Solar Photocatalytic Disinfection of Well Water Using Immobilised TiO_2: A Comparative Field Study with Solar Water Disinfection in Antananarivo, Madagascar

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Abstract

Access to safe drinking water remains a major challenge in rural areas of developing countries. This study investigates the feasibility of a simple low-cost solar photocatalytic reactor coated with a commercial titanium dioxide (TiO_2) pigment for the disinfection of well water contaminated with faecal coliforms. A (TiO_2) film was deposited on a glass plate using a straightforward acetone slurry method and exposed to natural sunlight in Antananarivo, Madagascar. The efficiency was compared with the conventional solar water disinfection (SODIS) method (solar disinfection without catalyst). Water samples from 10 different wells were characterised for physicochemical and bacteriological quality. After 10 min of solar exposure, the photocatalytic reactor reduced presumptive faecal coliform counts below the method detection limit (< 1 CFU/100 mL) in all 10 samples tested, whereas the SODIS control reduced the initial count by approximately 51% in a representative sample. While disinfection kinetics varied slightly with water turbidity and pH, inactivation below the detection limit was consistently achieved. Analysis of Pearson's correlation showed no statistically significant linear correlation between the

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inactivation rate constant and any measured water-quality parameter (all $p > 0.4$). The results demonstrate that even a non-uniform low-purity (TiO_2) coating significantly accelerates bacterial inactivation under solar radiation, offering a promising and affordable household-scale treatment technology for low-resource settings. However, longer-term validation, catalyst stability, dark-control assessment, and leaching studies are still required before widespread implementation can be recommended.

Keywords: titanium dioxide; solar photocatalysis; well water; water disinfection; faecal coliforms; immobilised (TiO_2) film

1 Introduction

In many rural regions of Madagascar, groundwater from shallow wells is the primary source of drinking water. However, these sources are frequently contaminated by faecal coliforms due to inadequate sanitation infrastructure and surface runoff [1]. Conventional disinfection methods such as chlorination or boiling are often inaccessible, unsustainable or culturally impractical for daily household use. Solar water disinfection (SODIS) – exposure of water in transparent bottles to sunlight – is a simple, low-cost technique that uses UV-A radiation and thermal effects to inactivate pathogens. Nevertheless, its efficiency is highly dependent on weather conditions and typically requires prolonged exposure (6–48 h depending on cloud cover) [2].

Heterogeneous photocatalysis using titanium dioxide (TiO_2) offers an attractive alternative to accelerate this process. When illuminated with UV light ($\lambda < 400$ nm), TiO_2 generates reactive oxygen species (ROS), mainly hydroxyl radicals (•OH), which are capable of non-selectively oxidising and destroying a wide range of microorganisms [3], [4]. TiO_2 is non-toxic, chemically stable, and can be immobilised on solid supports to facilitate reuse without the need for nanoparticle recovery. Several studies have indicated that TiO_2 photocatalysis can drastically reduce the time required for bacterial inactivation compared to SODIS alone [5], [6].

Although much research focuses on highly optimised anatase nanoparticles, there is a gap in translating this to real-world low-resource fabrication. The present work aims to design a simple solar photocatalytic reactor using commercial-grade TiO_2 pigment (widely available and cheaper than high-purity anatase) coated on a glass plate via a rudimentary deposition method. The objective is to evaluate its efficiency for the disinfection of well water that is naturally contaminated with faecal coliforms. A direct comparison with the classical SODIS method is performed under identical field conditions. Ten different wells were sampled to assess the variability in local water quality and its influence on disinfection kinetics.

The specific novelty of this study lies in the following:

- the use of a commercial rutile TiO_2 pigment (Tionox R-937; $TiO_2 \geq 94\%$, rutile $\geq 98\%$) rather than high-purity laboratory-grade anatase;
- a minimal-skill deposition method that requires no specialised equipment;
- field validation using 10 well-water samples that are naturally contaminated rather than synthetic laboratory water; and
- a direct side-by-side comparison with SODIS under identical solar conditions in Antananarivo.

2 Materials and Methods

2.1 Sampling and Water Quality Analysis

Water samples were collected from 10 different wells in the Antananarivo region (samples S1–S10). All wells were selected based on a history of faecal contamination and proximity to potential pollution sources (latrines, runoff). Samples were taken in 0.5 L polyethylene bottles pre-rinsed with the source water, transported in a cool box at 4 °C, and analysed within 24 h. On-site measurements included pH (pH meter) and electrical conductivity (conductivity meter). In the laboratory, turbidity was measured with a turbidimeter calibrated with 20–400 NTU standards. Chemical parameters (nitrates, nitrites, ammonium, calcium, magnesium, chlorides, sulphates, etc) were determined using a photometer (Photometer 7100) following the manufacturer's protocols.

2.2 Bacteriological Analysis

Presumptive faecal coliforms and total coliforms were quantified by the membrane filtration method using a Wagtech portable field kit. A volume of 100 mL of each sample was filtered through a sterile 0.45 µm membrane. The membrane was placed on a sterile absorbent pad saturated with selective culture medium (m-FC agar for faecal coliforms, incubated at 44 °C; m-Endo agar for total coliforms, incubated at 37 °C) for 18–24 h. Yellow colonies were counted and results expressed as colony forming units per 100 mL (CFU/100 mL). The detection limit for a 100 mL sample was 1 CFU/100 mL; therefore, "0 CFU/100 mL" indicates that no viable colonies were detected and that the concentration was below the method detection limit. Confirmatory tests (for example, oxidase, Gram stain, or EC broth) were not performed owing to field-kit limitations; the reported values are therefore presumptive faecal coliforms counts.

2.3 Preparation of TiO_2 Thin Film

A commercial TiO_2 pigment (Tionox R-937; rutile structure; TiO_2 content $\geq 94\%$; rutile content $\geq 98\%$; surface treated with Al_2O_3, SiO_2, and organic treatment) was selected for this study owing to its local availability and significantly lower cost compared to high-purity anatase nanopowders. According to the manufacturer's technical data sheet,

the pigment has a pH of 6.5–7.5, oil absorption of 19–22 g/100 g, and volatile content ≤ 0.5% at 105 °C. We mixed 10 g of TiO_2 with 250 mL of acetone to obtain a 40 g/L suspension. Glass plates (33.4 cm × 25.5 cm) were cleaned with soapy water and rinsed with hydrochloric acid. The suspension was poured onto the glass plate held at an 80° inclination, allowing the solvent to evaporate and the TiO_2 to deposit (Figure 1). The coated plates were dried in sunlight for one day, then rinsed with water to remove weakly adhered particles. The resulting coating was visibly non-uniform. The nominal TiO_2 loading, estimated from the suspension volume and plate area assuming 10–20% deposition efficiency, was approximately 0.5–1.0 mg cm^{-2}; because the coating was non-uniform and the loading was not gravimetrically measured, this value is indicative only. This method was chosen to evaluate the feasibility of a "minimal-skill" fabrication process suitable for local implementation. No XRD, SEM, particle-size or surface-area measurements were performed in this field study; this is acknowledged as a limitation.

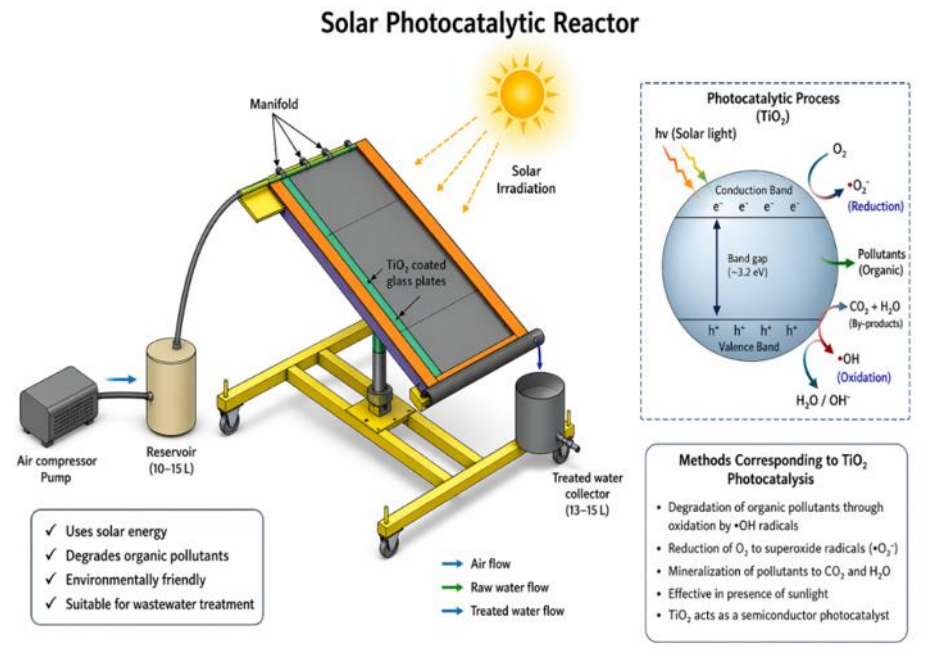


Figure 1: Schematic representation of a solar photocatalytic reactor for water treatment using TiO_2. The system utilises solar irradiation to activate the semiconductor catalyst, generating electron-hole pairs that produce reactive species (•OH, $•O_2^-$) responsible for bacterial inactivation

2.4 Solar Photocatalytic Experiments

Two identical reactors were used: one with a TiO_2-coated glass plate (photocatalytic reactor) and one with an uncoated glass plate (SODIS control). The reactors consisted of a simple metal tray (34 cm × 27 cm × 3 cm) with the glass plate placed at the bottom,

providing a thin water layer of approximately 1 cm depth. For each test, 1 L of well water was poured into the reactor and exposed to direct sunlight (Figure 1). Samples were taken at 0, 5 and 10 min of exposure. No dark control (either TiO_2-coated plate in the dark or untreated water in the dark) was performed in this study. The SODIS control (uncoated glass plate under sunlight) served as the primary comparator to distinguish photocatalysis from direct solar disinfection. The absence of a dark control is acknowledged as a limitation and recommended for future work.

The experiments were performed on a clear day with ambient temperature ranging from 22–25 °C. Although direct UV irradiance was not measured on site owing to equipment limitations, experiments were conducted between 11:00 and 13:00 local time. Based on satellite-derived climatological data for Antananarivo (approx. 18.9°S), the estimated ambient UV-air radiance during the experiment was approximately 40–50 W/m^2, with an estimated uncertainty of ± 15–20%. UV-A (315–400 nm) represents approximately 3–4% of total solar irradiance. The primary metric for this study is the relative comparison between the TiO_2 reactor and the SODIS control under identical instantaneous field conditions. Water temperature during irradiation was not measured directly; this is acknowledged as a limitation.

All analyses were performed in duplicate (technical replicates); results are presented as mean values. Statistical comparisons between treatments were performed using Student's *t*-test ($p < 0.05$ considered significant). For the 10 samples, the apparent first-order inactivation rate constant (k) was estimated by fitting the data to $\ln\left(\frac{N0}{N}\right) = kt$ at the 5 min time point. For samples that reached complete inactivation at 5 min ($N_5 = 0$), an exact rate constant cannot be calculated; these are reported as $k > 1.0$ min^{-1}. Pearson's correlation coefficients between k and the physicochemical parameters were calculated for the seven non-censored wells (S2, S4, S5, S6, S8, S9, S10) using standard two-tailed tests with $df = 5$.

3 Results

3.1 Physicochemical Characteristics of the 10 Wells

The physicochemical parameters of the 10 samples are presented in Table 1. The water was slightly acidic (pH = 5.1–6.6), with turbidity exceeding the WHO guideline (< 5 NTU) in a several wells (S7, S5, S3, S2). Conductivity was generally below 300 µS/cm, although S9 and S10 showed low values (9.8 and 9.6 µS/cm). These values were verified against the original field measurements. Ammonium was elevated in sample S4 (1.89 mg/L versus guideline < 0.5 mg/L). These values represent the initial quality before treatment.

Table 1: Physicochemical characteristics of the 10 well water samples (S1–S10)

Parameter	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Temperature (°C)	20.3	21.3	21.3	22.5	21.3	22.0	22.1	22.0	22.3	22.5
Turbidity (NTU)	3.8	6.7	7.2	1.8	9.3	0.7	10.3	3.3	0.7	0.7
pH	5.2	5.3	6.6	6.2	5.1	5.2	5.4	5.8	5.1	5.1
Conductivity (µS/cm)	49	208	139	289	99	129	112	218	9.8	9.6
Nitrates (mg/L)	1.1	3.4	0.9	1.9	1.6	2.1	0.9	1.0	0.4	0.35
Ammonium (mg/L)	0.01	0.7	0.03	2.0	0.02	0.02	0.12	0.1	0.02	0.02
Chlorides (mg/L)	8.5	32	7.8	37	20	7.1	26.27	42	2.8	0.8

3.2 Initial Bacteriological Contamination

Initial presumptive faecal coliform and total coliform counts for the 10 wells are presented in Table 2. All wells were contaminated with faecal coliforms ranging from 18 to 239 CFU/100 mL and total coliforms from 6 to 239 CFU/100 mL.

Table 2: Initial bacteriological contamination (CFU/100 mL)

Parameter	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Faecal coliforms	32	239	32	131	78	182	18	50	215	148
Total coliforms	25	150	6	212	21	93	13	20	152	123

It is important to note that the presumptive faecal coliform counts and total coliform counts were determined using two different selective media (m-FC agar at 44 °C and m-Endo agar at 37 °C, respectively), each with different selectivity and recovery efficiency. The two methods are therefore not strictly nested: some thermotolerant strains that grow on m-FC agar may not grow on m-Endo agar, and vice versa. In sample S2, the presumptive faecal coliform count (239 CFU/100 mL) exceeded the total coliform count (150 CFU/100 mL). This apparent anomaly is a known limitation of field-based membrane filtration methods using different selective media, particularly when confirmatory tests (oxidase, Gram stain or EC broth) are not performed. It does not affect the primary conclusion of this study, which is based on the relative comparison of the same medium (m-FC) before and after photocatalytic treatment. Similar discrepancies have been reported in field studies in low-resource settings [7], [8].

3.3 Disinfection Under TiO_2 Photocatalysis

After 5 min of solar exposure, faecal coliform counts decreased substantially (Table 3). Some wells showed complete inactivation (S1, S3, S7). After 10 min, all samples

reached below the detection limit (< 1 CFU/100 mL; reported as 0 CFU/100 mL in Table 4). Figure 2 shows the individual disinfection curves for all 10 wells. For samples that reached the detection limit, values were plotted at 1 CFU/100 mL with downward arrows to indicate “below detection limit”.

Catalyst leaching during the experiments was not quantitively evaluated in this study. This is acknowledged as a limitation and is recommended for future work.

Table 3: Faecal coliform counts (CFU/100 mL) after 5 min of solar exposure with TiO_2 photocatalysis

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
CFU/100 mL	0	102	0	30	7	41	0	3	62	36

Table 4: Faecal coliform counts (CFU/100 mL) after 10 min of solar exposure with TiO_2 photocatalysis

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
CFU/100 mL	0	0	0	0	0	0	0	0	0	0

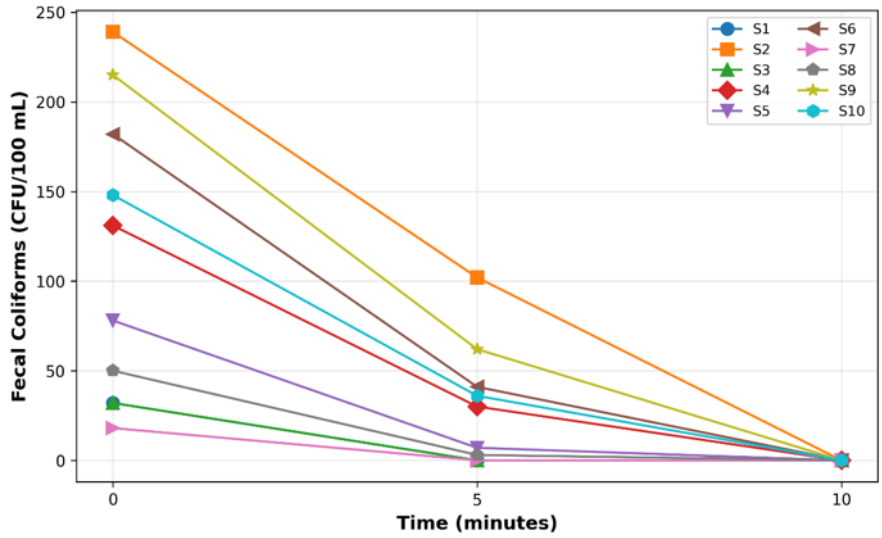


Figure 2: Disinfection kinetics of faecal coliforms for the 10 wells treated with the TiO_2 photocatalytic reactor. All samples reached below the detection limit (< 1 CFU/100 mL) within 10 min of solar exposure. Values below the detection limit are plotted at 1 CFU/100 mL with downward arrows

3.4 Apparent First-Order Rate Constants

The apparent first-order inactivation rate constants calculated at 5 min are presented in Table 5. Wells S1, S3, and S7 achieved complete inactivation within 5 min, indicating very rapid kinetics ($k > 1.0$ min^{-1}). The remaining wells showed k values ranging from 0.170 to 0.563 min^{-1}.

Table 5: Apparent first-order rate constants for faecal coliform inactivation at 5 min

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
k (min^{-1})	> 1.0*	0.17	> 1.0*	0.295	0.482	0.298	> 1.0*	0.56	0.248	0.283

*Complete inactivation at 5 min ($N_5 = 0$); exact rate constant cannot be calculated.

3.5 Comparison with SODIS (Sample S10)

To directly compare the photocatalytic reactor with the SODIS method, sample S10 (initial 148 CFU/100 mL) was exposed in both reactors simultaneously. Figure 3 shows the results. After 5 min, the photocatalytic reactor reduced the count to 38 CFU/100 mL (74% reduction), while SODIS only reduced it to 89 CFU/100 mL (40% reduction). After 10 min, photocatalysis achieved complete inactivation below the detection limit, whereas SODIS only reached 73 CFU/100 mL (51% reduction). The difference at 10 min was statistically significant ($p < 0.01$, Student's t-test). Duplicate measurements agreed within 10%. This confirms that the presence of the immobilised TiO_2 film is responsible for the accelerated kinetics. The SODIS comparison was limited to sample S10 because only one sample could be tested simultaneously under identical solar conditions during the available field window; S10 was selected as representative of mid-range contamination. A full SODIS exposure over the recommended 6–8 h was not performed; this is acknowledged as a limitation.

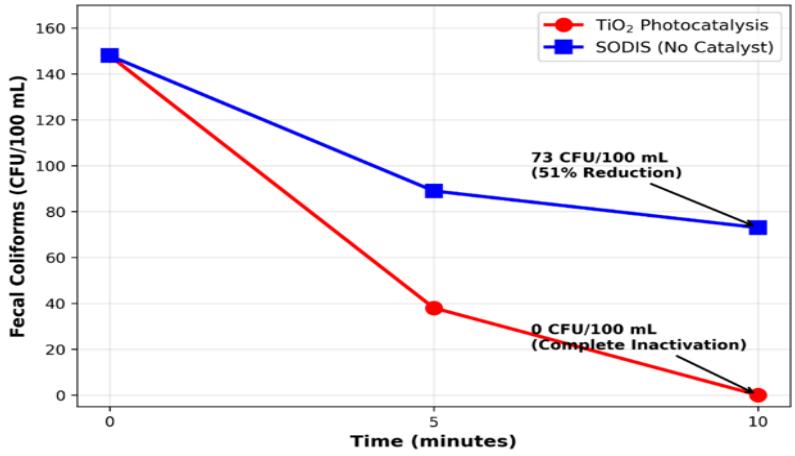


Figure 3: Comparison of faecal coliform inactivation between the photocatalytic reactor (TiO_2) and the SODIS control (no catalyst) for sample S10. Inactivation below the detection limit was achieved only in the presence of TiO_2. Values are means of duplicate measurements; duplicate agreement was within 10%

3.6 Correlation with Water Quality Parameters

Figure 4 shows the relationship between the apparent first-order rate constant k (at 5 min) and key physicochemical parameters for the 10 wells. Wells S1, S3 and S7 (inactivation below the detection limit at 5 min; $k > 1.0$ min^{-1}) are plotted as censored values and were excluded from the quantitative correlation analysis. Pearson's correlation coefficients were therefore calculated for the seven non-censored wells (S2, S4, S5, S6, S8, S9, S10) and are presented in Table 6.

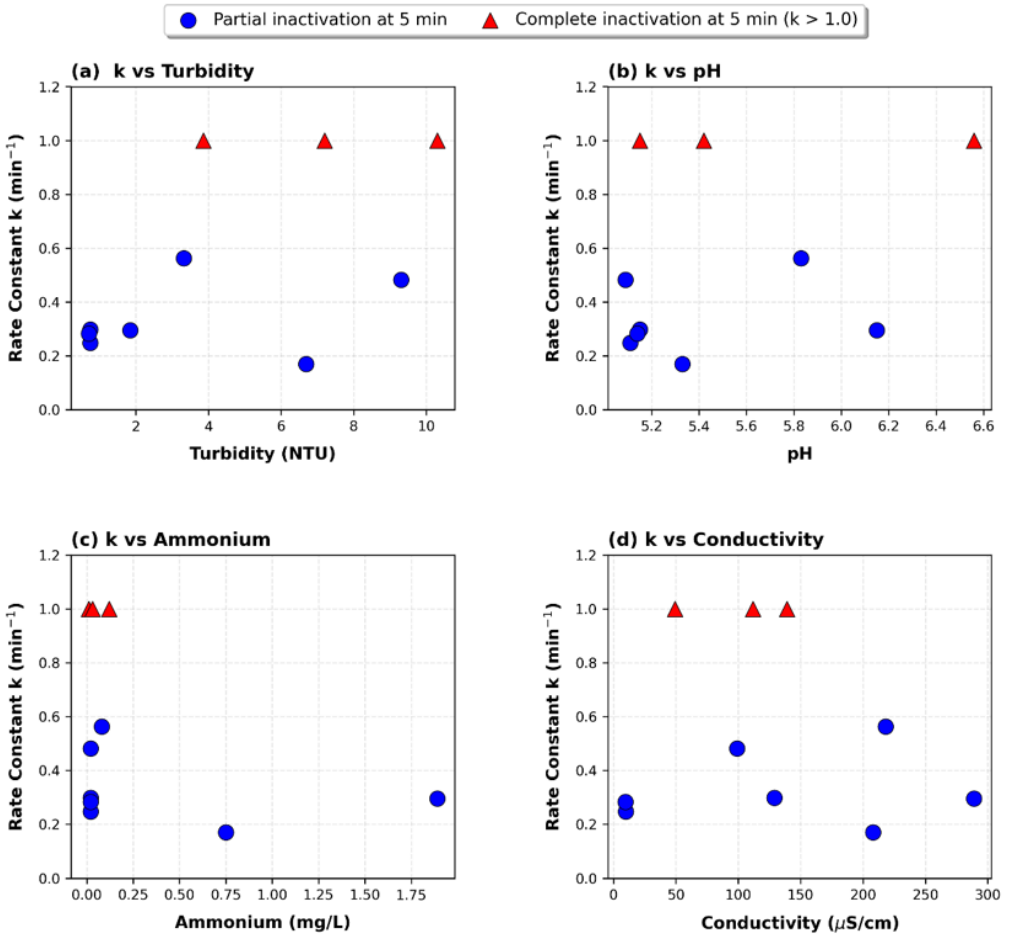


Figure 4: Correlation of the photocatalytic disinfection rate constant k (calculated at 5 min) with selected water quality parameters for the 10 wells. Wells S1, S3 and S7 (inactivation below detection limit at 5 min) are plotted as censored values ($k > 1.0$ min^{-1}) with arrows and were excluded from the quantitative analysis of Pearson's correlation. For the seven non-censored wells, no statistically significant correlation was observed for any parameter (all $|R| < 0.4$, all $p > 0.4$)

Table 6: Pearson's correlation coefficients between the apparent first-order rate constant k (at 5 min) and selected water quality parameters for the seven non-censored wells ($n = 7$; $df = 5$)

Parameter	Pearson R	R^2	t-statistic	p-value
Turbidity (NTU)	+0.299	0.089	+0.701	0.515
pH	+0.224	0.050	+0.514	0.630
Conductivity (µS/cm)	+0.146	0.021	+0.330	0.754
Ammonium (mg/L)	0.278	0.077	−0.647	0.546
Nitrates (mg/L)	0.333	0.111	−0.790	0.466
Chlorides (mg/L)	0.375	0.141	+0.905	0.407

No statistically significant linear correlation was observed for any parameter (all $|R| < 0.4$, all $R^2 < 0.15$, all $p > 0.4$). This indicates that the variability in initial counts and the presence of interfering substances did not systematically preclude complete disinfection within the 10 min window. However, the limited sample size ($n = 7$) reduces statistical power; a weak-to-moderate correlation could remain undetected. We note that samples with higher turbidity (S7: 10.3 NTU; S5: 9.3 NTU; S3: 7.2 NTU; S2: 6.7 NTU) showed slightly lower inactivation rates at 5 min, consistent with UV light scattering and ROS scavenging effects [9]. A larger dataset with controlled variation of individual parameters would be required to confirm these trends.

4 Discussion

4.1 Mechanism of Photocatalytic Disinfection

The accelerated disinfection observed with TiO_2 is explained by the generation of ROS upon UV illumination. When a photon with energy equal to or greater than the band gap of TiO_2 is absorbed, an electron (e^-) is promoted from the valence band (VB) to the conduction band (CB), leaving a hole (h^+) in the valence band:

$$TiO_2 + h\nu \rightarrow e^-_{CB} + h^+_{VB} \quad (1)$$

The photogenerated holes react with adsorbed water molecules or surface hydroxyl groups to produce hydroxyl radicals (•OH):

$$h^+ + H_2O_{ads} \rightarrow \bullet OH + H^+ \quad (2)$$

$$h^+ + OH^-_{ads} \rightarrow \bullet OH \quad (3)$$

Concurrently, electrons can be captured by dissolved oxygen to form superoxide radicals (•O− 2), which can further generate hydrogen peroxide and additional •OH:

$$e^- + O_2 \rightarrow \bullet O^-_2 \quad (4)$$

$$\bullet O^-_2 + H^+ \rightarrow HO\bullet_2 \quad (5)$$

$$2HO\bullet_2 \rightarrow H_2O_2 + O_2 \quad (6)$$

$$H_2O_2 + e^- \rightarrow \bullet OH + OH^- \quad (7)$$

These ROS attack the bacterial cell membrane, leading to lipid peroxidation, disruption of membrane integrity, and eventual cell lysis. Intracellular components such as DNA and enzymes are also oxidised, resulting in irreversible inactivation [10], [11], [12].

4.2 Comparison with SODIS and the Role of Low-Purity TiO_2

In the absence of a catalyst (SODIS), disinfection relies primarily on direct UV-B radiation (280–315 nm), which damages bacterial DNA, and to a lesser extent on thermal effects. The required exposure time is typically several hours [2]. Our results show that under the same solar conditions, the TiO_2 photocatalyst reduced the disinfection time to 10 min for complete inactivation below the detection limit, whereas SODIS only achieved 51% reduction after 10 min. This is consistent with previous studies that reported complete inactivation of faecal coliforms within 15–30 min using immobilised TiO_2 under sunlight [6], [13], [14].

Rutile TiO_2, despite its narrower band gap (~3.0 eV) and generally lower intrinsic photocatalytic activity compared to anatase, has been shown to generate ROS and in activate bacteria under UV-A irradiation [15], [16]. The photocatalytic activity of rutile depends strongly on its surface properties, particle size, defect structure, and the presence of surface hydroxyl groups [17]. Several studies have demonstrated that rutile-based films can achieve significant bacterial inactivation under solar irradiation, particularly when used in thin immobilised layers where light penetration is not limited by scattering [6], [18]. Ohno *et al*. [23] showed that pure rutile particles exhibit substantial photocatalytic activity for organic degradation, challenging the conventional view that rutile is photocatalytically inactive [19], [20]. Hurum *et al*. [24] also demonstrated that the interfacial charge-transfer properties of rutile can contribute to overall photocatalytic efficiency in mixed-phase systems [21]. More specifically for disinfection, Sunada *et al*. [26] reported effective photokilling of bacteria on TiO_2 thin films under UV illumination, with rutile-based coatings achieving substantial inactivation within minutes [22], [23]. Our results are consistent with these findings and also demonstrate that a commercial-grade rutile pigment can be effective for solar disinfection in shallow water layers, likely because the immobilised configuration minimises electron–hole recombination losses and maximises contact between ROS and bacteria.

Importantly, this study validates the use of a commercial rutile pigment rather than high-purity anatase. While anatase is generally considered more photoactive for certain applications owing to its band-edge positions and surface properties, the photocatalytic activity of TiO_2 depends strongly on particle morphology, defects, surface area, crystallinity, and interfacial processes. For the purpose of accelerating solar disinfection in shallow water layers, our results suggest that the specific crystalline phase is less

critical than the mere presence of an immobilised semiconductor surface to generate ROS. This finding has important implications for technology transfer to low-resource settings.

4.3 Influence of Water Matrix and Practical Implications

The physicochemical analysis revealed that the well water had several parameters outside the WHO's guidelines for drinking water, including slightly acidic pH (5.1–6.6) and elevated turbidity in some wells. Analysis of Pearson's correlation (Table 6) showed no statistically significant linear correlation between the inactivation rate constant k and any individual parameter ($|R| < 0.4$; $p > 0.4$ for all six parameters), indicating that the system is robust enough to handle the typical variability of shallow well water in this region. While high turbidity (S7, S5, S3, S2) slightly slowed the initial rate – likely due to UV light scattering and competition for ROS by natural organic matter – inactivation below the detection limit was still achieved within 10 min.

This is a critical finding for point-of-use applications: households do not need to pre-filter water to exacting standards for the reactor to work effectively within a short time window. The presence of ammonium (elevated in S4 at 1.89 mg/L) and chlorides did not appear to significantly inhibit the process, although previous studies have noted that chloride ions can act as hydroxyl radical scavengers at higher concentrations [18]. Dissolved organic carbon (DOC/TOC) was not measured in this study; natural organic matter could influence ROS availability and photocatalytic activity, and this should be addressed in future work.

4.4 Limitations and Future Perspectives

This study prioritised field validation over precise material characterisation. The limitations include the following:

- the non-uniformity of the TiO_2 coating (lack of precise thickness control and surface area measurement);
- estimation rather than direct measurement of UV irradiance, preventing calculation of exact UV doses;
- single-batch testing per well without seasonal replication;
- duplicate technical replicates only, limiting statistical power;
- SODIS comparison was performed for only one sample;
- water temperature during irradiation was not measured;
- DOC/TOC was not measured;
- catalyst leaching and TiO_2 release were not quantified;
- no dark control was performed;

- the limited sample size for correlation analysis ($n = 7$); and
- long-term stability and reusability was not assessed.

Future work should focus on the following:

- performing dark controls (both TiO_2-coated plate in the dark and untreated water in the dark) to confirm that adsorption and natural die-off are negligible;
- optimising the deposition method (for example, using a simple doctor blade technique or spray coating) to improve film uniformity and adhesion while maintaining low-cost fabrication;
- conducting systematic studies of the influence of individual water quality parameters (pH, turbidity, NOM) under controlled laboratory conditions with larger sample sizes;
- using a solar radiometer to quantify UV dose and enable direct comparison with other studies;
- performing long-term stability and reusability tests over multiple cycles to assess the practical lifespan of the coated plates;
- quantifying TiO_2 release into treated water and assessing potential health and environmental implications; and
- exploring the use of visible-light-active photocatalysts or TiO_2 doping to extend the useful spectrum beyond UV-A [24], [25], [26].

5 Conclusion

This work demonstrates that a simple solar photocatalytic reactor using a low-cost, commercial-grade TiO_2 film can effectively disinfect well water contaminated with faecal coliforms in a short exposure time (10 min). Using 10 different well water samples from Antananarivo, we showed that inactivation below the detection limit (< 1 CFU/100 mL) is achieved consistently, despite significant variations in initial contamination levels (18–239 CFU/100 mL) and water quality parameters (pH 5.1–6.6, turbidity 0.7–10.3 NTU). Analysis of Pearson's correlation showed no statistically significant linear correlation between the inactivation rate constant and any measured water-quality parameter (all $p > 0.4$ for the seven non-censored wells).

Compared to the conventional SODIS method, which achieved only 51% reduction after 10 min, photocatalysis significantly accelerates bacterial inactivation by a factor sufficient to make it a promising practical daily household intervention. The use of commercial-grade rutile TiO_2 pigment (Tionox *R*-937), rather than high-purity anatase nanoparticles, demonstrates that effective photocatalytic disinfection can be achieved with locally available low-cost materials.

Such a system represents a promising, low-cost and sustainable household water treatment technology for rural Madagascar and similar low-resource settings. However, further validation studies – including long-term stability testing, seasonal variation, multiple cycle reuse, catalyst leaching assessment, dark controls, and full SODIS comparison – are needed before widespread implementation can be recommended. The simplicity of the reactor design and the minimal-skill fabrication process make it well suited for local implementation and technology transfer.

6 Acknowledgements

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7 References

[1] M. Szopińska, *et al*., "Drinking water safety evaluation in the selected sub-Saharan African countries: A case study of Madagascar, Uganda and Rwanda, *Sci. Total Environ*., vol. 947, p. 174496, 2024, doi: 10.1016/j.scitotenv.2024.174496.

[2] K. G. McGuigan, R. M. Conroy, H. J. Mosler, M. du Preez, E. Ubomba-Jaswa, and P. Fernandez-Ibañez, "Solar water disinfection (SODIS): A review from bench-top to roof-top," *J. Hazard. Mater*., vol. 15, nos 235–236, pp. 29–46, Oct. 2012, doi: 10.1016/j.jhazmat.2012.07.053.

[3] M. N. Chong, B. Jin, C. W. K. Chow, and C. Saint, "Recent developments in photocatalytic water treatment technology: A review," *Water Res*., vol. 44, no. 10, pp. 2997–3027, May 2010, doi: 10.1016/j.watres.2010.02.039.

[4] A. Fujishima, X. Zhang, and D. A. Tryk, "TiO2 photocatalysis and related surface phenomena," *Surf. Sci. Rep*., vol. 63, no. 12, pp. 515–582, Dec. 2008, doi: 10.1016/j.surfrep.2008.10.001.

[5] M. A. Lazar, S. Varghese, and S. S. Nair, "Photocatalytic Water Treatment by Titanium Dioxide: Recent Updates," *Catalysts*, vol. 2, no. 4, pp. 572–601, Dec. 2012, doi: 10.3390/catal2040572.

[6] A. G. Rincón, and C. Pulgarin, "Field solar *E. coli* inactivation in the absence and presence of TiO_2: is UV solar dose an appropriate parameter for standardization of water solar disinfection?" *Sol. Energy*, vol. 77, no. 5, pp. 635–648, Nov. 2004, doi: 10.1016/j.solener.2004.08.002.

[7] R. Bain, R. Cronk, J. Wright, H. Yang, T. Slaymaker, and J. Bartram, "Fecal Contamination of Drinking-Water in Low- and Middle-Income Countries: A Systematic Review and Meta-Analysis," *PLoS Med*., vol. 11, no. 5, p. e1001644, May 2014, doi: 10.1371/journal.pmed.1001644.

[8] S. Malato, P. Fernández-Ibáñez, M. I. Maldonado, J. Blanco, and W. Gernjak, "Decontamination and disinfection of water by solar photocatalysis: Recent overview and trends," *Catal. Today*, vol. 147, no. 1, pp. 1–59, Sept. 2009, doi: 10.1016/j.cattod.2009.06.018.

[9] S. K. Loeb *et al*., "The Technology Horizon for Photocatalytic Water Treatment: Sunrise or Sunset?" *Environ. Sci. Technol*., vol. 53, no. 6, pp. 2937–2947, doi: 10.1021/acs.est.8b05041.

[10] M. Herraiz-Carboné *et al*., "A review on disinfection technologies for controlling the antibiotic resistance spread," *Sci. Total Environ.*, vol. 797, p. 149150, 2021, doi: 10.1016/j.scitotenv.2021.149150.

[11] J. Luo *et al*., "Photocatalyst degradation of perfluorooctanoic acid in water: Mechanisms, approaches, and perspectives," *Sep. Purif. Technol.*, vol. 338, p. 126503, Jun. 2024, doi: 10.1016/j.seppur.2024.126503.

[12] R. Peletz, E. Kumpel, M. Bonham, Z. Rahman, and R. Khush, "To what extent is drinking water tested in sub-Saharan Africa? A comparative analysis of regulated water quality monitoring," *Int. J. Environ. Res. Public Health*, vol. 13, no. 3, p. 275, Mar. 2016, doi: 10.3390/ijerph13030275.

[13] J. A. Byrne *et al*., "A review of heterogeneous photocatalysis for water and surface disinfection," *Molecules*, vol. 20, no. 4, pp. 5574–5615, Mar. 2015, doi: 10.3390/molecules20045574.

[14] O. K. Dalrymple, E. Stefanakos, M. A. Trotz, and D. Y. Goswami, "A review of the mechanisms and modeling of photocatalytic disinfection," *Appl. Catal. B*, vol. 98, nos 1–2, pp. 27–38, Jul. 2010, doi: 10.1016/j.apcatb.2010.05.001.

[15] M. Cho, H. Chung, W. Choi, and J. Yoon, "Linear correlation between inactivation of *E. coli* and OH radical concentration in TiO_2 photocatalytic disinfection," *Water Res*., vol. 38, no. 4, pp. 1069–1077, doi: 10.1016/j.watres.2003.10.029.

[16] Y. Aguas, M. Hincapie, P. Fernández-Ibáñez, and M. I. Polo-López, "Solar photocatalytic disinfection of agricultural pathogenic fungi (*Curvularia* sp.) in real urban wastewater," *Sci. Total Environ.*, vols 607–608, pp. 1213–1224, Dec. 2017, doi: 10.1016/j.scitotenv.2017.07.085.

[17] X. Chen *et al*., "Solar driven photocatalytic disinfection by Z-scheme heterojunction of In_2O_3/g-C_3N_4: Performance, mechanism and application," *Appl. Catal. B: Environ.*, vol. 340, p. 123235, Jan. 2024, doi: 10.1016/j.apcatb.2023.123235.

[18] S. Giannakis, M. I. Polo López, D. Spuhler, J. A. Sánchez Pérez, P. F. Ibáñez, and C. Pulgarin, "Solar disinfection is an augmentable, in situ-generated photo-Fenton reaction –Part 1: A review of the mechanisms and the fundamental aspects of the process," *Appl. Catal. B*., vol. 199, pp. 199–223, Dec. 2016, doi: 10.1016/j.apcatb.2016.06.009.

[19] S. Gelover, L. A. Gómez, K. Reyes, M. T. Leal, “A practical demonstration of water disinfection using TiO_2 films and sunlight,” *Water Res*., vol. 40, no. 17, pp. 3274–3280, Oct. 2006, doi: 10.1016/j.watres.2006.07.006.

[20] J.-Z. Yeoh, S.-Y. Pung, V. M. Vadivelu, and S. Ramakrishnan, “Recent advances in the development of effective TiO_2-based photocatalysts immobilized on floating substrates: A mini review,” *Environ. Nanotechnol. Monit. Manag.*, vol. 22, p. 101021, Dec. 2024, doi: 10.1016/j.enmm.2024.101021.

[21] I. Y. Qudsieh, M. A. Ali, and I. M. Maafa, “Effect of water matrix on photocatalytic degradation of organic pollutants in water: A literature review, *Rev. Chem. Eng.*, vol. 41, no. 6, Jun. 2025, doi: 10.1515/revce-2024-0093.

[22] Y. Ye, H. Bruning, W. Liu, H. Rijnaarts, and D. Yntema, “Effect of dissolved natural organic matter on the photo catalytic micropollutant removal performance of TiO_2 nanotube array,” *Journal of Photochemistry and Photobiology A: Chemistry*, vol. 371, pp. 216–222, Feb. 2019, https://doi: 10.1016/j.jphotochem.2018.11.012.

[23] T. Ohno, K. Sarukawa, and M. Matsumura, “Photocatalytic activities of pure rutile particles isolated from TiO_2 powder by dissolving the anatase component in HF solution,” *J. Phys. Chem. B*., vol. 105, no. 12, pp. 2417–2420, Mar. 2001, doi: 10.1021/jp003211z.

[24] D. C. Hurum, A. G. Agrios, K. A. Gray, T. Rajh, and M. C. Thurnauer, “Explaining the enhanced photocatalytic activity of Degussa P25 mixed-phase TiO_2 using EPR,” *J. Phys. Chem. B*., vol. 107, no. 19, pp. 4545–4549, Apr. 2003, doi: 10.1021/jp0273934.

[25] A. Mills, and S. le Hunte, “An overview of semiconductor photocatalysis,” *J. Photochem. Photobiol. A: Chem*., vol. 108, no. 1, pp. 1–35, Jul. 1997, doi: 10.1016/S1010-6030(97)00118-4.

[26] K. Sunada, T. Watanabe, and K. Hashimoto, “Studies on photokilling of bacteria on TiO_2 thin film,” *J. Photochem. Photobiol. A: Chem*., vol. 156, nos. 1–3, pp. 227–233, Mar. 2003, doi: 10.1016/S1010-6030(02)00434-3.