JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Design of Sustainable Rural Drinking Water Supply Systems Using Non-Conventional Methods: A Review and Case Application for Kolhapur District

[1]Mr. Pravin Patil, [2]Prof. G.N.Kanade, [3]Prof. P.B.Kolekar
[1]PG Student,, [2]Assistant Professor
[1]Civil (Construction Management), Tatyasaheb Kore Institute of Engineering and Technology, Warananagar, Pin – 416113, Maharashtra, India
[2]Civil (Construction Management), Tatyasaheb Kore Institute of Engineering and Technology, Warananagar, Pin – 416113, Maharashtra, India
[3]Civil (Construction Management), Tatyasaheb Kore Institute of Engineering and Technology, Warananagar, Pin – 416113, Maharashtra, India

Abstract: Access to safe and reliable drinking water remains one of the most critical challenges in rural regions worldwide, where traditional supply systems often struggle with limitations such as source depletion, high operational costs, energy dependency, and inadequate maintenance. In India, particularly in rural areas like the Kolhapur district of Maharashtra, these challenges are further intensified by seasonal variability, population growth, and uneven infrastructure development. To address these issues, the integration of non-conventional technologies presents a promising pathway toward sustainable and self-reliant water supply solutions. This review paper explores various non-conventional methods applicable to rural water supply systems, including rainwater harvesting, solar-powered pumping, decentralized filtration units, and groundwater recharge techniques. Through a comprehensive analysis of global and national case studies, the paper identifies innovative practices that enhance efficiency, community participation, and resilience of rural water systems. These case studies demonstrate that adopting context-specific, renewable, and low-cost solutions can significantly improve long-term sustainability and reduce dependence on external resources. Focusing on the Kolhapur district, this research compiles data from multiple villages to assess existing water supply schemes, examining their performance, success factors, and reasons for failure. Based on this analysis, a specific village is selected for detailed study and design of an improved water supply system using the most feasible non-conventional technologies. The findings emphasize the need for integrating local resource availability, community engagement, and renewable energy in system design to ensure sustainable, equitable, and climate-resilient rural water management.

Index Terms **- Rural Water Supply, Non-Conventional Methods, Sustainability, Kolhapur District, Case Study, Water System Design.**

1. INTRODUCTION

1.1 Background and Context

Access to safe and adequate drinking water is a fundamental human necessity and a cornerstone of sustainable development. Globally, more than two billion people still lack access to safely managed drinking water, with rural communities facing the greatest challenges. In developing countries, particularly in regions of Asia and Africa, rural populations depend heavily on local water sources such as wells, ponds, and small streams, many of which are highly vulnerable to seasonal fluctuations, contamination, and depletion. The United Nations Sustainable Development Goal (SDG) 6 emphasizes the need to "ensure availability and sustainable management of water and sanitation for all," yet achieving this goal in rural settings remains a complex task due to limited financial resources, technical expertise, and institutional support.

Traditionally, rural water supply systems have relied on conventional infrastructure such as borewells, hand pumps, gravity-fed schemes, and piped distribution networks. While these systems have significantly improved rural water accessibility, their long-term sustainability has been questionable. Borewell-based systems, for instance, have led to severe groundwater depletion in many parts of India, as extraction rates often exceed natural recharge. Similarly, hand pumps and piped systems require continuous maintenance, reliable power supply, and technical supervision—conditions that are frequently lacking in rural environments. As a result, breakdowns and water shortages are common, and many schemes fail to operate efficiently after initial implementation.

The limitations of conventional methods are further compounded by energy dependence and escalating maintenance costs. Diesel-powered pumps contribute to greenhouse gas emissions and incur high operational expenses, while grid-dependent systems often face interruptions due to erratic rural electricity supply. Additionally, the centralized nature of conventional water systems often leads to inequitable distribution, with marginalized communities being disproportionately affected during scarcity periods. These challenges highlight the urgent need to rethink the existing water supply paradigms and adopt sustainable, decentralized, and adaptive approaches.

In this context, non-conventional and renewable solutions are emerging as viable alternatives to bridge the rural water gap. Methods such as rainwater harvesting, solar-powered pumping, decentralized treatment units, greywater recycling, and artificial groundwater recharge offer environmentally friendly and economically feasible options. These technologies leverage local resources, reduce dependency on centralized systems, and can be tailored to the specific climatic and geographical conditions of each village. Globally, successful applications of such approaches have demonstrated improved reliability, lower operational costs, and enhanced community participation. Thus, integrating non-conventional technologies into rural water supply design not only promotes sustainability but also aligns with national priorities such as India's Jal Jeevan Mission (JJM) and the National Rural Drinking Water Programme (NRDWP), which advocate for self-sufficient and resilient rural water systems.

In summary, the global and local experiences underscore a critical transition—from conventional, resource-intensive models toward innovative, renewable-based, and community-centric systems. This transition represents the future of rural water supply management, ensuring that every household, regardless of location, can access safe, affordable, and sustainable drinking water.

1.2 Rationale and Need for Research

The provision of reliable and safe drinking water in rural areas continues to be one of the most pressing developmental challenges in India. Despite decades of government initiatives and investments, a significant gap persists between the growing rural water demand and the capacity of existing infrastructure. Rapid population growth, agricultural expansion, and lifestyle changes have intensified the pressure on conventional water sources such as wells, borewells, and small reservoirs. In many villages, the available infrastructure—often established decades ago—has become inadequate or inefficient due to aging components, poor maintenance, and overexploitation of groundwater. Seasonal shortages, erratic supply, and water quality deterioration are now common issues that directly affect public health and rural livelihoods. This growing disparity between supply and demand highlights the urgent need for innovative, sustainable, and adaptive water management strategies tailored to rural contexts.

In alignment with India's rural development goals and national water policies, several schemes such as the National Rural Drinking Water Programme (NRDWP) and the Jal Jeevan Mission (JJM) have been introduced to ensure "Har Ghar Jal" — tap water for every household. These programs aim to achieve universal access, improve water quality, and strengthen local governance. However, while these schemes have accelerated coverage, their success is often hindered by regional disparities, infrastructure maintenance issues, and heavy reliance on conventional technologies. The operational sustainability of many rural schemes remains a challenge, particularly in areas where groundwater sources are declining or surface water availability is seasonal. Therefore, integrating non-conventional methods such as solar energy-based pumping, rainwater harvesting, and decentralized treatment systems can complement government efforts by enhancing reliability and reducing dependence on grid power and centralized networks.

The Kolhapur district in Maharashtra presents a unique case study for such an approach due to its diverse climatic and geographical conditions. While parts of the district receive abundant rainfall during the monsoon, several villages face acute water scarcity during the dry months. The undulating terrain, varied soil permeability, and inconsistent groundwater levels make it difficult to sustain traditional water supply systems year-round. Moreover, many rural settlements in Kolhapur depend on distant surface sources or deep borewells, which are both energy-intensive and vulnerable to seasonal fluctuations. The region thus exemplifies the broader challenge of achieving water security in semi-rural and hilly landscapes, where both physical and socio-economic constraints limit the feasibility of conventional approaches.

Non-conventional water supply methods offer a promising pathway to address these constraints. Technologies such as rainwater harvesting systems, solar-powered pumping units, decentralized filtration modules, and artificial recharge structures can provide cost-effective, environmentally sustainable, and community-managed alternatives. These systems reduce dependency on external energy sources, enhance water availability through local resource utilization, and encourage participatory management by villagers. Moreover, they improve system resilience against climatic variability and reduce the carbon footprint of rural water infrastructure.

In this context, there is a clear need for systematic research to evaluate, design, and demonstrate the feasibility of such non-conventional methods specifically suited to the socio-economic and climatic realities of Kolhapur's rural areas. By analyzing existing schemes, identifying their limitations, and proposing context-specific designs, this study seeks to bridge the gap between policy intent and on-ground sustainability. The research aims to contribute actionable insights for planners, engineers, and policymakers to create resilient, self-sustaining, and future-ready rural water supply systems that align with India's broader vision of inclusive and sustainable rural development.

2. Literature Review

2.1. Conventional vs. Non-Conventional Water Supply Systems

- Overview of conventional systems: source development, treatment, and distribution.

Conventional rural water supply systems are typically designed following a linear engineering approach consisting of three sequential components: (a) source development, (b) treatment, and (c) distribution.

Source development commonly involves groundwater abstraction through dug wells, borewells, or tube wells, or surface water withdrawal from rivers, tanks, and reservoirs. These sources are designed based on yield analysis, safe drawdown limits, and population-based water demand projections (IS 1172:1993). Treatment units generally include aeration, coagulation–flocculation, sedimentation, filtration, and disinfection processes to meet the quality parameters prescribed under IS 10500:2012. Distribution systems employ gravity-fed or pumping-based piped networks, designed hydraulically using Hazen–Williams or Darcy–Weisbach equations to maintain minimum residual pressure and head losses within permissible limits.

While conventional systems have ensured broad coverage in many regions, they remain energy-intensive, centralized, and maintenance-dependent. Groundwater depletion due to unsustainable pumping, particularly from deep aquifers, has caused a decline in yield and increased pumping head requirements, directly raising energy consumption (Jain et al., 2019). Surface sources are often seasonal and susceptible to contamination and siltation. Consequently, operation and maintenance (O&M) burdens — such as frequent motor repairs, chlorination inconsistencies, and leakages — lead to partial functionality or system collapse in several rural schemes (World Bank, 2021).

- Concept and Definition of Non-Conventional Methods

"Non-conventional" methods in the rural water sector refer to decentralized, renewable-energy-driven, and resource-efficient approaches that diverge from the traditional, centralized supply model. These methods rely on local water resource harvesting, energy substitution (solar, wind, gravity), and low-cost treatment technologies to achieve sustainability. Typical examples include rainwater harvesting, solar-powered pumping, bio-sand and ceramic filtration, greywater reuse, and artificial groundwater recharge.

Unlike conventional systems that depend on external electricity and centralized treatment plants, non-conventional systems emphasize autonomy, community participation, modular scalability, and environmental resilience (IRENA, 2016). They integrate hydrological, mechanical, and renewable-energy engineering principles to create closed-loop, low-carbon supply systems suited to rural geographies.

2.2. Review of Non-Conventional Methods

- Rainwater Harvesting (RWH) – Design Principles, Storage, and Recharge Models

Rainwater harvesting represents one of the most direct and technically viable non-conventional solutions. The principle involves interception, conveyance, filtration, storage, and utilization of rainwater from rooftops, courtyards, or open catchments. The design of RWH systems depends on three critical parameters:

Catchment yield (Q) determined by rainfall intensity (R), catchment area (A), and runoff coefficient (C):

$$Q = R \times A \times C$$

Storage volume (V) computed for the desired reliability period considering average daily demand and dry-spell duration.

Recharge structure capacity, if recharge-based RWH is adopted, estimated through infiltration rate and aquifer transmissivity.

Modern RWH designs integrate first-flush diverters, silt traps, and filtration media (gravel–sand–charcoal filters) to maintain water quality. In India, percolation tanks, recharge shafts, and contour bunds are common recharge structures promoted under the *Atal Bhujal Yojana* and *Jal Shakti Abhiyan*. Studies by CGWB (2020) and Goyal et al. (2021) demonstrate that rooftop RWH combined with sub-surface recharge can increase groundwater levels by 1–2 meters annually in semi-arid zones.

- Solar-Powered Pumping Systems

Solar photovoltaic (PV) pumping systems convert solar radiation directly into electrical energy to drive submersible or surface pumps. The core components include PV modules, motor–pump set, variable-frequency controller (VFD), and storage tank. The system sizing is governed by:

Total dynamic head (TDH) = static head + frictional losses + minor losses,

Required discharge (Q) based on population and per capita demand,

PV array power (P) estimated as:

$$P = \frac{\rho \times g \times Q \times H}{\eta_m \times \eta_p \times \eta_{PV}}$$

where η_m, η_p, and η_{PV} are the efficiencies of motor, pump, and PV module respectively.

Solar pumping has proven particularly effective in off-grid rural settlements. It eliminates diesel fuel dependency, reduces O&M costs, and supports climate-resilient infrastructure. IRENA (2016) and MNRE (2022) reported energy savings of 40–60% compared to grid-based pumping. Hybrid systems combining solar with battery or gravity-fed storage further enhance reliability, especially during cloudy periods.

- Desalination and Filtration Innovations

Water quality challenges—such as high turbidity, fluoride, arsenic, and microbial contamination—necessitate decentralized, low-energy purification methods. Technologies like biosand filters, silver-impregnated ceramic filters, and low-pressure membrane filtration units have emerged as efficient and affordable alternatives to centralized treatment.

Biosand filters operate via biological schmutzdecke layers, achieving up to 95% bacterial removal and 90% turbidity reduction (CAWST, 2020).

Ceramic filters, fabricated with clay and combustible materials, utilize micro-porosity (~0.5 µm) for mechanical filtration and silver impregnation for disinfection (Simonis et al., 2019).

Membrane filtration systems such as ultrafiltration (UF) and reverse osmosis (RO) are increasingly used for community-scale desalination, especially in saline groundwater areas like Gujarat and Tamil Nadu.

These technologies offer modularity, minimal energy consumption, and compatibility with solar operation—making them suitable for decentralized deployment.

- Greywater Recycling

Greywater recycling involves **collection, treatment, and reuse** of wastewater from non-toilet sources such as kitchens, baths, and laundries. Treatment systems typically comprise **settling chambers, anaerobic filters, and constructed wetlands**, which achieve substantial reductions in biochemical oxygen demand (BOD) and suspended solids. Designs are guided by **hydraulic retention time (HRT)** and **organic loading rate (OLR)**, ensuring treatment efficiency and minimal odour generation. Studies in arid regions of Rajasthan and Tamil Nadu have demonstrated 50–70% reduction in freshwater demand through greywater reuse for irrigation and flushing (UNEP, 2020). When integrated with RWH or solar systems, greywater reuse significantly improves the sustainability index of rural water schemes.

- Artificial Recharge and Groundwater Management

Artificial recharge techniques focus on **augmenting subsurface storage** to mitigate groundwater depletion and ensure source sustainability. Common structures include **percolation ponds, recharge shafts, check dams, infiltration trenches, and sand dams**. The recharge rate is calculated based on infiltration capacity (f), hydraulic conductivity (K), and hydraulic gradient (i). In semi-arid zones, sand dams have been recognized as cost-effective solutions—each capable of storing up to 3,000–5,000 m³ of water per season (Lasage et al., 2015). In India, projects under NRDWP and Atal Bhujal Yojana emphasize integrating recharge interventions with watershed management. Successful recharge depends on hydrogeological suitability, catchment treatment, and community-led maintenance.

2.3. Technological Developments and Innovations

- IoT-Based Monitoring and Automation

The integration of Internet of Things (IoT) technology in rural water systems has revolutionized monitoring and control mechanisms. Real-time sensors for flow rate, pressure, turbidity, pH, chlorine residual, and tank level enable predictive maintenance and data-driven management. IoT-based systems can automatically regulate pump operation, detect leaks, and optimize energy use through SCADA (Supervisory Control and Data Acquisition) frameworks. Studies by Lakshmikantha et al. (2021) and Shinde et al. (2022) show that IoT-based automation can reduce non-revenue water losses by up to 20% and operational energy by 15–25%.

- GIS Mapping and Hydraulic Modeling

Geographic Information Systems (GIS) and hydraulic modeling tools (e.g., EPANET, WaterGEMS) are integral to modern water supply design. GIS facilitates spatial mapping of sources, topography, and population clusters, while hydraulic modeling optimizes pipe diameters, pressure zones, and storage capacities based on demand nodes and elevation data. For rural areas with irregular terrain (like Kolhapur's hilly regions), such modeling ensures hydraulic balance and energy-efficient design. Integration of GIS-based decision support systems with IoT sensors can further enable dynamic simulation of flow and pressure variations, aiding rapid fault diagnosis and performance benchmarking (Esri, 2023).

2.4. Previous Case Studies (Global and National)

- Global Case Studies

Kenya: Community-led sand dam projects in Kitui and Machakos have shown remarkable success in sustaining year-round water availability. Each sand dam stores up to 10,000 m³ of water in riverbeds, raising nearby groundwater levels by 1–2 meters. The design utilizes locally available materials, ensuring low cost and community ownership (Lasage et al., 2015).

Bangladesh: Implementation of arsenic removal filters and deep-tube wells under the BAMWSP program has provided safe drinking water to millions. These decentralized interventions demonstrate how low-cost filtration combined with awareness programs can mitigate groundwater contamination risks (Ahmed et al., 2018).

- National Case Studies (India)

Rajasthan: Rooftop RWH integrated with recharge shafts under NRDWP projects has successfully stabilized groundwater levels and improved water quality in semi-arid regions (CGWB, 2020).

Gujarat: The Saurashtra solar-powered village schemes have replaced diesel-driven borewell pumps with 3–5 HP PV systems, reducing O&M costs by 50% and ensuring uninterrupted supply (MNRE, 2022).

Maharashtra: Pilot greywater recycling units in Kolhapur and Sangli have demonstrated reuse potential of up to 40% of domestic wastewater for irrigation (MJP, 2021).

- Key Learnings and Transferability

From the reviewed studies, several critical insights emerge:

» Local resource optimization utilizing rainfall, solar energy, and shallow aquifers enhances sustainability.

» Decentralized design and community participation ensure long-term functionality.

» Technological integration coupling solar, IoT, and GIS enables efficiency and monitoring.

» Contextual adaptation non-conventional methods must align with local hydrogeological and socio-economic conditions. These learnings are directly transferable to rural districts such as Kolhapur, where terrain variability, seasonal rainfall, and energy access remain limiting factors.

3. Case Studies and Data Analysis (Kolhapur District Focus)

3.1. Overview of Rural Water Supply Schemes in Kolhapur District

The Kolhapur district, located in the southern part of Maharashtra, is characterized by diverse hydrogeological and topographic conditions—ranging from the hilly terrains of the Western Ghats to the alluvial plains along the Panchganga basin. The district experiences an average annual rainfall of 1,000–2,500 mm, concentrated mainly between June and September. Despite substantial rainfall, spatial and temporal variability results in localized water scarcity during the dry season.

- General Water Sources

Rural water supply schemes in Kolhapur primarily depend on the following sources:

1. Open Wells and Dug Wells: Common in alluvial and lateritic formations, these serve as traditional sources but are increasingly affected by groundwater table decline due to over-extraction and reduced recharge.
2. Borewells and Tube Wells: These form the backbone of *piped water supply schemes (PWSS)* under the *National Rural Drinking Water Programme (NRDWP)* and *Jal Jeevan Mission (JJM)*. Average depth ranges from 45–120 m, with submersible pumps driven by 3–7.5 HP electric or diesel motors.
3. Surface Sources: Rivers such as Panchganga, Bhogawati, Tulsi, and Vedganga and several minor reservoirs (e.g., Radhanagari, Kalammawadi) provide bulk water to regional schemes.
4. Storage Structures: Villages typically have Elevated Service Reservoirs (ESRs) ranging from 25,000–100,000 L capacity, with ground-level sumps acting as intermediate storage.

- Existing Supply Network and Management Practices

Kolhapur's rural water supply is governed by a decentralized institutional framework, wherein:

» Gram Panchayats (GPs) oversee daily operations and tariff collection.

» Zilla Parishad (ZP) / Rural Development Department (RDD) handle design, funding, and maintenance oversight.

» Maharashtra Jeevan Pradhikaran (MJP) and Groundwater Survey and Development Agency (GSDA) provide technical support.

Most schemes follow a gravity or pumping-based distribution model with PVC/HDPE pipelines (63–110 mm dia) supplying to standposts and household taps. However, field surveys and official progress reports (ZP Kolhapur, 2023) indicate recurring issues of intermittent supply, unequal pressure zones, and non-functional pumps during dry months. Additionally, chlorination irregularity and absence of real-time monitoring contribute to water quality degradation, particularly in decentralized schemes.

3.2. Comparative Analysis of Selected Villages

To assess technical and managerial variations, a comparative study was carried out for four villages in Karveer taluka — Wadipir, Kasba Bavda, Shiroli, and Vashi. Data were compiled through official records (Zilla Parishad and MJP) and field-level interactions with local operators and users.

Table No.1 Comparative Analysis of Selected Villages

Parameter	**Wadipir**	**Kasba Bavda**	**Shiroli**	**Vashi**
Primary Source	Borewell (90 m deep) + Open well (seasonal)	Surface water (Panchganga river intake)	Borewell (120 m deep)	Borewell (70 m)
Storage Capacity	3 ESRs (25,000 L, 45,000 L, 90,000 L)	2 ESRs (60,000 L, 80,000 L)	1 ESR (50,000 L)	1 ESR (30,000 L)
Treatment Facility	Chlorination unit (manual dosing)	Rapid sand filtration + chlorination	Chlorination (basic)	None
Distribution Type	Pumped + gravity distribution	Gravity-fed system	Pumped	Pumped
Energy Source	Grid electricity (intermittent supply)	Grid + DG backup	Grid electricity	Grid
Average Supply Duration	1.5–2 hrs/day	3–4 hrs/day	1 hr/day	1–1.5 hrs/day
User Coverage	85% households	100% households	70% households	60% households
Reliability	Moderate (seasonal source fluctuation)	High	Low (frequent breakdowns)	Moderate
Community Participation	Moderate (Gram Panchayat-led O&M)	Strong (user committees active)	Weak	Weak

Common Issues	Pump motor failures, low voltage, pipeline leakage	High O&M cost but efficient service	Source depletion, poor chlorination	Inadequate pressure, water quality complaints
Potential for Non-Conventional Solutions	High – suitable for rainwater harvesting and solar pumping	Moderate	High – solar + recharge system	High – recharge and reuse potential

- Analysis Highlights
  - » Wadipir: The presence of multiple ESRs and mixed sources offers flexibility; however, dependence on grid electricity and absence of recharge measures reduce resilience. The system's design could be strengthened by introducing solar-powered pumping and rooftop RWH with recharge shafts to enhance groundwater reliability.
  - » Kasba Bavda: A relatively well-managed scheme, supported by river intake and filtration, demonstrates how community-led management and operator training ensure efficiency even with higher O&M costs.
  - » Shiroli and Vashi: These villages exhibit typical rural vulnerabilities—dependence on deep borewells, unsupervised chlorination, and poor user participation—leading to low service continuity.

3.3. Critical Observations

- Patterns of Sustainability
  - » Villages with diversified water sources (surface + groundwater + rainwater) and distributed storage tend to show higher reliability indices (>0.75).
  - » Solar and gravity-fed systems significantly reduce operational cost per cubic meter of water delivered.
  - » Schemes with community financial contribution and tariff recovery exhibit better maintenance and rapid fault response.
- Operational and Technical Gaps
  - » Energy Dependence: Wadipir's scheme suffers from voltage fluctuations and frequent motor failures, leading to irregular supply. Integration of solar PV-based pumping can reduce downtime and ensure supply continuity.
  - » Groundwater Stress: Borewell yield reduction during summer months highlights the absence of aquifer recharge interventions. Recharge shafts or percolation tanks could stabilize the water table.
  - » Water Quality Management: Manual chlorination lacks dosage accuracy. Introducing automated chlorination or IoT-based residual monitoring sensors can ensure consistent disinfection.
  - » Pipeline Leakage and Hydraulic Losses: Unaccounted-for water losses (10–15%) indicate suboptimal hydraulic design and maintenance. Hydraulic modeling (using EPANET) can be employed to redesign pressure zones and pipe diameters.
  - » Data Deficiency: Absence of real-time flow and pressure data limits system diagnostics. Adopting smart flow meters and SCADA-based logging can enable predictive maintenance.
- Institutional and Capacity Gaps
  - » Operator Training Deficit: Pump operators and Gram Panchayat staff lack formal training in preventive maintenance, water testing, and energy management.
  - » Weak Monitoring Framework: Periodic audits and reporting mechanisms are inconsistent, leading to reactive rather than proactive management.
  - » Limited Technical Guidance: Dependency on higher-level agencies (MJP/GSDA) delays problem resolution and upgrades.

3.4. Lessons for Improved System Design

From the case analysis across the Kolhapur district, the following lessons are derived for the design of improved, non-conventional rural water supply systems:

- » Hybrid Source Development: Combine borewell abstraction with rainwater harvesting and aquifer recharge to ensure source sustainability and reduce dependency on deep groundwater.
- » Renewable Energy Integration: Deploy solar-powered pumping systems with gravity-based distribution to reduce energy costs and improve supply reliability.
- » Water Quality Automation: Introduce IoT-based chlorination and turbidity monitoring to maintain consistent drinking water standards.
- » Hydraulic Optimization: Utilize GIS-integrated EPANET modeling for pipe network redesign, ensuring adequate head distribution and minimizing leakage losses.
- » Community-Centric Management: Strengthen Gram Panchayat capacities through technical training, financial autonomy, and community water user committees to enhance accountability.

» Greywater Reuse and Dual Supply Networks: Implement decentralized greywater reuse for irrigation and flushing, thereby conserving potable water for essential domestic use.

4. Selection and Analysis of Target Village

4.1. Village Selection Criteria

The selection of a target village for detailed design analysis was guided by a set of technical, demographic, and hydrological criteria to ensure that the chosen site represents the broader challenges of rural water supply in semi-arid Maharashtra. The criteria included:

1. **Population Size and Demographics:** The study targeted a **medium-sized village (population between 2,000–3,000)** to represent a typical rural settlement where water demand, infrastructure, and maintenance capacities are moderate and manageable.
2. **Topography and Geographical Setting:** Preference was given to villages with **undulating terrain and mixed soil composition** (lateritic and alluvial), as these influence both hydraulic design and groundwater recharge potential.
3. **Water Scarcity and Seasonal Variation:** The village should experience **partial to moderate water scarcity** during summer months, highlighting the necessity of sustainable, non-conventional methods.
4. **Existing Infrastructure and Feasibility of Intervention:** Villages with **functioning but underperforming water supply schemes** were prioritized, enabling realistic evaluation and redesign rather than full reconstruction.
5. **Administrative Accessibility and Institutional Support:** Availability of cooperation from **Gram Panchayat, Zilla Parishad (ZP), and Rural Development Department (RDD)** was also a deciding factor for field surveys and data collection.

Based on these parameters, Wadipir village, located approximately 12–13 km from Kolhapur city in Karveer Taluka, was selected as the target study area. The village falls under the Wadipeer Gram Panchayat, which is directly responsible for operation and maintenance of its rural water supply scheme under the technical supervision of the Zilla Parishad, Kolhapur.

4.2. Current Water Supply System Description

The existing rural water supply system in Wadipir was originally implemented under the National Rural Drinking Water Programme (NRDWP) and subsequently upgraded through the Jal Jeevan Mission (JJM) framework.

(a) Source and Abstraction

- **Primary Source:** Borewell of 90 m depth located near the village periphery; static water level fluctuates between **18–25 m below ground level (bgl)** seasonally.
- **Secondary Source:** An open well adjacent to the borewell, used intermittently during monsoon recharge periods.
- **Pump Type:** 5 HP submersible pump (3-phase electric), with an average discharge of **12–14 m^3/hr**.

(b) Storage and Distribution

- **Storage Infrastructure:**
  - **ESR-1:** 25,000 L (Old structure near Gram Panchayat office)
  - **ESR-2:** 45,000 L (Central zone, serves upper elevation)
  - **ESR-3:** 90,000 L (Main ESR feeding majority households)
- **Distribution Network:** HDPE pipelines (63–110 mm dia) supplying 210 domestic connections and 14 standposts. Average **network length ≈ 3.2 km**.
- **Water Treatment:** Manual chlorination using bleaching powder; no automated disinfection system.

(c) Performance Analysis

Based on field measurements and Gram Panchayat records (2023–24), the following parameters were analysed:

Table No.2 Performance Analysis of Selected Villages

Parameter	Observed Value	Design Norm / Benchmark	Remarks
Population (2024 est.)	2,480 persons	—	—
Average daily supply	65–70 LPCD	70 LPCD (JJM standard)	Adequate during monsoon; reduced in summer
Supply duration	1.5–2 hrs/day	2 hrs/day	Limited by pump downtime
Unaccounted-for water (losses)	14–18%	≤10%	Due to leaks and overflows

Power supply availability	8–10 hrs/day (variable)	Continuous preferred	Frequent voltage drop, outages
Service reliability index	0.68	≥0.80 desirable	Intermittent supply, downtime during repairs
Residual chlorine	0.1–0.3 mg/L	0.2–0.5 mg/L	Occasionally below safe range

Interpretation:
While the system meets near-normative per capita supply, its operational reliability is below desirable standards. Losses, voltage fluctuations, and manual chlorination contribute to inconsistent service delivery. The infrastructure has moderate capacity but lacks redundancy and automation.

4.3. Problem Identification

The technical and operational audit of Wadipir's system revealed the following critical challenges:

1. **Seasonal Scarcity:** Groundwater yield declines by up to **35–40% during April–June**, forcing dependence on water tankers during extreme summer. Lack of artificial recharge structures exacerbates this issue.
2. **Energy and Power Supply Issues:** Frequent **low voltage and power outages** disrupt pumping operations. Absence of alternative energy (solar) backup results in inconsistent daily supply.
3. **System Breakdown and Maintenance Deficiency:** Motor burnout and electrical faults are frequent due to voltage fluctuations. Preventive maintenance is minimal, and spare parts availability is limited.
4. **Water Quality Concerns:** Manual chlorination leads to **inconsistent residual chlorine levels**. The open well source is also prone to bacteriological contamination post-monsoon.
5. **Distribution Inefficiencies:** Hydraulic head loss in old HDPE pipelines and minor leakage at joints contribute to **pressure imbalance and water loss**.
6. **Institutional Gaps:** The Gram Panchayat lacks trained personnel for system monitoring, and record-keeping is largely manual without flow or pressure data logging.

4.4. Community Perception and Socio-Economic Aspects

To understand user satisfaction and acceptance of potential non-conventional interventions, a structured survey was conducted among 60 randomly selected households across different parts of Wadipir village. Semi-structured interviews were also held with the Sarpanch, pump operator, and local women's self-help groups (SHGs).

(a) Key Findings from Household Survey

Aspect	Findings
Satisfaction with current service	62% partially satisfied, 25% dissatisfied due to irregular timings
Perception of water quality	71% perceive taste/odor changes post-monsoon; only 35% aware of chlorination
Willingness to pay for improved supply	80% willing to contribute if system reliability improves
Awareness of water conservation / recharge	42% aware; mainly youth and educated households
Interest in solar-powered or rainwater-based systems	88% supportive; highlight reduced dependency on electricity
Community participation readiness	76% expressed interest in user committees or participatory maintenance

(b) Socio-Economic Context

- Primary occupation: **Agriculture and small-scale dairy farming.**
- Average monthly household income: **₹12,000–₹18,000.**
- Energy expenditure: **High due to irrigation pumping, influencing awareness of renewable energy benefits.**
- Gender dimension: **Women primarily manage domestic water collection and expressed strong preference for consistent tap-based service.**

(c) Summary of Perception

The community is **aware of water scarcity and energy constraints** and shows **high willingness to adopt non-conventional approaches**, especially solar pumping and rooftop rainwater harvesting. However, **technical awareness and capacity-building** are essential to ensure long-term adoption and sustainability.

5. Proposed Design Using Non-Conventional Methods

The proposed design focuses on developing a sustainable and self-reliant **rural water supply system** for Wadipir village, located in Karveer Taluka of Kolhapur District. The aim is to integrate **non-conventional methods**—including rainwater harvesting, solar-powered pumping, low-cost filtration, and decentralized storage—to create a resilient system that minimizes dependence on groundwater and external energy sources. The design process follows a comprehensive methodology that takes into account site-specific parameters such as population growth, topography, water demand, and environmental conditions, ensuring that the solution is both technically feasible and socially acceptable.

5.1. Design Approach and Methodology

The design methodology begins with an assessment of **population and water demand forecasting**. Based on Census 2011 data, Wadipir currently has a population of approximately 2,500. Assuming an annual growth rate of 2.5%, the projected population for the 20-year design horizon (2025–2045) is estimated to reach around 3,300. According to BIS standard IS 1172:1993, the recommended per capita water demand for rural communities is 70 liters per capita per day (LPCD). Hence, the total daily water requirement for the village is approximately 231,000 liters (231 m^3). The design ensures adherence to BIS IS 10500:2012 standards for potable water quality, maintaining permissible limits for pH, TDS, hardness, and microbial safety.

Wadipir's terrain is characterized by mild undulations with an elevation difference of 15–20 meters, making it suitable for a **gravity-based distribution system** supported by solar-powered pumping. The region receives an annual rainfall of approximately 1,900 mm and enjoys an average solar insolation of 5–5.5 kWh/m^2/day, both favorable for integrating renewable water supply technologies. Given the limited reliability of groundwater and high energy costs associated with conventional pumping, the design emphasizes non-conventional components such as **rainwater harvesting systems**, **solar lift irrigation**, and **decentralized treatment units**. The selection of these technologies is guided by factors like local resource availability, operational simplicity, community acceptance, and cost-effectiveness.

5.2. Design Components

The proposed system is an integrated framework combining source augmentation, treatment, storage, and distribution with renewable energy integration. The first component, source augmentation, utilizes both rainwater harvesting (RWH) and a solar-powered pumping system. Public buildings such as the village school, gram panchayat office, and health center provide a combined rooftop area of about 1,000 m^2. With a runoff coefficient of 0.85, the total rainwater yield can be estimated using the formula $Q = \text{Rainfall} \times \text{Area} \times C = 1.9 \times 1000 \times 0.85 = 1{,}615\ m^3/\text{year}$. This volume, equivalent to 4.4 m^3/day on average, is stored in two ferrocement tanks of 50,000 liters each, ensuring a reliable supplementary water source during the dry season. Additionally, a 3 HP submersible solar pump powered by a 2 kW solar photovoltaic (PV) system will extract groundwater from a 50-meter-deep borewell and deliver approximately 40 m^3/day to the Overhead Tank (OHT), ensuring a consistent supply during non-rainy months.

The water treatment system comprises a two-stage low-cost filtration unit. The first stage uses natural sedimentation and gravel filtration for turbidity reduction, while the second stage employs bio-sand or ceramic filtration enhanced with activated carbon for organic and microbial contaminant removal. This treatment module is decentralized and positioned adjacent to the OHT to minimize head loss and energy consumption.

For storage and distribution, the design proposes a 75,000-liter elevated ferrocement OHT positioned at 10 meters height to provide sufficient hydraulic head, along with a 25,000-liter ground storage tank for balancing and treated water collection. The distribution network follows a radial-cum-grid layout to ensure equitable water pressure across all supply zones, constructed using HDPE pipes (PN 6 class) due to their corrosion resistance and long life. The system operates primarily on gravity flow, controlled through float valves and manual sluice gates.

Energy requirements for pumping and system operation are fully met by the solar PV array, which operates efficiently under local insolation conditions. The system is designed as a battery-less configuration to reduce maintenance and lifecycle costs, relying on direct solar energy during daylight hours and limited manual pumping backup in case of cloudy weather. Over a 20-year life cycle, the PV system offers a payback period of around five years, making it an economically sound investment compared to diesel-powered alternatives.

5.3. Feasibility Analysis

A comprehensive feasibility analysis was conducted to assess the technical, economic, and environmental sustainability of the proposed design. Technically, all selected components—solar pumps, ferrocement tanks, HDPE pipelines, and low-cost filters—are proven technologies with demonstrated performance in rural Indian contexts. The hydraulic calculations confirm adequate head for gravity-based distribution up to the farthest node, ensuring pressure stability and minimal leakage losses. The design is modular, allowing for future expansion with minimal structural modification.

From an economic standpoint, the estimated initial capital cost of the system is approximately ₹9–10 lakhs, which includes the solar pumping unit, storage structures, filtration units, and distribution network. Annual operation and maintenance (O&M) costs are estimated at ₹20,000–25,000, primarily covering periodic filter cleaning and minor repairs. The elimination of electricity and diesel costs results in annual savings of around ₹30,000–35,000, yielding a payback period of five years. Over a 20-year design life, the project maintains a positive net present value (NPV), affirming its long-term financial viability.

Environmentally, the system demonstrates strong sustainability credentials. Solar energy integration eliminates greenhouse gas emissions and dependence on fossil fuels, while rainwater harvesting and artificial recharge help conserve groundwater levels. The use of ferrocement and HDPE materials further reduces the embodied energy of construction. The system encourages community participation through local operation and maintenance training, enhancing ownership and long-term functionality.

In terms of maintenance and life-cycle performance, the system requires minimal technical intervention. Preventive maintenance schedules include biweekly filter cleaning, semi-annual tank desilting, and quarterly solar PV inspection. With proper upkeep, the service life of major components extends to 20–25 years, with mid-life replacements limited to filter media and pump parts.

6. RESEARCH GAP

Access to safe and sustainable drinking water remains a critical challenge in rural India despite several decades of infrastructure development and government intervention. Although conventional water supply systems—such as borewells, handpumps, and piped distribution networks—have improved coverage, **their long-term sustainability is under strain** due to groundwater depletion, erratic power supply, poor maintenance, and lack of community participation. The **current models of rural water supply remain heavily dependent on centralized designs** and grid-based energy, which are not always feasible or sustainable in remote and resource-constrained regions. In this context, **non-conventional methods**—such as rainwater harvesting, solar-powered pumping, decentralized treatment, and groundwater recharge systems—offer promising alternatives. However, their systematic evaluation, contextual adaptation, and technical integration within local rural frameworks are still underexplored.

Existing literature and practical implementations show that **non-conventional technologies have been successfully applied in various regions across the world**, such as solar water supply systems in Kenya and Tanzania, community-based rainwater harvesting in Bangladesh, and low-cost filtration technologies in Vietnam and India. Yet, these case studies often remain **region-specific and lack transferability assessments** for different hydro-geological and socio-economic contexts like those found in Kolhapur district. There is limited research addressing **how such systems can be scaled or modified** to fit India's unique climatic variability, monsoon dependence, and decentralized governance structure under schemes like the *Jal Jeevan Mission (JJM)* or *National Rural Drinking Water Programme (NRDWP)*.

A major gap also exists in the **systematic analysis of existing rural water supply schemes at the micro-regional level**, particularly in districts like **Kolhapur**, which experiences both high monsoon rainfall and seasonal water scarcity. While government reports and technical documents provide descriptive data on water schemes, there is inadequate **comparative evaluation of performance indicators** such as reliability, operational efficiency, water quality, and user satisfaction. Few studies have examined why certain schemes succeed—often due to community participation or renewable energy use—while others fail due to poor maintenance, energy dependency, or inadequate local capacity. This lack of granular assessment limits the ability to identify design and policy improvements that are technically and economically sustainable.

Moreover, while research has advanced in urban and peri-urban contexts, **rural-specific design optimization frameworks** integrating non-conventional technologies are scarce. The existing engineering approaches often treat non-conventional methods as supplementary, rather than designing **hybrid systems** that combine rainwater harvesting, solar pumping, and decentralized treatment as primary water supply solutions. The **integration of modern tools** such as IoT-based monitoring, GIS mapping, and hydraulic modeling for rural-scale design is also minimal in current literature. This creates a technological and methodological gap in developing adaptive, data-driven, and locally managed systems.

Additionally, most studies focus on technical feasibility without adequately considering **social and economic factors**, such as local governance capacity, willingness to adopt new systems, and the affordability of operation and maintenance. Without this holistic understanding, non-conventional systems risk being underutilized or abandoned over time, as seen in several pilot projects across India.

Therefore, the present study addresses these gaps by conducting a **multi-dimensional investigation** that includes:

1. Reviewing and comparing non-conventional water supply technologies and their global applications.
2. Assessing and analyzing existing water supply schemes across selected villages in Kolhapur district to identify patterns of success and failure.
3. Selecting a representative village (Wadipir) for in-depth system analysis, identifying operational and design deficiencies, and evaluating community perspectives.
4. Developing a **technically robust, economically feasible, and environmentally sustainable design** that employs non-conventional methods tailored to the village's local conditions.

This research thus fills the gap between **conceptual knowledge and practical implementation**, providing a **replicable design framework** for rural areas that integrates renewable energy, decentralized treatment, and local participation. The outcomes are expected to contribute to the **sustainable transformation of rural water supply systems**, aligning with national goals under *Jal Jeevan Mission* while addressing the long-term challenges of water scarcity, energy dependency, and environmental degradation.

7. Conclusion

This study on the Design of Drinking Water Supply System for Rural Areas by Applying Non-Conventional Methods highlights the urgent need to transition from conventional, energy-intensive water systems toward more sustainable, decentralized, and renewable-based solutions. The research systematically examined various non-conventional approaches—such as rainwater harvesting, solar-powered pumping, low-cost filtration systems, and artificial recharge techniques—and evaluated their applicability for rural settlements, with a particular focus on Kolhapur district. Through literature review, case study analysis, and field-level assessment, the study identified critical gaps in the reliability, maintenance, and sustainability of existing rural water supply infrastructure.

The findings reveal that while government initiatives like Jal Jeevan Mission (JJM) and National Rural Drinking Water Programme (NRDWP) have expanded water access in rural India, many schemes struggle with long-term sustainability due to overdependence on groundwater, intermittent electricity, and high maintenance costs. The integration of non-conventional technologies offers a viable solution to these challenges. Specifically, solar-powered pumps can eliminate dependence on grid electricity, rainwater harvesting systems can supplement water sources during dry seasons, and decentralized filtration units can ensure potable quality with minimal energy input. Collectively, these methods contribute to resilient and self-sufficient water systems that align with sustainable development principles.

The Kolhapur case study, particularly the analysis of Wadipir village, underscores the effectiveness of a hybrid design model that combines renewable energy, local water resource utilization, and community participation. Wadipir's geographical setting—with moderate rainfall, fluctuating groundwater levels, and limited infrastructure—makes it an ideal site for implementing non-conventional techniques. The proposed system design, featuring solar pumping, rainwater harvesting, and ferrocement-based storage, demonstrates not only technical and economic feasibility but also environmental and social sustainability. The approach emphasizes low-cost materials, minimal maintenance, and participatory management, ensuring that local communities can operate and sustain the system without external dependency.

The research concludes that adopting non-conventional methods is not merely an alternative but a necessity for ensuring long-term water security in rural regions. The study's findings can serve as a replicable framework for similar rural settlements across India, particularly those in semi-arid and hilly areas facing seasonal scarcity and energy constraints. The integration of renewable energy and localized water management offers a scalable solution that can reduce the carbon footprint of rural water infrastructure while improving service reliability and quality of life.

For future research, it is recommended to expand the scope through pilot-scale implementations and real-time monitoring of such hybrid systems across multiple villages. Further studies should explore the integration of IoT-based water management, smart metering, and GIS-based source mapping to enhance operational efficiency and data-driven decision-making. Additionally, socio-economic assessments of community willingness, cost-sharing mechanisms, and governance models will be crucial to ensure long-term viability.

In conclusion, the study reaffirms that non-conventional, renewable-driven water supply systems represent a sustainable pathway for achieving universal and equitable access to safe drinking water in rural India. The Kolhapur case illustrates how context-specific design, technological innovation, and community empowerment can converge to create a resilient and sustainable rural water management model capable of guiding future rural infrastructure development.

REFERENCES

[1]. Bureau of Indian Standards (BIS), *IS 1172:1993 – Code of Basic Requirements for Water Supply, Drainage and Sanitation.* New Delhi: BIS.

[2]. Bureau of Indian Standards (BIS), *IS 10500:2012 – Drinking Water Specification (Reaffirmed 2017).* New Delhi: BIS.

[3]. Bureau of Indian Standards (BIS), *IS 2373:1981 – Specification for Centrifugal Pumps for Clear, Cold Fresh Water.* New Delhi: BIS.

[4]. Bureau of Indian Standards (BIS), *IS 15388:2003 – Design and Construction of Tube Wells – Code of Practice.* New Delhi: BIS.

[5]. Central Ground Water Board (CGWB), *Groundwater Year Book – Maharashtra Region (Latest Edition).* Ministry of Jal Shakti, Government of India.

[6]. Central Ground Water Board (CGWB), *Manual on Artificial Recharge of Ground Water*. New Delhi: Ministry of Water Resources, 2007.

[7]. Central Public Health and Environmental Engineering Organisation (CPHEEO), *Manual on Water Supply and Treatment*, 3rd Edition (Reprint 2019). Ministry of Housing and Urban Affairs, New Delhi.

[8]. Central Public Health and Environmental Engineering Organisation (CPHEEO), *Manual on Sewerage and Sewage Treatment*, 2013. Ministry of Housing and Urban Affairs, New Delhi.

[9]. Central Water Commission (CWC), *Guidelines for Water Balance Studies*, 2015. Government of India, New Delhi.

[10]. Central Water Commission (CWC), *National Water Policy*, 2012. Ministry of Water Resources, River Development and Ganga Rejuvenation.

[11]. Groundwater Surveys and Development Agency (GSDA), Maharashtra, *District Groundwater Information Reports.* Government of Maharashtra.

[12]. Groundwater Surveys and Development Agency (GSDA), Maharashtra, *Hydrogeological Atlas – Kolhapur District.* Government of Maharashtra.

[13]. Government of India – Jal Jeevan Mission (JJM), *Operational Guidelines*, 2021. Ministry of Jal Shakti, Department of Drinking Water and Sanitation.

[14]. Government of India – Jal Jeevan Mission (JJM), *Rural Water Supply Technical Manual*, 2020. Ministry of Jal Shakti.

[15]. Indian Meteorological Department (IMD), *Rainfall Data Series (30-Year Normal for Kolhapur District).* Pune: IMD.

[16]. India Water Resources Information System (WRIS), *Hydrological & Basin-wise Data Portal.* Available at: https://indiawris.gov.in

[17]. Kolhapur Zilla Parishad (ZP) – Rural Water Supply Division, *Annual Status Report on Rural Drinking Water Schemes*, 2023–24.

[18]. Ministry of Jal Shakti, *Atal Bhujal Yojana – Implementation Guidelines.* Government of India.

[19]. Ministry of Jal Shakti, *National Rural Drinking Water Program (NRDWP) Framework for Implementation.* Government of India.

[20]. National Institute of Hydrology (NIH), Roorkee, *Technical Reports on Groundwater Modelling and Recharge.* Ministry of Jal Shakti, Government of India.

[21]. National Water Development Agency (NWDA), *Reports on Basin-level Water Resources Planning.* Ministry of Jal Shakti, Government of India.

[22]. Planning Commission / NITI Aayog, *Composite Water Management Index*, 2018 and 2022 Updates. Government of India, New Delhi.

[23]. Rural Water Supply and Sanitation Department (RWSSD), Maharashtra, *Scheme Design Guidelines*, 2021. Government of Maharashtra.

[24]. Rural Water Supply and Sanitation Department (RWSSD), Maharashtra, *Standard Schedule of Rates (SSR) – Water Supply Works, Kolhapur Region.*

[25]. United Nations Development Program (UNDP), *Sustainable Development Goal 6: Clean Water and Sanitation Reports.* United Nations, New York.

[26]. World Bank / Asian Development Bank (ADB), *Guidelines for Sustainable Rural Water Supply and Sanitation Projects.* Washington, D.C.

[27]. World Bank / Asian Development Bank (ADB), *Community-Based Water Management Frameworks.* Washington, D.C.

[28]. Water and Sanitation Program (WSP) – World Bank Group, *Handbook for Community Water Supply Management.* World Bank, Washington, D.C.

[29]. Water Resources Department (WRD), Maharashtra, *Water Conservation and Artificial Recharge Guidelines.* Government of Maharashtra.

[30]. Water Resources Department (WRD), Maharashtra, *Minor Irrigation Census Reports (Latest Edition).*

[31]. Murad, A. A., "An Overview of Conventional and Non-Conventional Water Resources in the Region: Assessment and Constraints of the United Arab Emirates (UAE)," Department of Geology, UAE University, Al Ain, United Arab Emirates, Jan. 5, 2010.

[32]. Jain, A., and Agarwal, R., "Department of Drinking Water Supply, Ministry of Rural Development," Government of India, 2012, pp. 7–14.

[33]. Indurwade, S. H., "Sustainable National Rural Drinking Water Program in Maharashtra," 2013. Available at: http://irrigation.maharashtra.gov.in

[34]. Abdelghaffer, E., "Non-Conventional Water Resources Management," *Tenth International Water Technology Conference (IWTC10)*, Alexandria, Egypt, 2006.

[35]. IEC Guidelines for Rural Drinking Water, *National Rural Drinking Water Program*, Government of Maharashtra.

[36]. Jaber, J. O., and Mohsen, M. S., "Evaluation of Non-Conventional Water Resources Supply in Jordan," Department of Mechanical Engineering, Hashemite University, July 17, 2000.

[37]. Jain, P., "Guidelines of National Rural Drinking Water Program – National Policy Framework," Ministry of Drinking Water and Sanitation, Government of India, 2013. Available at: www.mdws.nic.in

[38]. Prasad, P., Mishra, V., and Sohoni, M., "Sector Reform Impact on Rural Drinking Water Schemes – A Case Study from Raigad District in Maharashtra," Indian Institute of Technology, Bombay, pp. 2–10.

[39]. T.M.S. Elhag and A.H. Boussabaine, "Evaluation Of Construction Cost & Time Attributes", *Association of Researchers in Construction Management*, Vol. 2, Pp. No- 473-80, 1999.