructure services on water filtration and nitrogen absorption. The sewage of all lake polluters is treated, including lake periphery population, lake dwellers and houseboats. A mix of the following STP technologies is assumed: • Activated sludge process • Sequencing batch reactor • Moving bed biofilm reactor Pumping stations and STPs are entirely powered by solar PV. Treating the sewage of lake dwellers and houseboats is done by providing Johkasou STPs for all units.

The simulated scenarios are used to analyze the impacts of constructing the Western Foreshore Road along the lake. The construction of the road will be analyzed in isolation (Scenario 5.1), and also in combination with sewage treatment interventions applied in the scenarios described above (Scenario 5.2). The impacts of road construction on population development and N loadings reaching the lake are assessed to determine water quality impacts. Polluters treated and interventions considered for the road construction scenarios are summarized in Table 28.

Table 28. Scenario assumptions road construction scenarios

Scenario	Polluters covered	Interventions considered	Implementation completed by:
1.) Business-as-usual	None	None	N/A
5.1) Road construction	None	• Construction of 20 km Western Foreshore Road	2025
5.2) Road construction + artificial wetland construction + improved sewage treatment for all polluter groups + installation of solar PV	Periphery, dwellers & houseboats	• Construction of Noor-Bagh STP • 100 per cent of periphery connected to sewage network • Johkasou STPs for all dwellers and houseboats • Solar PV is used to power all sewage treatment • Construction of 500 ha artificial wetland • Construction of 20 km Western Foreshore Road	2025

Summary of Results

The construction of the road allows for better access to land in the periphery of the lake. Additionally, the sealed surface of the road leads to more stormwater being directly discharged into the lake. In this scenario, the population initially grows as a result of road construction, followed by encroachment of land next to the road. In Scenario 5.1, the increase in population increases average N loadings by 3.6 per cent, which causes N concentrations in the lake to increase by 20.2 per cent and water clarity of the lake to decline by 0.19 m by 2060 compared to the baseline. Scenario 5.2 combines the road construction and interventions for the sewage treatment of all polluters. This scenario serves to analyze whether enhanced sewage treatment is capable of mitigating road-related impacts on the ecological health of Lake Dal. The expansion of treatment coverage in Scenario 5.2 significantly contributes to reducing N loadings by 52.2 per cent, improving lake quality and attracting tourists, which in turn leads to additional economic activity around the lake. This causes people from rural areas to migrate to Srinagar. The total population increases by 16.9 per cent and population in the periphery of the lake by 22.6 per cent respectively compared to the BAU scenario. Table A5.1 in Appendix V summarizes the impacts for the road construction scenarios and shows the developments of key indicators over time.

- The construction of the road is projected to lead to additional encroachment, as land becomes more easily accessible. Encroachment reduces the lake's water body, which potentially increases the N concentration in the lake if N loadings reaching the lake remain unchanged. In other words, reducing the size of the water body while N loadings remain constant, will cause the N concentration in the lake to increase. Compared to the BAU scenario which itself leads to devastating impacts on the lake's ecosystem, the construction of the road in isolation leads to an even further increase of 3.6 per cent in total N loadings due to more stormwater runoff resulting from the additional sealed surface area of the newly constructed road, and a 20.2 per cent increase in N concentration. This provides beneficial conditions for aquatic plants to flourish. The decreasing water quality has negative impacts on the tourism and fishery sector: total revenues in Scenario 5.1 are even 20 per cent lower compared to the BAU scenario.

- The sewage treatment of all polluter groups in Scenario 5.2 partly mitigates the additional pressures resulting from road construction. Assuming that the new road and houses constructed on encroached parts of the lake are connected to sewage treatment, the construction of the STP Noor-Bagh provides sufficient capacity to treat the additional wastewater. The expansion of sewage network coverage (assuming that this would take place and that it would be coupled with stormwater runoff water channelling) would avoid part of the stormwater flowing into the lake. This mitigates the increase in N loadings resulting from road construction that enters the lake, but would not improve the situation of the lake and its water quality overall. In fact, the increased encroachment caused by road construction would make the existing problems worse.

Description of Results

a. Population Development

In Scenario 5.1, the construction of the road increases the pressures on the lake and reduces water quality, which lowers work-related migration and total population. Srinagar's population is projected to decrease by 4.7 per cent compared to the baseline, which is equivalent to a reduction of approximately 139,600 people. The total population in 2060 reaches around 2.7 million people. If the road is constructed while sewage treatment for all polluter groups is provided, population is projected to increase by 16.9 per cent to 3.29 million people by 2060. The increase in population yields additional pressures on the sewage treatment systems. Indicators related to population are presented in Table 29.

Table 29. Population trends road construction scenarios

	Population Srinagar			Population in the periphery			Lake dwellers		
2016 value	**1,530,000**			**199,450**			**59,850**		
Scenario	**Total (2060)**	**Net difference**	**% vs BAU**	**Total (2060)**	**Net difference**	**% vs BAU**	**Total (2060)**	**Net difference**	**% vs BAU**
1.) BAU	2,837,592	—	—	368,887	—	—	66,804	—	—
5.1) Road construction	2,697,943	-139,648	-4.7%	374,783	5,896	1.6%	66,804	0	0.0%
5.2) All polluters + PV + wetland + Road	3,292,604	455,013	16.9%	452,089	83,202	22.6%	66,804	0	0.0%

b. Nitrogen Loadings

Scenario 5.1 indicates a 3.6 per cent increase in N loadings compared to the BAU scenario. The increase in loadings emerges due to stormwater runoff from the road as well as forecasted population growth, while treatment capacity is assumed to remain unchanged. In Scenario 5.2, the assumed expansion of STP capacity and sewage network coverage mitigates the negative impacts of the road and leads to lower N loadings in the long run. The expansion of wastewater treatment capacity yields a 52.2 per cent decrease in total N loadings if the road is constructed. Compared to the full treatment scenario (3.2), the construction of the road in addition to treatment interventions increases average N loadings reaching the lake by 1.7 per cent respectively. Compared to the baseline, by 2060 total N loadings are 14.9 tons per year higher in Scenario 5.1 and 312.5 tons per year lower in Scenario 5.2 respectively. Indicators related to N loadings in the BAU and the two road construction scenarios are presented in Table 30.

Table 30. N loadings in road construction scenarios

	Total N loadings (kg/year)				N loadings from population (kg/year)				Residual N loadings (kg/year)			
2016 value	**361,867**				**302,069**				**59,798**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	587,020	511,222	—	—	538,717	459,267	—	—	48,303	51,955	—	—
5.1) Road construction	601,940	529,537	18,316	3.6%	553,553	477,499	18,232	4.0%	48,387	52,038	83	0.2%
5.2) All polluters + PV + wetland + Road	274,520	244,327	-266,895	-52.2%	221,058	191,652	-267,615	-58.3%	53,462	52,674	719	1.4%

c. Water Quality

The increase in N loadings from the construction of the road in isolation (Scenario 5.1) contributes to an increase of the N concentration in the lake water. The average N concentration increases by 20.2 per cent for the period between 2030 and 2060. This disproportional increase in N concentration is caused by a combination of shrinking the waterbody as a result of encroachment and increased N loadings from road-related stormwater runoff and overall population growth. The increase in loadings of Scenario 5.1 causes chlorophyll-a concentrations to be 47 per cent higher compared to the BAU scenario. This accelerates the growth of aquatic plants and decreases water clarity by 20.7 per cent. In Scenario 5.2, the implementation of additional sewage treatment capacity and the construction of an artificial wetland contribute to a 60.7 per cent reduction in N concentration compared to the baseline. This reduction benefits water quality by reducing the concentration of chlorophyll-a. By 2060, chlorophyll-a levels in Scenario 5.2 are on average 86.2 per cent lower and Secchi depth 1.31 m higher compared to the BAU scenario. However, Scenario 5.2 yields worse results than Scenario 3.2 because the latter assumes all sewage treatment interventions but no road construction. N concentration of Scenario 5.2 is 4.8 per cent higher, average Secchi depth is 0.32 m lower and chlorophyll-a concentration is 3.3 per cent higher compared to Scenario 3.2. Water quality indicators for baseline and road construction scenarios are presented in Table 31.

Table 31. Water quality indicators road construction scenarios

	N Concentration (mg N/litre)				Secchi depth (metre)				Chlorophyll-a concentration (Ug/litre)			
2016 value	0.83				1.36				21.28			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	1.526	1.282	—	—	0.754	0.936	—	—	71.1	53.7	—	—
5.1) Road construction	1.818	1.542	0.259	20.2%	0.57	0.74	-0.19	-20.7%	102.6	78.8	25.1	46.7%
5.2) All polluters + PV + wetland + Road	0.579	0.504	-0.778	-60.7%	1.94	2.25	1.31	140.4%	9.9	7.4	-46.3	-86.2%

d. Economic Impacts

In terms of economic impacts, the assessment indicates that Scenario 5.1 yields a reduction in revenues, while projections for Scenario 5.2 indicate a strong increase. The additional encroachment of the lake and stormwater runoff caused by the assumed road construction in Scenario 5.1 deteriorate water quality over time which reduces economic opportunities. Revenues from tourism are projected to be 20.4 per cent lower than baseline, and fish stocks are expected to collapse sooner than indicated in the BAU scenario. By 2060, total revenues from tourism and fisheries are projected to be INR 7 million and INR 1.38 billion lower respectively. This represents a INR 1.39 billion reduction in total revenues compared to the baseline.

In Scenario 5.2, an improvement in water quality is caused by sewage treatment interventions that counteract the negative impacts of the road construction. These improvements are beneficial for the tourism and fishery sector. Projections indicate an increase in average annual tourism revenues of 139.2 per cent, and an increase in fishery revenues of 167.5 per cent compared to the baseline. This is equivalent to an increase of approximately INR 7.3 billion and INR 2.24 billion respectively. However, these positive economic developments are lower than in Scenario 3.2. This provides evidence for the overall counterproductive impacts of the road construction. Total and sectoral revenues are summarized in Table 32.

Table 32. Economic impacts road construction scenarios

	Tourism revenues (INR million/year)				Fisheries revenues (INR million/year)				Total revenues (INR million/year)			
2016 value	**7,628**				**1,076**				**8,704**			
Scenario	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**	**2060**	**Average (2030-2060)**	**Net difference**	**% vs BAU**
1.) BAU	5,443	5,940	—	—	25	719	—	—	5,468	6,660	—	—
5.1) Road construction	4,059	4,726	-1,214	-20.4%	18	592	-128	-17.7%	4,077	4,776	-1,224	-20.1%
5.2) All polluters + PV + wetland + Road	12,741	14,212	8,271	139.2%	2,266	1,924	1,205	167.5%	15,008	16,136	9,476	142.3%

e. Integrated Cost–Benefit Analysis

Table 33 presents the results of the integrated cost–benefit analysis (CBA) for the road construction scenarios. The integrated CBA compares the results of Scenarios 5.1 and 5.2 with the BAU scenario and lists required investments, added benefits induced by the interventions and costs avoided across social, economic and environmental indicators.

The construction of the Western Foreshore Road requires high capital expenditures and some operation and maintenance costs, with total expenditures for Scenario 5.1 of approximately INR 16 billion. In addition to these, Scenario 5.2 assumes necessary expenditures for implementing all interventions of Scenario 3.2 (sewage treatment for all polluter groups, solar PV installation and construction of artificial wetland). Total expenditures for this scenario are almost INR 33.1 billion.

The two scenarios imply contrasting developments for the lake's water quality. While Scenario 5.1 will lead to a collapse of the lake and cause decreasing revenues for the fishery and tourism sectors of approximately INR 42.7 billion, interventions of Scenario 5.2 will sustain the lake's ecosystem despite the road construction and an increasing population in Srinagar. Interventions remove in total 18,406 tons of nitrogen from the lake. Consequently, Scenario 5.2 yields total added benefits of INR 304.5 billion thanks to additional revenues in the tourism and fishery sectors—these are the second-highest added benefits among all assessed scenarios. Moreover, the scenario allows for reduced social costs of carbon as diesel generators are replaced by solar PV. These additional savings do not occur in Scenario 5.1. In total, Scenario 5.2 yields a positive net result of INR 271.5 billion, while Scenario 5.1 causes net losses of INR 58.8 billion.

Table 33. Integrated CBA road construction scenarios

Scenario	5.1 Road construction	5.2 Road construction + treatment all + solar PV + wetland
EXPENDITURES (in INR million)		
Upgrade sewage treatment network	**29**	**10,382**
Investment in STPs	0	6,750
O&M costs STPs	0	3,141
Electricity costs nitrogen removal	29	492
Artificial wetland construction	**0**	**1,321**
Investment in artificial wetlands	0	336
O&M cost artificial wetlands	0	985
Sewage treatment of lake population	**0**	**4,933**
Houseboat sewage treatment	0	768
Lake dwellervs sewage treatment	0	4,165
Road construction	**16,032**	**16,032**

Scenario	5.1 Road construction	5.2 Road construction + treatment all + solar PV + wetland
Investment for road construction	**15,658**	**15,658**
O&M cost roads	**374**	**374**
Costs of solar energy capacity	**0**	**423**
Total costs	16,061	33,092
ADDED BENEFITS (in INR million)		
Revenues for benefiting sectors		
Revenues from tourism	-42,403	301,478
Revenues from fisheries	-321	3,027
Total added benefits (in INR million)	-42,724	304,506
AVOIDED COSTS (in INR million)		
Social costs of carbon	-4	75
Net results	-58,788	271,489
Benefit to cost ratio	**N/A**	**9.2**
Rehabilitation Benefit for the lake		
Additional tons of nitrogen removed	289	18,406
Net benefits (in INR million) per ton of nitrogen avoided	**N/A**	**15**
Costs per ton of nitrogen avoided	N/A	1.80

Part V: Comparative Analysis of Intervention Scenarios

The analysis provides evidence that no new investments into sewage treatment capacity will result in negative impacts on Lake Dal and would increase the risk of ecological collapse before 2060. Population growth and the continuation of insufficient sewage treatment means that all different polluter groups will significantly increase the amount of N loadings reaching the lake, which decreases water quality and leads to rapid growth of aquatic plants, algae blooms and oxygen depletion. Such eutrophication trends will negatively affect the reproduction of fish populations and impair recreational activities. This development will have adverse impacts on tourism and endanger the fishing industry at Lake Dal and hence put all livelihoods depending on tourism and fisheries at risk, on top of possibly causing negative health impacts for the population.

Scenario 5.1, which includes the construction of the Western Foreshore Road next to business-as-usual activities, shows increasingly worsening trends for the sustainability of the lake. By 2060, the N concentration in the lake is 19 per cent higher, which reduces the revenues in the tourism sector by 25 per cent and in the fishery sector by 31 per cent below the revenues attained in the BAU scenario. The net benefits for each scenario are displayed in Figure 9. This figure underlines that only Scenario 5.1 leads to negative net benefits.

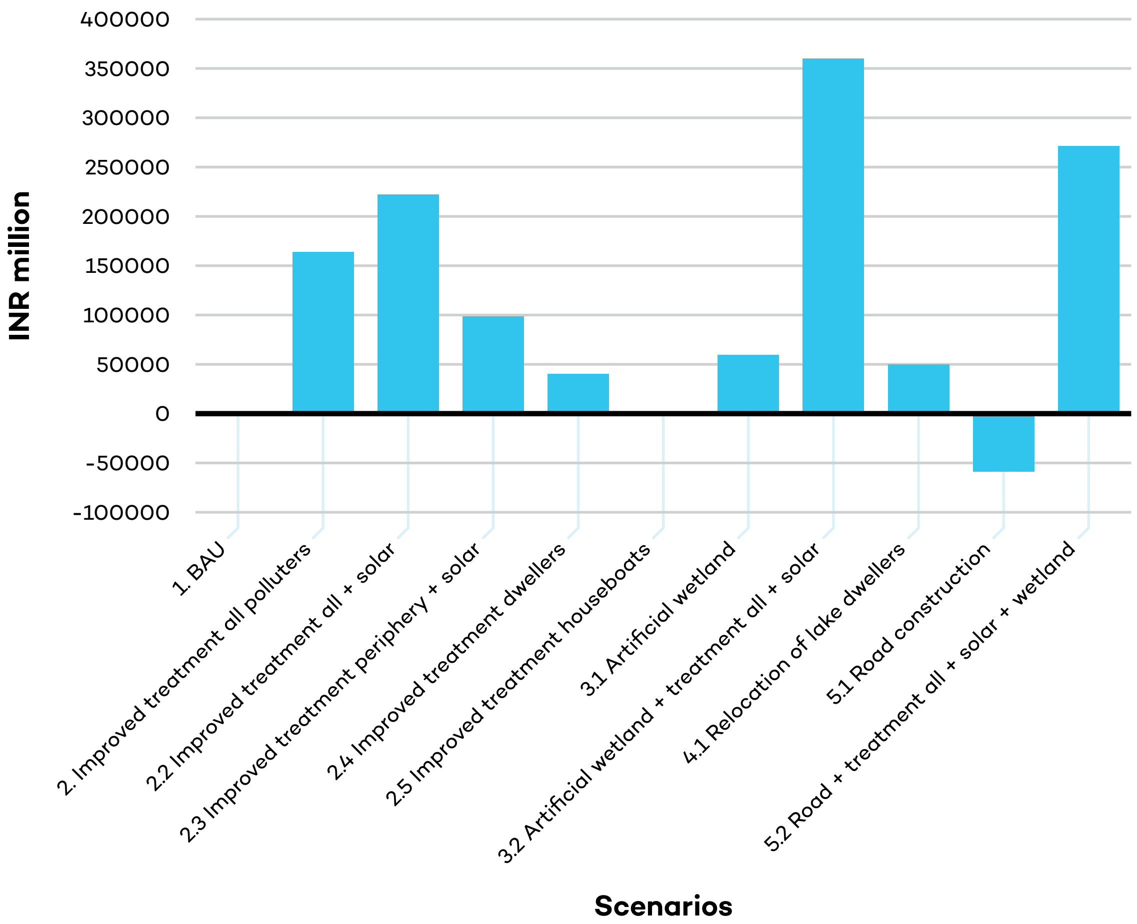


Figure 9. **Cumulative net benefits by scenario**

The expansion of sewage network connectivity, the combined implementation of sewage treatment technologies for all polluter groups and the installation of solar PV for STPs (Scenario 2.2) yields the highest reductions in N concentration by 2060 and improvements in water quality among all grey treatment scenarios. If an artificial wetland is additionally constructed (Scenario 3.2), the water quality of the lake improves even further. Revenues in the tourism sector for this scenario are projected to increase by 173 per cent and revenues in the fishery sector by 170 per cent compared to the BAU scenario. Consequently, Scenario 3.2 yields the highest net benefits for the region among all scenarios, as highlighted in Figure 9.

All interventions related to lake dwellers reduce the direct discharge of sewage into the lake and yield positive impacts for water quality and economic development in Srinagar. The relocation of lake dwellers to Rakh-e-Arth (Scenario 4.1) yields slightly better results than the sewage treatment of dwellers on site (Scenario 2.4) as displayed in above Figure 9. The relocation of dwellers and the removal of structures and landmasses from the lake could change its water volume and have additional benefits for water circulation and overall water quality. An ecological study would help to clarify and quantify these additional benefits for water quality. However, the relocation of dwellers bears the risk of policy resistance and requires actively preventing former dwellers from returning to their structures on the lake before they could be removed. This uncertainty and the already identified lower cost effectiveness of this intervention compared to treating the sewage of dwellers on site (see Figure 11)—must be considered when deciding on conservation measures for the lake dwellers. To sustain Lake Dal over time, it will however not be sufficient to only treat sewage from dwellers.

Figure 10 compares the different scenarios in light of their average effect on N concentration in the lake and their cumulative net benefits until 2060. The chart highlights the causal relation between N concentration in the lake and net benefits: the lower the N concentration in the lake, the higher the net benefits. Scenario 3.2 shows the strongest performance in terms of benefits and N concentration, while Scenario 5.1 has detrimental impacts that worsen the situation below the baseline. While Figure 11 indicates a strong performance for Scenario 5.2, it is unclear to what extent the additional encroachment will change the pressures on the lake.

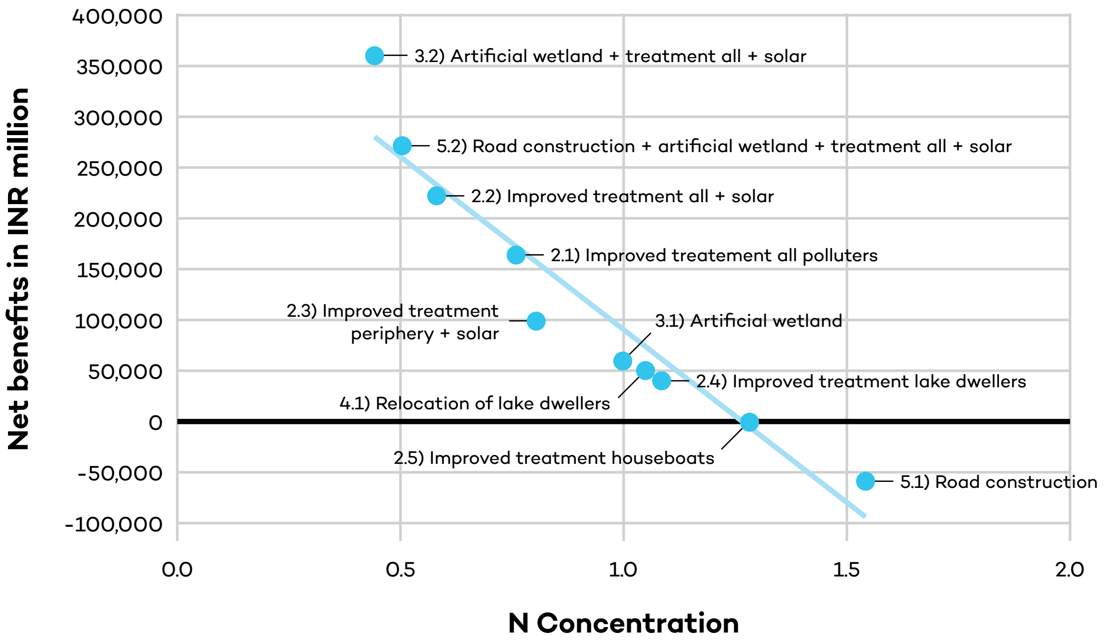
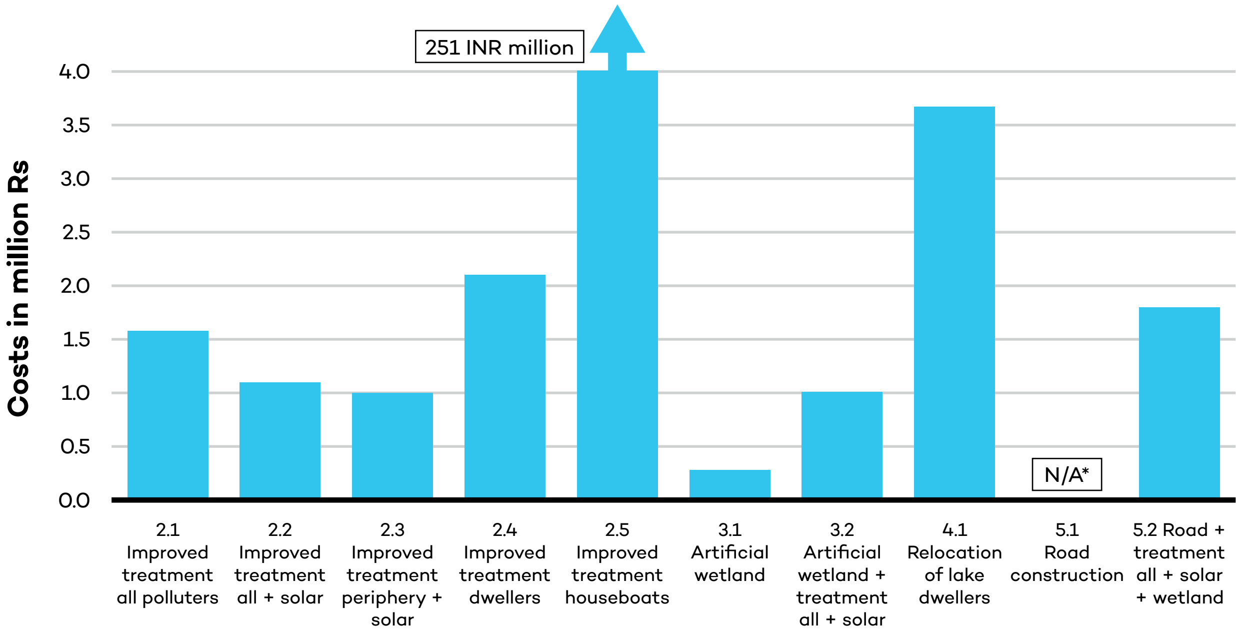


Figure 10. **Net benefits and N concentration by scenario**

The abovementioned conclusions are supported by the respective cost effectiveness for all interventions in terms of costs per ton of N removed or avoided. Figure 11 illustrates that scenarios 2.2, 2.3 and 3.2 remove significant volumes of N from the lake and appear cost effective at the same time, whereby Scenario 3.2 shows by far the strongest performance in terms of reducing N loadings and concentration. While Scenario 3.1 seems most cost effective, it should be considered that the N removal capacity of the artificial wetland in isolation is insufficient to counter the increasing pressures and to maintaining or improving the ecosystem integrity of the lake. The connection of the lake´s periphery to STPs and the expansion of respective sewage treatment capacity (scenario 2.3) and the management of sewage generated by the lake dwellers must be of priority in Srinagar when deciding which polluter groups should be addressed first. Treating the sewage of the periphery population yields the highest water quality improvements among the three assessed polluter groups, allows for the highest economic benefits and is the most cost-effective option.



Tons of N removed per scenario	10,027	14,206	10,432	2,079	3	4,743	16,767	2,591	289	18,406

Figure 11. Costs per ton of N removed by scenario

** The modelling reveals that Scenario 5.1 removes an additional 289 tons of N from the lake compared to the BAU scenario as it is assumed that stormwater runoff from the constructed road is (partly) channelled to STPs and treated there. However, since no additional investments for lake conservation interventions take place in this scenario, costs per ton of N removed are not calculated.*

The analysis further reveals that the on-site treatment of sewage from houseboats (Scenario 2.5) has hardly any positive effect on the lake's water quality since most of the pressures are caused from untreated sewage from the periphery and lake dwellers. The pressures from houseboats are hence comparatively small compared to those of other polluter groups.

Figure 12 below highlights the limited benefits and minimal cost effectiveness of this scenario. This underlines that the amount of sewage generated by families and tourists staying on houseboats is low compared to sewage pressures created from the lake's periphery and lake dwellers. Finally, the study provides evidence that wastewater related pressures resulting from the construction of the Western Foreshore Road can be compensated when all sewage treatment interventions of Scenario 3.2 are implemented. This is why the combined Scenario 5.2 performs relatively well when considering the net benefits of this scenario. However, the construction of the road must be thoroughly assessed, and strict regulatory measures must be enforced as encroachment might cause further detrimental ecological impacts. As displayed in Figure 12, the scenario generates fewer net benefits than Scenario 3.2 and requires significantly higher costs.

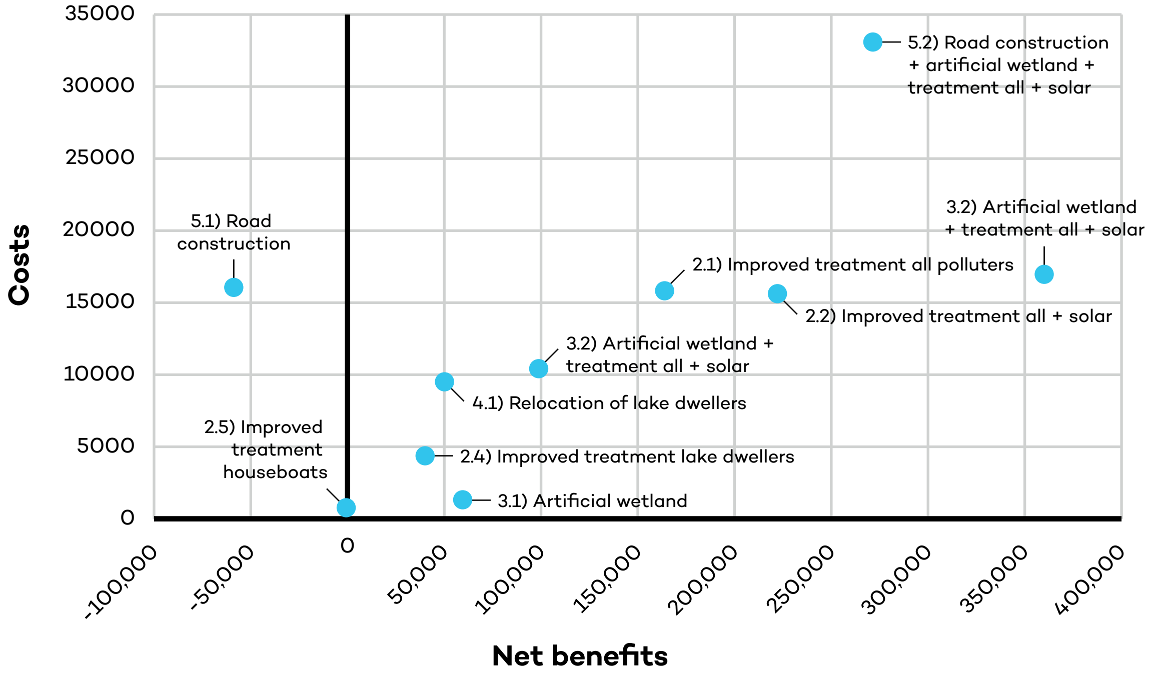


Figure 12. Costs and net benefits by scenario

Part VI: Conclusions

The SAVi assessment applied in this study for examining treatment options for the conservation of Lake Dal in Jammu & Kashmir, India reveals a range of key insights that will allow policy-makers to define conservation priorities. More effective and systemic measures for reducing pressures on the lake need to be implemented urgently instead of treating only the symptoms of pollution such as algae growth. Preventive measures comprise in particular the treatment of sewage from the population living at the periphery of the lake and the treatment of sewage from lake dwellers. A critical balancing loop has to be considered when interventions are planned: improving water quality in Lake Dal will attract more people over time and will facilitate more economic activities in proximity to the lake. This will increase sewage and other wastewater pressures on the lake that must be considered when sewage treatment capacities are renovated and newly built.

The SAVi assessment emphasizes that neither business-as-usual nor the incautious construction of the Western Foreshore Road are viable options at Srinagar if the ecological collapse of Lake Dal is to be prevented and if fishing activities are to be maintained over time. Neither will it be sufficient to address only sewage pressures caused by lake dwellers or houseboats.

The assessment highlights that the hybrid infrastructure approach deployed in Scenario 3.2 is most cost-effective for reducing nitrogen loadings reaching the lake, removing nitrogen from the lake and for generating economic benefits in the region. The scenario envisions the simultaneous implementation of four interventions. First, establishing sewage network connectivity and STP capacity for treating sewage from populations living in the periphery of the lake. Second, installing solar PV to provide reliable and emission-free electricity to STPs and pumping stations to avoid accidental discharge during power cuts. Third, implementing on-site sewage treatment for lake dwellers and houseboats, and fourth the construction of an artifical wetland. Through analyzing projections of Scenario 5.2, the assessment further reveals that the resulting pressures from construction of the Western Foreshore Road will be mitigated if sewage treatment capacity is expanded, but this could come at the cost of the ecological health of Lake Dal. Still, the road project would create additional runoff and encroachment pressures on the lake and significantly reduce overall net benefits associated with sewage treatment interventions compared to Scenario 3.2.

When budget priorities need to be made, it remains most important to treat sewage from the lake's periphery effectively (Scenario 2.3) as this represents by far the biggest population group among remaining polluters. Treating the sewage from houseboats, by contrast, has hardly any significance for the rehabilitation of the lake. Given the political difficulty of relocating lake dwellers permanently and prevent them from returning to their old habitats, as well as the high costs associated with their relocation, it is recommended that authorities explore on-site sewage treatment for lake dwellers at their current locations.

In order to prevent future problems related to nitrogen loadings reaching the lake, it is recommended to carefully screen sewage treatment technologies concerning their nitrogen removal effectiveness and to define necessary performance specifications before publishing public tenders that aim to replace outdated STPs. Furthermore, it has to be planned where the construction of artificial wetlands would be most feasible, would generate the most beneficial impact and could be most effective in complementing grey infrastructure measures.

Next Steps of the Analysis for Lake Dal

Results presented in this report provide in-depth insights about the environmental, social and economic impacts of assessed intervention scenarios to rehabilitate and maintain the ecosystem integrity of Lake Dal. These insights can serve as a cornerstone for policy-making and for prioritizing conservation measures at Lake Dal. To finance and implement the most effective interventions, further assessment steps promise valuable insights for policy implementation. Political stalemate and the introduction of the governor's rule in Jammu & Kashmir in June 2018 did not provide solid conditions for further consultations with former key stakeholder in local authorities in Srinagar for proceeding with a financial assessment. IISD is prepared to pick up this assessment at any time when the political situation allows the capacity to provide relevant information for the assessment as well as taking assessment results into account for policy-making at Lake Dal.

Extended SAVi assessment: Several components are meant to be included in the assessment of economic implications resulting from the implementation of viable sewage treatment measures. As shown in this report, a clean and ecologically sustainable lake will not only allow for additional revenues in the tourism and fishery sector, but it will also have positive implications prices for real estate in proximity to the lake. A valuation of real estate price developments will highlight the economic co-benefits of selected intervention scenarios. Moreover, the assessment will include an evaluation of additional tax revenues for the Jammu & Kashmir government resulting from increased economic acitivities around the lake and higher real estate values in the region. Finally, interventions will also be evaluated in terms of their potential co-benefits for flood protection during the monsoon season.

Implementation and financing of interventions: Financing models to implement interventions of the most beneficial Scenarios 2.2, 2.3 and 3.2 will be evaluated:

- Upgrade, construction and operation of sewage treatment plants: Evaluation of how a performance contract or a public–private partnership can be planned.
- On-site treatment options for lake inhabitants and houseboats: Identification of viable financing models will include the assessment of polluter pays schemes in combination with government subsidies; issuance of a social impact bond based on the Swachh Bharat Mission; availability payment mechanism based on a public–private partnership.
- Artificial wetland: Identification of subsidy schemes and government budgets to finance its construction and maintenance; exploration of financing through carbon credits based on carbon sequestration benefits of wetlands.

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Appendix I – Summary Of Results: Scenario 5.2

Table A1 presents the development of key variables and drivers in the BAU scenario and Scenario 5.2 for selected years. In the Scenario 5.2, the implementation of lake conservation measures leads to decreasing pressures on the lake despite the road construction and a significant increase in population. The sewage treatment measures for all polluter groups are able to curb the growth of aquatic plants and maintain ecosystem integrity with beneficial effects for the lake's ecosystem. Improvements in water quality benefits the reproduction of fish and counteracts a depletion of local fish stocks. These developments are beneficial for tourism and fishery-dependent livelihoods. Migration increases compared to the baseline due to increasing economic opportunities provided by activities around the lake, supported by the construction of the road. Still, the road project would create additional runoff and encroachment pressures on the lake and significantly reduce overall net benefits associated with sewage treatment interventions compared to Scenario 3.2.

Table A1.1 Summary of key indicators Scenario 5.2

Population

Population Srinagar	Unit	2016	2020	2025	2030	2040	2050	2060
1.) BAU	People	1,533,622	1,728,397	1,940,868	2,126,033	2,447,984	2,691,297	2,837,592
5.2) Scenario 5.2	People	1,533,622	1,728,397	1,945,162	2,181,199	2,620,647	2,977,013	3,292,604
Population in the periphery	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**
1.) BAU	People	199,371	7,120	6,880	7,028	5,742	5,986	5,443
5.2) Scenario 5.2	People	199,371	224,692	270,514	306,424	364,694	411,061	452,089
Lake dwellers	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**
1.) BAU	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804
5.2) Scenario 5.2	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804

N loadings

Total N loadings	Unit	2016	2020	2025	2030	2040	2050	2060
1.) BAU	kg N/year	398,764	403,795	456,672	475,449	489,717	572,597	587,020
5.2) Scenario 5.2	kg N/year	398,764	372,752	198,049	212,892	236,214	254,646	274,520
N loadings from population	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**
1.) BAU	kg N/year	338,966	345,174	399,487	419,664	436,632	522,074	538,717
5.2) Scenario 5.2	kg N/year	338,966	314,129	140,787	157,026	183,046	204,039	221,058
Residual N loadings	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**
1.) BAU	kg N/year	59,798	58,621	57,185	55,785	53,085	50,523	48,303
5.2) Scenario 5.2	kg N/year	59,798	58,622	57,261	55,867	53,168	50,607	53,462

Water quality

N Concentration	Unit	2016	2020	2025	2030	2040	2050	2060
1.) BAU	mg N/litre	0.91	0.93	1.08	1.18	1.21	1.45	1.53
5.2) Scenario 5.2	mg N/litre	0.91	0.83	0.40	0.43	0.48	0.53	0.58
Secchi depth	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**
1.) BAU	metre	1.28	1.28	1.09	1.07	1.05	0.74	0.75
5.2) Scenario 5.2	metre	1.28	1.37	2.72	2.65	2.33	2.11	1.94
Chlorophyll-a concentration	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**
1.) BAU	Ug/litre	26.22	25.57	39.40	40.47	41.99	71.28	71.10
5.2) Scenario 5.2	Ug/litre	26.22	21.24	4.93	5.20	6.76	8.19	9.85

Economic impacts

Tourism revenues	Unit	2016	2020	2025	2030	2040	2050	2060
1.) BAU	INR million/ year	7,533	7,120	6,880	7,028	5,742	5,986	5,443
5.2) Scenario 5.2	INR million/ year	7,533	7,244	13,375	15,798	14,552	13,822	12,741
Fisheries revenues	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**
1.) BAU	INR million/ year	1,076	1,209	1,354	1,481	1,082	173	25
5.2) Scenario 5.2	INR million/ year	1,076	1,209	1,358	1,523	1,824	2,068	2,266
Total revenues	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**
1.) BAU	INR million/ year	8,609	8,329	8,234	8,508	6,824	6,159	5,468
5.2) Scenario 5.2	INR million/ year	8,609	8,453	14,733	17,321	16,376	15,891	15,008

Description of Results

In the alternative scenarios, Srinagar's population is projected to reach from 2.7 million people in Scenario 5.1 to 3.18 million people in Scenario 5.2. By 2060, this represents a decrease of 139,650 people (-5 per cent) and an increase of 455,000 people (+16 per cent) respectively compared to the BAU scenario. The development of the entire population and the population living in the periphery of the lake of all scenarios is displayed in Figure A1.1.

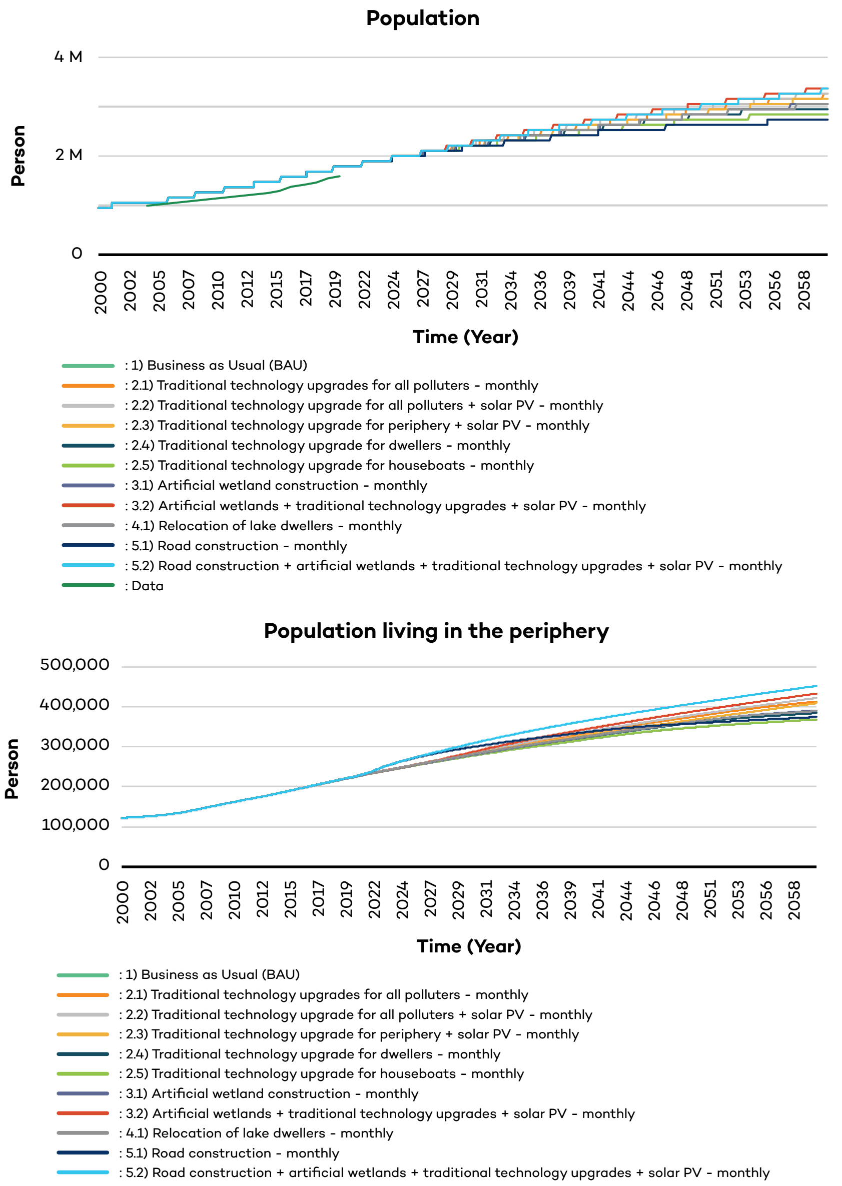

Figure A1.1 Population, population in the periphery of the lake and lake dwellers – All scenarios

The reduction of the population in Scenario 5.1 compared to the BAU scenario is caused by the lack of sewage treatment network and treatment capacity and accelerated degradation of the lake's water quality following the construction of the road. This curbs economic opportunity and disincentivizes migration to Srinagar. The increase in population in Scenario 5.2 is caused by work-related migration into Srinagar. In Scenario 5.2, additional sewage treatment measures for all polluters and the use of solar PV reduce total N loadings reaching the lake to a sustainable level. This improves the quality of the lake and creates economic opportunities in the tourism and fishery sectors. Migration to Srinagar also affects the population in the periphery of the lake. By 2060, the number of people living in the periphery of the lake ranges from around 368,900 in the baseline to around 452,100 people in Scenario 5.2. The development of total population, population in the periphery of the lake and lake dwellers in all scenarios are summarized in Table A2.

Table A1.2. Summary of population projections – All scenarios

	Population Srinagar			Population in the periphery			Lake dwellers		
2016 value	**1,530,000**			**199,450**			**59,850**		
Scenario	**Total (2060)**	**Net difference**	**% vs BAU**	**Total (2060)**	**Net difference**	**% vs BAU**	**Total (2060)**	**Net difference**	**% vs BAU**
1.) BAU	2,837,592	—	—	368,887	—	—	66,804	—	—
2.2) Treatment all + PV	3,248,298	410,706	12.9%	422,279	53,392	14.5%	66,804	0	0%
2.3) Treatment periphery + PV	3,148,230	310,639	9.6%	409,270	40,383	10.9%	66,804	0	0%
2.4) Treatment of lake dwellers	2,958,565	120,973	3.8%	384,613	15,727	4.3%	66,804	0	0%
2.5) Treatment of houseboats	2,837,839	248	0.0%	368,919	32	0.0%	66,804	0	0%
3.1) Artificial wetlands	3,009,077	171,485	6.0%	391,180	22,293	6.0%	66,804	0	0%
3.2) Treatment all + Wetlands + PV	3,237,943	400,352	13.3%	420,933	52,046	14.1%	66,804	0	0%
4.1) Relocation of lake dwellers	2,997,010	159,419	4.9%	389,611	20,724	5.6%	0	-66,804	-100%
5.1) Road construction	2,697,943	-139,648	-4.7%	374,783	5,896	1.6%	66,804	0	0.0%
5.2) All polluters + PV + wetland + Road	3,292,604	455,013	16.9%	452,089	83,202	22.6%	66,804	0	0.0%

The implementation of the planned sewage treatment options in Scenarios 2.1, 2.2, 3.2, and 5.2 provides full coverage for all polluters by 2025. This means that the entire population in the periphery is connected to STPs and both lake dwellers and houseboats are equipped with Johkasou STPs.

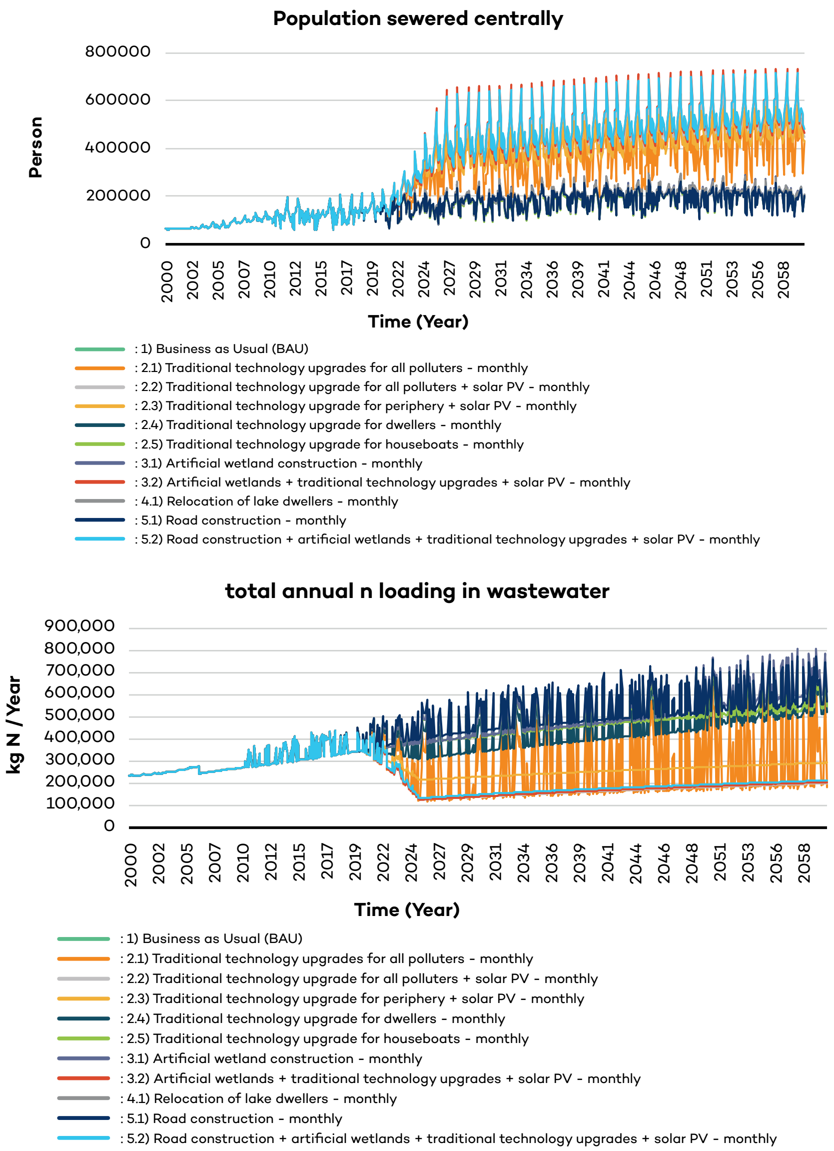

Figure A1.2. Population sewered centrally and annual N loadings in wastewater – All scenarios

The analysis in this report reveals that the treatment of both the lake periphery and lake dwellers is imperative for reducing N loadings to a sustainable level. The highest impact on N loadings is observed in Scenario 2.2. Treating all polluters and providing solar PV for STPs and pumping stations reduces N loadings by 326.6 tons per year in 2060, which is 55.6 per cent lower compared to the baseline. The individual implementation of interventions for lake periphery and lake dwellers yields respective reductions of 236.8 tons per year (40.3 per cent) and 62.2 tons per year (10.6 per cent) compared to the baseline.

Expanding sewage network coverage and STP capacity should be implemented as soon as possible to remediate current—and avoid future—pollution of the lake. A coordinated implementation of the interventions outlined by LAWDA and UEED is projected to reduce N loadings significantly. Full sewage network coverage and the expansion of STPs reduce N loadings by 40.3 per cent in the long term, which benefits the health of the lake.

The relocation of lake dwellers reduces N loadings in 2060 by 12% compared to the BAU scenario. This reduction in N loadings is comparatively small to the potential 40.3% reduction of treating the periphery. However, the removal of lake dwellers and artificial islands and the relocation of houseboats would significantly benefit the circulation of the lake water and counteract eutrophication in brackish waters.

In the scenarios in which all polluters receive sewage treatment, the N loadings from population depend on the efficiency of the installed sewage treatment options. For the other scenarios, N loadings depend on the assumptions used for the respective scenario. Total annual N loadings and the concentration of N in the lake for all scenarios are displayed in Figure A3. The projections show that N loadings in the full treatment scenarios are on average between 40.3 per cent and 55.6 per cent lower compared to the BAU scenario. Total N loadings in the Scenario 5.2 are projected to reach 274.5 tons by 2060, which represents a 53.2 per cent reduction compared to the baseline. The reduction in loadings leads to a 62.1 per cent reduction in the average N concentration by 2060, from 1.53 mg per litre in the BAU scenario to 0.58 mg per litre in Scenario 5.2. The reduction in loadings considerably reduces the pressure on the lake's ecosystem.

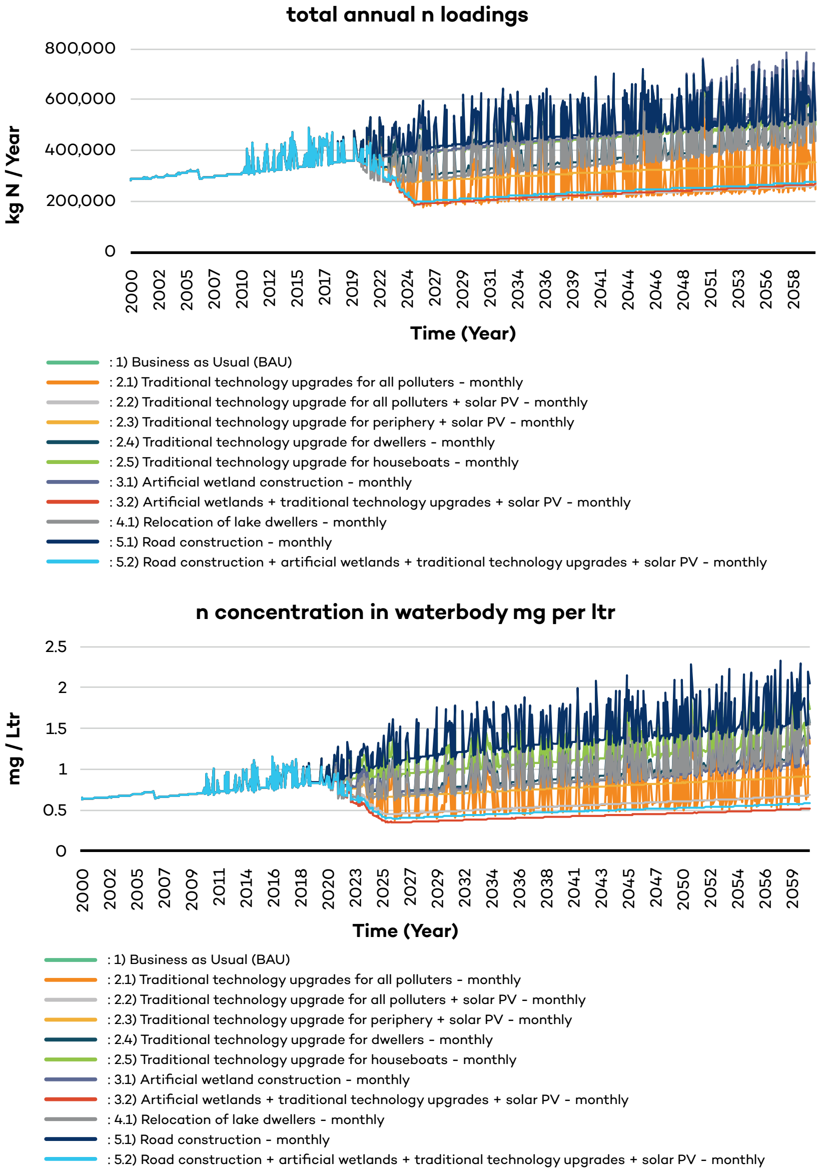

Figure A1.3. Annual N loadings and N concentration in Lake Dal – All scenarios

The reduction in N concentration reduces the potential for algae and other aquatic plants to flourish. The chlorophyll-a concentration in Scenario 5.2 decreases to 9.85 ug per litre by 2060, which is 86.1 per cent lower compared to the baseline. Between 2030 and 2060, the average concentration of chlorophyll-a is 7.44 ug per litre, which is considerably less than in the baseline (53.71 ug per litre). Expanding sewage treatment for all polluters hence considerably contributes to reducing the risk of eutrophication and benefits water clarity. In Scenario 5.2, the average Secchi depth is projected to increase from 1.36 m in 2016 to 1.94 m in 2060. Secchi depth in 2060 and average Secchi depth between 2030 and 2060 in Scenario 5.2 are 1.19 m and 1.31 m higher respectively compared to the BAU scenario. The average water clarity, or Secchi depth, in Scenario 5.2 between 2030 and 2060 is 2.25 m. The development of chlorophyll-a concentration and Secchi depth in all scenarios and the BAU scenario are illustrated in Figure A4.

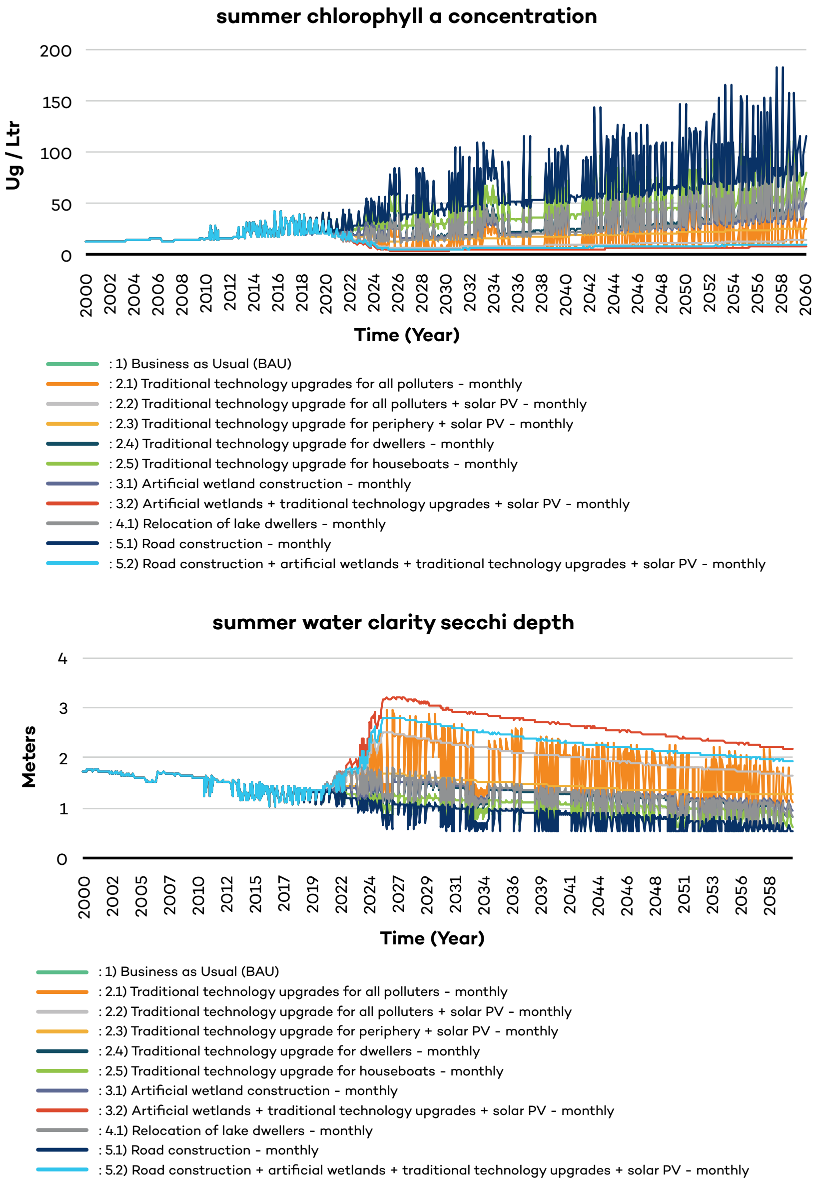

Figure A1.4. Scenario chlorophyll-a concentration and Secchi depth

The increase in environmental quality of the lake makes it more attractive for tourists and increases the annual number of visitors over time. In Scenario 5.2, improving water clarity levels increase the number of tourists over time. By 2060, the annual number of visitors is projected at 1.39 million, compared to approximately 900,000 in the year 2016. This increase is equivalent to a 54.8 per cent increase in tourists over the next 30 years. This leads to a proportional increase in tourism-related spending and revenues generated in Srinagar's tourism industry. Revenues from tourism grow by 69.1 per cent from INR 7.5 billion in 2016 to INR 12.7 billion in 2060. This increase in visitors benefits the many lake-dependent livelihoods and draws additional people to Srinagar in search of work. The development of tourists and tourism revenues for all scenarios is presented in Figure A5.

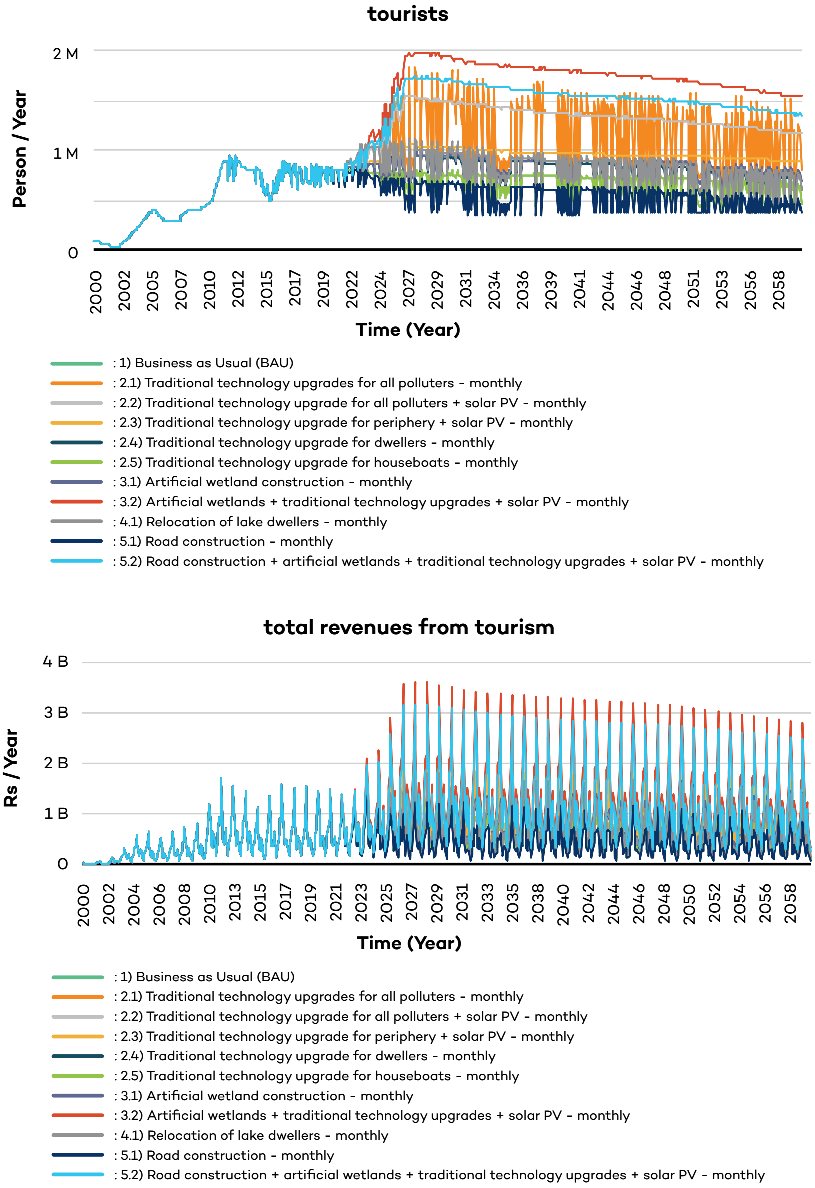

Figure A1.5. Scenario projections on number of tourists and tourism revenues

Next to tourism, fisheries are a livelihood of many people living in and around the lake. The reproduction rate of fish highly depends on water quality, as fish depend on oxygen in the water to survive. In Scenario 5.2, the decrease in nutrients and aquatic plants leads to sufficient oxygen in the lake to maintain the fish reproduction rate over time. Figure A6 illustrates the development of fish catch and total revenues from fisheries for all scenarios.

The analysis indicates that the fish stocks are collapsing in Scenarios 1, 2.1, 2.4, 2.5, 3.1, 4.1, and 5.1. This observation also indicates that full treatment of all polluters is insufficient to maintain good water quality as long as sewage overflows caused by power cuts remain (Scenario 2.1). The fish stocks are able to maintain the desired catching rates until 2034, before the catching rate itself is affected by fish scarcity. In conclusion, depending on the interventions implemented, the lake's water quality declines to a point where it is no longer sufficient to maintain the required fish reproduction rates and sustain the projected catch.

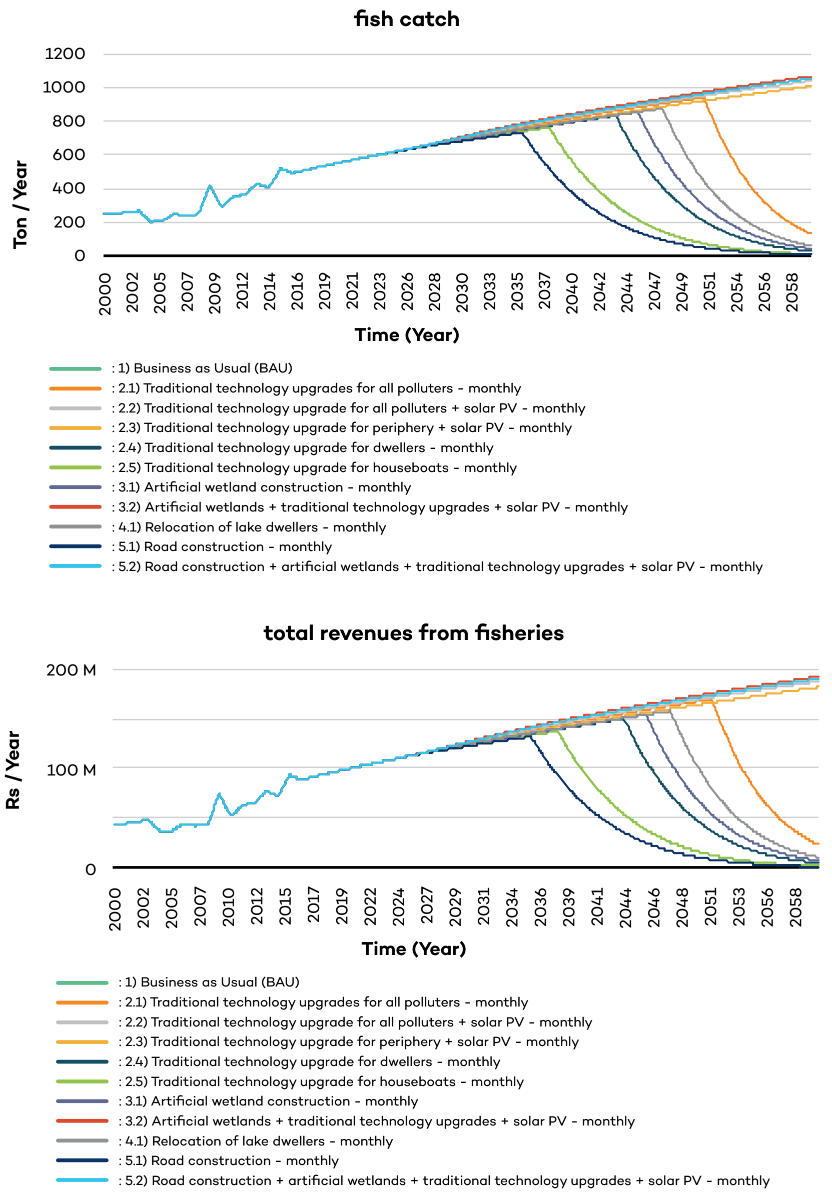

Figure A1.6. **Baseline fish catch and reproduction and total revenues from fisheries**

Appendix II – Summary Table Scenarios 2.2 – 2.5

Table A2.1. **Summary of results traditional treatment scenarios**

Population

Population Srinagar	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	People	1,533,622	1,728,397	1,940,868	2,126,033	2,447,984	2,691,297	2,837,592	0%
2.1) All polluters	People	1,533,622	1,728,397	1,943,051	2,161,219	2,565,136	2,908,238	3,179,374	12%
2.2) All polluters + solar	People	1,533,622	1,728,397	1,943,597	2,172,341	2,595,376	2,941,805	3,248,298	14%
2.3) Periphery + solar	People	1,533,622	1,728,397	1,942,355	2,148,971	2,524,993	2,849,393	3,148,230	11%
2.4) Lake dwellers	People	1,533,622	1,728,397	1,941,699	2,138,415	2,487,879	2,785,774	2,958,565	4%
2.5) Houseboats	People	1,533,622	1,728,397	1,940,870	2,126,058	2,448,061	2,691,499	2,837,839	0.01%
Population in the periphery	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	People	199,371	224,692	252,313	276,384	318,238	349,869	368,887	0%
2.1) All polluters	People	199,371	224,692	252,597	280,959	333,468	378,071	413,319	12%
2.2) All polluters + solar	People	199,371	224,692	252,668	282,404	337,399	382,435	422,279	14%
2.3) Periphery + solar	People	199,371	224,692	252,506	279,366	328,249	370,421	409,270	11%
2.4) Lake dwellers	People	199,371	224,692	252,421	277,994	323,424	362,151	384,613	4%
2.5) Houseboats	People	199,371	224,692	252,313	276,388	318,248	349,895	368,919	0.01%
Lake dwellers	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0%
2.1) All polluters	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0%
2.2) All polluters + solar	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0%
2.3) Periphery + solar	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0%
2.4) Lake dwellers	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0%
2.5) Houseboats	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0%

N loadings

Total N loadings	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	kg/year	398,764	403,795	456,672	475,449	489,717	572,597	587,020	0.0%
2.1) All polluters	kg/year	398,764	387,123	277,977	288,126	280,000	378,154	379,439	-35.4%
2.2) All polluters + solar	kg/year	398,764	372,258	189,572	201,902	223,862	241,704	260,402	-55.6%
2.3) Periphery + solar	kg/year	398,764	380,619	278,772	290,769	312,395	331,357	350,225	-40.3%
2.4) Lake dwellers	kg/year	398,764	395,475	367,797	387,311	402,621	499,853	524,861	-10.6%
2.5) Houseboats	kg/year	398,764	403,781	456,526	475,303	489,606	572,507	586,975	-0.01%

N loadings from population	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	kg/year	338,966	345,174	399,487	419,664	436,632	522,074	538,717	0.0%
2.1) All polluters	kg/year	338,966	328,502	220,792	232,342	226,915	327,631	327,716	-39.2%
2.2) All polluters + solar	kg/year	338,966	313,637	132,387	146,117	170,777	191,181	207,725	-61.4%
2.3) Periphery + solar	kg/year	338,966	321,998	221,586	234,984	259,310	280,834	299,167	-44.5%
2.4) Lake dwellers	kg/year	338,966	336,854	310,612	331,526	349,536	449,330	476,362	-11.6%
2.5) Houseboats	kg/year	338,966	345,160	399,341	419,519	436,521	521,984	538,672	-0.01%

Residual N loadings	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	kg/year	59,798	58,621	57,185	55,785	53,085	50,523	48,303	0.0%
2.1) All polluters	kg/year	59,798	58,621	57,185	55,785	53,085	50,523	51,723	7.1%
2.2) All polluters + solar	kg/year	59,798	58,621	57,185	55,785	53,085	50,523	52,677	9.1%
2.3) Periphery + solar	kg/year	59,798	58,621	57,185	55,785	53,085	50,523	51,058	5.7%
2.4) Lake dwellers	kg/year	59,798	58,621	57,185	55,785	53,085	50,523	48,499	0.4%
2.5) Houseboats	kg/year	59,798	58,621	57,185	55,785	53,085	50,523	48,303	0.0%

Water quality

N Concentration	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	mg N/litre	0.909	0.930	1.084	1.178	1.213	1.449	1.526	0.0%
2.1) All polluters	mg N/litre	0.909	0.896	0.660	0.740	0.695	0.953	0.986	-35.4%
2.2) All polluters + solar	mg N/litre	0.909	0.868	0.450	0.486	0.553	0.614	0.677	-55.6%
2.3) Periphery + solar	mg N/litre	0.909	0.885	0.662	0.700	0.772	0.841	0.911	-40.3%
2.4) Lake dwellers	mg N/litre	0.909	0.913	0.873	0.966	0.997	1.264	1.365	-10.6%
2.5) Houseboats	mg N/litre	0.909	0.930	1.084	1.178	1.212	1.449	1.526	0.0%

Secchi depth	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	metre	1.28	1.28	1.09	1.07	1.05	0.74	0.75	0.0%
2.1) All polluters	metre	1.28	1.31	1.78	1.94	1.99	1.33	1.32	75.7%
2.2) All polluters + solar	metre	1.28	1.32	2.44	2.32	2.03	1.83	1.67	121.3%
2.3) Periphery + solar	metre	1.28	1.31	1.69	1.61	1.45	1.35	1.27	68.1%
2.4) Lake dwellers	metre	1.28	1.29	1.32	1.31	1.26	0.92	0.90	19.5%
2.5) Houseboats	metre	1.28	1.28	1.10	1.07	1.05	0.74	0.75	0.0%

Chlorophyll-*a* concentration	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	Ug/litre	26.22	25.57	39.40	40.47	41.99	71.28	71.10	0.0%
2.1) All polluters	Ug/litre	26.22	24.12	16.56	15.15	12.13	33.43	27.59	-61.2%
2.2) All polluters + solar	Ug/litre	26.22	23.10	6.19	6.81	8.96	11.13	13.66	-80.8%
2.3) Periphery + solar	Ug/litre	26.22	23.76	13.35	14.64	18.00	21.53	25.40	-64.3%
2.4) Lake dwellers	Ug/litre	26.22	24.88	25.98	26.49	27.38	54.11	56.01	-21.2%
2.5) Houseboats	Ug/litre	26.22	25.56	39.37	40.43	41.96	71.24	71.08	0.0%

Economic impacts

Tourism revenues	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	INR million/ year	7,533	7,120	6,880	7,028	5,742	5,986	5,443	0.0%
2.1) All polluters	INR million/ year	7,533	7,120	11,243	14,225	9,872	10,935	9,908	82.0%
2.2) All polluters + solar	INR million/ year	7,533	7,160	12,277	13,803	12,708	11,928	10,947	101.1%
2.3) Periphery + solar	INR million/ year	7,533	7,160	9,121	9,539	9,046	8,771	8,285	52.2%
2.4) Lake dwellers	INR million/ year	7,533	7,120	8,159	8,683	7,014	6,999	6,296	15.7%
2.5) Houseboats	INR million/ year	7,533	7,120	6,883	7,030	5,744	5,987	5,444	0.0%

Fisheries revenues	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	INR million/ year	1,076	1,209	1,354	1,481	1,082	173	25	0%
2.1) All polluters	INR million/ year	1,076	1,209	1,356	1,508	1,785	2,020	318	1155%
2.2) All polluters + solar	INR million/ year	1,076	1,209	1,357	1,517	1,806	2,044	2,236	8719%
2.3) Periphery + solar	INR million/ year	1,076	1,209	1,356	1,498	1,756	1,979	2,167	8446%
2.4) Lake dwellers	INR million/ year	1,076	1,209	1,355	1,490	1,730	492	68	169%
2.5) Houseboats	INR million/ year	1,076	1,209	1,354	1,481	1,083	173	25	0%

Total revenues	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	INR million/ year	8,609	8,329	8,234	8,508	6,824	6,159	5,468	0.0%
2.1) All polluters	INR million/ year	8,609	8,329	12,600	15,733	11,657	12,955	10,226	87.0%
2.2) All polluters + solar	INR million/ year	8,609	8,369	13,634	15,320	14,514	13,972	13,183	141.1%
2.3) Periphery + solar	INR million/ year	8,609	8,369	10,477	11,037	10,802	10,750	10,451	91.1%
2.4) Lake dwellers	INR million/ year	8,609	8,329	9,514	10,173	8,744	7,490	6,364	16.4%
2.5) Houseboats	INR million/ year	8,609	8,329	8,237	8,510	6,828	6,161	5,470	0.0%

Appendix III – Summary Table Scenarios 3.1 – 3.2

Table A3.1. Summary of results hybrid treatment scenarios

Population

Population Srinagar	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	People	1,533,622	1,728,397	1,940,868	2,126,033	2,447,984	2,691,297	2,837,592	0.0%
3.1) Artificial wetland	People	1,533,622	1,728,397	1,942,396	2,139,459	2,494,856	2,807,099	3,009,077	6.0%
3.2) Wetland + all + PV	People	1,533,622	1,728,397	1,944,272	2,166,012	2,577,407	2,924,355	3,237,943	14.1%
Population in the periphery	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	People	199,371	224,692	252,313	276,384	318,238	349,869	368,887	0.0%
3.1) Artificial wetland	People	199,371	224,692	252,512	278,130	324,331	364,923	391,180	6.0%
3.2) Wetland + all + PV	People	199,371	224,692	252,755	281,582	335,063	380,166	420,933	14.1%
Lake dwellers	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0.0%
3.1) Artificial wetland	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0.0%
3.2) Wetland + all + PV	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0.0%

N loadings

Total N loadings	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	kg N/ year	398,764	403,795	456,672	475,449	489,717	572,597	587,020	0.0%
3.1) Artificial wetland	kg N/ year	398,764	403,804	457,108	477,815	496,230	601,460	637,085	8.5%
3.2) Wetland + all + PV	kg N/ year	398,764	372,266	189,845	203,221	226,948	245,911	266,667	-54.6%
N loadings from population	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	kg N/ year	338,966	345,174	399,487	419,664	436,632	522,074	538,717	0.0%
3.1) Artificial wetland	kg N/ year	338,966	345,183	399,923	422,031	443,145	550,937	587,938	9.1%
3.2) Wetland + all + PV	kg N/ year	338,966	313,645	132,660	147,437	173,863	195,388	212,661	-60.5%
Residual N loadings	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	kg N/ year	59,798	58,621	57,185	55,785	53,085	50,523	48,303	0.0%
3.1) Artificial wetland	kg N/ year	59,798	58,621	57,185	55,785	53,085	50,523	49,147	1.7%
3.2) Wetland + all + PV	kg N/ year	59,798	58,621	57,185	55,785	53,085	50,523	54,006	11.8%

Water quality

N Concentration	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	mg N/ litre	0.91	0.93	1.08	1.18	1.21	1.45	1.53	0.0%
3.1) Artificial wetland	mg N/ litre	0.91	0.88	0.85	0.90	0.93	1.14	1.23	-19.7%
3.2) Wetland + all + PV	mg N/ litre	0.91	0.83	0.35	0.37	0.42	0.47	0.51	-66.4%

Secchi depth	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	metre	1.28	1.28	1.09	1.07	1.05	0.74	0.75	0.0%
3.1) Artificial wetland	metre	1.28	1.32	1.33	1.36	1.31	1.06	1.02	35.1%
3.2) Wetland + all + PV	metre	1.28	1.37	3.07	3.00	2.68	2.41	2.19	190.9%

Chlorophyll-a concentration	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	Ug/litre	26.22	25.57	39.40	40.47	41.99	71.28	71.10	0.0%
3.1) Artificial wetland	Ug/litre	26.22	23.38	24.20	23.02	23.85	42.58	45.12	-36.5%
3.2) Wetland + all + PV	Ug/litre	26.22	21.16	3.84	3.89	5.10	6.26	7.66	-89.2%

Economic impacts

Tourism revenues	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	INR million/ year	7,533	7,120	6,880	7,028	5,742	5,986	5,443	0.0%
3.1) Artificial wetland	INR million/ year	7,533	7,207	8,048	8,858	7,502	7,595	6,879	26.4%
3.2) Wetland + all + PV	INR million/ year	7,533	7,244	14,929	17,939	16,746	15,812	14,387	164.3%

Fisheries revenues	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	INR million/ year	1,076	1,209	1,354	1,481	1,082	173	25	0.0%
3.1) Artificial wetland	INR million/ year	1,076	1,209	1,355	1,491	1,735	714	100	294.9%
3.2) Wetland + all + PV	INR million/ year	1,076	1,209	1,359	1,530	1,841	2,092	2,293	8944%

Total revenues	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	INR million/ year	8,609	8,329	8,234	8,508	6,824	6,159	5,468	0.0%
3.1) Artificial wetland	INR million/ year	8,609	8,416	9,403	10,349	9,237	8,309	6,979	27.6%
3.2) Wetland + all + PV	INR million/ year	8,609	8,453	16,288	19,469	18,586	17,904	16,680	205.0%

Appendix IV – Summary Table Scenario 4.1

Table A4.1. Summary of results dweller relocation scenario

Population

Population Srinagar	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	People	1,533,622	1,728,397	1,940,868	2,126,033	2,447,984	2,691,297	2,837,592	0.0%
4.1) Relocate lake dwellers	People	1,533,622	1,728,397	1,944,572	2,150,151	2,501,068	2,805,431	2,997,010	5.6%
Population in the periphery	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	People	199,371	224,692	252,313	276,384	318,238	349,869	368,887	0.0%
4.1) Relocate lake dwellers	People	199,371	224,692	252,794	279,520	325,139	364,706	389,611	5.6%
Lake dwellers	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0.0%
4.1) Relocate lake dwellers	People	59,846	60,448	331	2	0	0	0	-100.0%

N loadings

Total N loadings	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	kg N/year	398,764	403,795	456,672	475,449	489,717	572,597	587,020	0.0%
4.1) Relocate lake dwellers	kg N/year	398,764	366,167	350,588	370,606	385,410	486,494	516,496	-12.0%
N loadings from population	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	kg N/year	338,966	345,174	399,487	419,664	436,632	522,074	538,717	0.0%
4.1) Relocate lake dwellers	kg N/year	338,966	307,545	293,403	314,821	332,324	435,971	467,503	-13.2%
Residual N loadings	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	kg N/year	59,798	58,621	57,185	55,785	53,085	50,523	48,303	0.0%
4.1) Relocate lake dwellers	kg N/year	59,798	58,621	57,185	55,785	53,085	50,523	48,994	1.4%

Water quality

N Concentration	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	mg N/litre	0.91	0.93	1.08	1.18	1.21	1.45	1.53	0.0%
4.1) Relocate lake dwellers	mg N/litre	0.91	0.85	0.83	0.93	0.95	1.23	1.34	-12.0%
Secchi depth	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	metre	1.28	1.28	1.09	1.07	1.05	0.74	0.75	0.0%
4.1) Relocate lake dwellers	metre	1.28	1.36	1.40	1.37	1.30	0.96	0.92	22.1%
Chlorophyll-a concentration	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	Ug/litre	26.22	25.57	39.40	40.47	41.99	71.28	71.10	0.0%
4.1) Relocate lake dwellers	Ug/litre	26.22	22.40	23.42	24.21	24.88	51.18	54.11	-23.9%

Economic impacts

Tourism revenues	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU2060
1.) BAU	INR million/ year	7,533	7,120	6,880	7,028	5,742	5,986	5,443	0.0%
4.1) Relocate lake dwellers	INR million/ year	7,533	7,120	9,027	9,179	7,281	7,228	6,409	17.7%
Fisheries revenues	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	INR million/ year	1,076	1,209	1,354	1,481	1,082	173	25	0.0%
4.1) Relocate lake dwellers	INR million/ year	1,076	1,209	1,358	1,499	1,739	1,059	144	469.6%
Total revenues	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU2060**
1.) BAU	INR million/ year	8,609	8,329	8,234	8,508	6,824	6,159	5,468	0.0%
4.1) Relocate lake dwellers	INR million/ year	8,609	8,329	10,385	10,677	9,020	8,287	6,553	19.8%

Appendix V – Summary Table Scenario 5.1 – 5.2

Table A5.1. **Summary of results road construction scenarios**

Population

Population Srinagar	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU
1.) BAU	People	1,533,622	1,728,397	1,940,868	2,126,033	2,447,984	2,691,297	2,837,592	0.0%
5.1) Road construction	People	1,533,622	1,728,397	1,940,478	2,116,937	2,403,094	2,581,299	2,697,943	-4.9%
5.2) All treatment + Road + PV	People	1,533,622	1,728,397	1,945,162	2,181,199	2,620,647	2,977,013	3,292,604	16.0%
Population in the periphery	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	People	199,371	224,692	252,313	276,384	318,238	349,869	368,887	0.0%
5.1) Road construction	People	199,371	224,692	269,905	298,070	336,413	359,618	374,783	1.6%
5.2) All treatment + Road + PV	People	199,371	224,692	270,514	306,424	364,694	411,061	452,089	22.6%
Lake dwellers	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0.0%
5.1) Road construction	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0.0%
5.2) All treatment + Road + PV	People	59,846	60,448	61,208	61,978	63,547	65,155	66,804	0.0%

N loadings

Total N loadings	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU
1.) BAU	kg N/year	398,764	403,795	456,672	475,449	489,717	572,597	587,020	0.0%
5.1) Road construction	kg N/year	398,764	404,366	477,762	499,594	507,822	589,283	601,940	2.5%
5.2) All treatment + Road + PV	kg N/year	398,764	372,752	198,049	212,892	236,214	254,646	274,520	-53.2%
N loadings from population	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	kg N/year	338,966	345,174	399,487	419,664	436,632	522,074	538,717	0.0%
5.1) Road construction	kg N/year	338,966	345,744	420,500	443,728	454,654	538,675	553,553	2.8%
5.2) All treatment + Road + PV	kg N/year	338,966	314,129	140,787	157,026	183,046	204,039	221,058	-59.0%
Residual N loadings	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	kg N/year	59,798	58,621	57,185	55,785	53,085	50,523	48,303	0.0%
5.1) Road construction	kg N/year	59,798	58,622	57,261	55,867	53,168	50,607	48,387	0.2%
5.2) All treatment + Road + PV	kg N/year	59,798	58,622	57,261	55,867	53,168	50,607	53,462	10.7%

Water quality

N Concentration	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU
1.) BAU	mg N/ litre	0.91	0.93	1.08	1.18	1.21	1.45	1.53	0.0%
5.1) Road construction	mg N/ litre	0.91	0.93	1.27	1.43	1.46	1.73	1.82	19.1%
5.2) All treatment + Road + PV	mg N/ litre	0.91	0.83	0.40	0.43	0.48	0.53	0.58	-62.1%
Secchi depth	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	metre	1.28	1.28	1.09	1.07	1.05	0.74	0.75	0.0%
5.1) Road construction	metre	1.28	1.28	0.92	0.86	0.85	0.62	0.57	-23.8%
5.2) All treatment + Road + PV	metre	1.28	1.37	2.72	2.65	2.33	2.11	1.94	157.9%
Chlorophyll-a concentration	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	Ug/litre	26.22	25.57	39.40	40.47	41.99	71.28	71.10	0.0%
5.1) Road construction	Ug/litre	26.22	25.68	54.59	60.46	61.89	103.32	102.64	44.4%
5.2) All treatment + Road + PV	Ug/litre	26.22	21.24	4.93	5.20	6.76	8.19	9.85	-86.1%

Economic impacts

Tourism revenues	Unit	2016	2020	2025	2030	2040	2050	2060	% vs BAU
1.) BAU	INR million/ year	7,533	7,120	6,880	7,028	5,742	5,986	5,443	0.0%
5.1) Road construction	INR million/ year	7,533	7,120	6,135	6,098	4,275	4,754	4,059	-25.4%
5.2) All treatment + Road + PV	INR million/ year	7,533	7,244	13,375	15,798	14,552	13,822	12,741	134.1%
Fisheries revenues	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	INR million/ year	1,076	1,209	1,354	1,481	1,082	173	25	0.0%
5.1) Road construction	INR million/ year	1,076	1,209	1,354	1,473	724	114	18	-30.7%
5.2) All treatment + Road + PV	INR million/ year	1,076	1,209	1,358	1,523	1,824	2,068	2,266	8838.8%
Total revenues	**Unit**	**2016**	**2020**	**2025**	**2030**	**2040**	**2050**	**2060**	**% vs BAU**
1.) BAU	INR million/ year	8,609	8,329	8,234	8,508	6,824	6,159	5,468	0.0%
5.1) Road construction	INR million/ year	8,609	8,329	7,489	7,572	4,999	4,868	4,077	-25.4%
5.2) All treatment + Road + PV	INR million/ year	8,609	8,453	14,733	17,321	16,376	15,891	15,008	174.5%

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