

1 Table S1. Study quality assessment of the included studies (From 24 articles)

Authors	Novelty of the Photocatalyst/ Material	Environment al Relevance of the Study	Photocatal yst Synthesis Method Clarity	Characterizati on Techniques (e.g., XRD, SEM, UV-Vis)	Experimen tal Design and Control Setup	Reaction Conditions Reported (pH, Time, Dosage)	Mechanism Proposed or Analyzed (e.g., ROS generation)	Reusability and Stability Evaluated	Mineralization Assessed (TOC or COD measurements)	Real Sample Testing Included (e.g., industrial wastewater)	Statistical Analysis and Reproducibility	Research Gaps Identified	Environmental Impact and Scalability Discussed
(Hasan et al. 2020)	Green chitosan– ascorbic acid route	Strong; eco-friendly remediation	Clear (time/temp given)	FTIR, XRD, SEM, TEM, UV-Vis, VSM	Controlled: pH, conc., time, power	pH, conc., time, ultrasonic power given	•OH/ROS confirmed by scavengers	Yes; structure intact after reuse	Yes; TOC 95%, COD 97% (240 min)	No; synthetic MG only	R ² , RMSE; robustness limited	Green sonophotoc atalysis gap stated	Scale-up potential; no secondary pollution
(Khosravi-Far et al. 2024)	Ternary ZIF-8/Ag/Ag ₂ S	Strong; dye removal, green process	Clear co-precipitatio n	XRD, SEM, DRS, PL, TEM, BET, FTIR	RSM-CCD structured design	pH, dose, time, conc. detailed	ROS trapping discussed	5 cycles; stability analyzed	TOC + COD confirm	Multiple dyes; no industrial sample	RSM-CCD + ANOVA; high fit	Recombina tion limits noted	Scalability, sustainability discussed
.(Mostafa and Amdeha 2022)	ZnVFeO ₄ tri-composite; pH-optimized	Dye removal at neutral pH, visible light	Precipitatio n at each pH detailed	XRD, FTIR, TEM, DRS, PL, BET	Controls (FO, FZ), light/dark, parametric	pH, dose, conc., time fully given	Scavengers: •OH, •O ₂ ⁻ roles	5 cycles; minimal loss; XRD check	No TOC/COD; only dye decrease	No; synthetic only	Rate constants, R ² ; reproducibility implied	Recombina tion briefly noted	Economics, light source, scalability noted
(Zahedi et al. 2025)	Green CQDs + MXene	Strong; visible light, green materials	Both syntheses well detailed	SEM, XRD, FTIR, UV-Vis, EDX	Varied pH, conc., dosage	pH 6, 25 min, dosage clear	•OH/•O ₂ ⁻ proposed, illustrated	3 cycles; declining efficiency	COD removal 49–78%	No	Kinetics; limited statistics	Stability beyond 3 cycles untested	Brief scalability; green synthesis stressed
.(Zhu et al. 2021)	Original BiVO ₄ /NiFe ₂ O ₄ /ATP ternary	Strong; visible-light water treatment	Ultrasound - hydrotherm al clear	XRD, FTIR, SEM, XPS, BET, DRS, EIS	Compositio n/condition s varied; PFO kinetics	Time, dose, neutral pH, conc.	Scavengers; h ⁺ dominant	3 cycles; 94% retained	No TOC/COD; DLS indirect	No	Basic kinetics; no advanced stats	BiVO ₄ limits; composite as solution	Magnetic recovery; practical potential
(Abdullah et al. 2024)	rGO/SnSe soft nanohybrid	High; visible-light MG removal	Hydrotherm al + Hummer's clear	XRD, FTIR, SEM, Raman, PL, XPS, BET	Structured; dark- adsorption control	Time, conc., dose, dark step	e ⁻ , h ⁺ , •O ₂ ⁻ , •OH via scavengers	5 cycles; 86.45%; XRD stability	TOC 76.56%	No	Some kinetics; limited stats	Stability; rGO synergy	Scalability in conclusion
(Ma et al. 2024)	K-doped g-C ₃ N ₄ @ATP-Fe ₃ O ₄	Strong; dye wastewater	Steps, ratios, conditions detailed	XRD, SEM, TEM, FTIR, XPS, UV-Vis, PL, VSM	Dark/light, ratios, dosages, pH	pH, time, conc., dose reported	•OH, •O ₂ ⁻ , h ⁺ by EPR + scavenging	4 cycles; >80%	LC-MS intermediates; partial data	No	Basic kinetics; limited reproducibility	Excessive-doping effect noted	Scalability, magnetic recovery discussed

(Li et al. 2022)	Z-scheme heterostructure	Visible light; MG toxicity focus	Hydrothermal, clear ratios	SEM, XRD, XPS, BET, UV-Vis, FTIR, LC-MS	TiO ₂ , no-catalyst, doping controls	pH, time, dose, ionic strength, conc.	ROS confirmed (•O ₂ ⁻ , h ⁺)	5 cycles; 81.4%	TOC 35.55%	No; simulated only	SD given; reproducibility addressed	Magnetic separation, improvements noted	Combined treatment, economics
(Yulizar et al. 2023)	TiO ₂ /YMnO ₃ , plant-based	Water purification, visible light	AMLE two-phase method detailed	XRD, FTIR, SEM, TEM, UV-Vis, PL, EDS	Photolysis, adsorption, single-oxide controls	120 min, 10 mg dose, conc. given	•O ₂ ⁻ , h ⁺ trapping tests	5 cycles; stable	No TOC/COD	No	Kinetics; no error bars	TiO ₂ visible-light gap; green route	Green-synthesis scalability discussed
(Mohan et al. 2021)	Ti-BiVO ₄ polymer film	High; MG and water treatment	Solid-state + film casting clear	XRD, SEM, Raman, DRS, UV-Vis, EDS	Photolysis/adsorption controls	Dose, time, conc. under visible light	e ⁻ , h ⁺ , •OH, •O ₂ ⁻ proposed	Powder 3 cycles OK; film lower	No TOC/COD	No	Minimal; mostly qualitative	Separation/film recovery gaps	Industrial scalability, reactor potential
(Guo et al. 2025)	Z-scheme Ag ₂ S/MoS ₂ @ZnPc	Sterilization + degradation relevance	Hydrothermal clear	XRD, SEM, TEM, XPS, BET, UV-Vis	Strong design with control groups	pH 7.0, 125 mg/L dose, conc. optimized	ROS, scavengers, ESR	5 cycles; minimal loss	TOC 63.8%	Partial; MG degradation synthetic, bacterial assay in wastewater	Kinetics; R ² > 0.999	Dual-action materials need	Scalability; antibacterial application
(Tanuj et al. 2024)	Green Cr-doped ZnO	Dye pollution via green catalyst	Extract synthesis detailed	XRD, SEM, UV-Vis, EDX, FTIR	Controls + optimization	pH 10, 25 ppm, dose given	•OH, •O ₂ ⁻ pathways	11 cycles; slight drop	No TOC/COD	No	PFO kinetics; little error analysis	Doping, selectivity gaps	Green-route scalability discussed
(Shao et al. 2023)	Flowerlike SnO ₂ /g-C ₃ N ₄	Strong; MG toxicity context	Hydrothermal + calcination clear	XRD, SEM, TEM, XPS, FTIR, DRS, PL, BET	Pure-phase controls	pH, time, dose detailed	Scavenger-based ROS; illustrated	5 cycles; 89%	No TOC/COD	No	Basic kinetics; stats could improve	Flowerlike-morphology gap	Brief scalability in conclusion
(Meena et al. 2024)	Gelatin-assisted Ce-CuS	High; MG water treatment	Hydrothermal; Ce content optimized	XRD, SEM, BET, UV-DRS, PL, GC-MS	Conc., pH, loading, kinetics studied	pH, time, dose, wt%, airflow	Ce ⁴⁺ /Ce ³⁺ , •OH, •O ₂ ⁻ with reactions	4 cycles;	COD 95.8%	No	Kinetics + L–H; reproducibility limited	Industrial use, surface anchoring	Low-cost treatment scalability
(El-Hout et al. 2020)	rGO/CuS, optimal 7% loading	Textile wastewater target	Co-precipitation + in-situ reduction clear	XRD, FTIR, Raman, SEM, TEM, BET, XPS, DRS, PL	pH, dose, conc., sunlight intensity	Conditions optimized, detailed	•OH, •O ₂ ⁻ confirmed	5 cycles; minimal loss	TOC 76%	No	R ² only; no error bars	Sunlight performance, TOC comparison	Sunlight-use scalability discussed
(Bhasin and Mishra 2025)	Cu-MOFs, aliphatic linkers	Direct MG wastewater target	Solvothermal detailed	PXRD, FTIR, SEM, BET, UV-Vis, TGA	pH, temp., H ₂ O ₂ , dose controls	pH 4, 50 °C, H ₂ O ₂ dose, conc.	•OH via scavengers	4 cycles	No direct TOC/COD; MG absorbance (619 nm) only	No	Some quantitative; error data limited	MOF pH-adaptability limits	Scalability; sustainability noted

(Jasrotia et al. 2022)	Dy-doped Zn–Mg spinel ferrites	MG pollutant, solar light	Sol-gel auto-combustion detailed	XRD, FESEM, EDX, UV-Vis, FTIR, Raman, VSM	Controls; PFO kinetics	pH, conc., dose, time given	ROS + VB/CB transitions	4 cycles; minimal loss	No TOC/COD	No	Reproducibility noted; stats limited	Dy-doping, synthesis optimization	Scalability, magnetic separability
(Himanshi et al. 2025)	Co/Dy co-doped BaFe ₁₂ O ₁₉	Strong; sunlight MG removal	SGAC with temps/reagents	XRD, FESEM, FTIR, UV-Vis, Raman, BET, VSM, XPS	Dose, pH, kinetics design	pH, dose, time studies	ROS with visual scheme	5 cycles; minimal drop	No TOC/COD; efficiency only	No	Basic kinetics; limited stats	Real samples, mineralization gaps	Industrial application discussed
(Liu et al. 2024)	Dual-function NFO@C from PET waste	MG + socio-economic angle	Molten salt + mechanochemical detailed	XRD, SEM, TEM, BET, Raman, XPS, UV-Vis, VSM	Parameter + comparative studies	pH, dose, time, conc., temp.	Scavengers + band-structure	No reuse-cycle data	No TOC/COD	No	Basic modeling; stats lacking	PET-derived dual-function gap	Circular economy, low-cost purification
(Pang et al. 2021)	Oil-palm AC/TiO ₂	Waste-derived catalyst for MG	Sol-gel clear	XRD, SEM-EDX, FTIR, TGA, BET	Basic; controls not detailed	pH not stated; temp., dose, time given	Adsorption–photocatalysis; no ROS tests	83.1% after 1 cycle	COD 96.7%	No	PFO kinetics	Temperature effect; limited gaps	Biomass-reuse scalability brief
(Tiwari et al. 2023)	Fecal-sludge biochar + dual oxides	Highly relevant biochar treatment	Impregnation well explained	XRD, SEM, BET, UV-Vis, FTIR	Setup + comparative controls clear	pH, dose, time thorough	ROS pathways discussed	6 cycles; minimal loss	TOC estimate; limited detail	Yes: sewage wastewater	Basic stats; could be stronger	Future scope stated	Scalability, real impact discussed
(Devi et al. 2023)	ZnO/ZnS core–shell optimized	Strong dye-removal focus	Co-precipitation detailed	XRD, FESEM, EDX, UV-Vis, PL, dielectric	pH, dose, time, scavengers	pH, dose, conc., scavenger effects	Electrons main species	100→58% in 3 runs	No TOC/COD	No	Kinetics; some k ₁ /k ₂ stats	ZnO limits, optimization	Scalability shallow; multifunctionality noted
(Wang et al. 2021)	Molecular imprinting + Bi ₂ O ₃ /TiO ₂ -AC	Selective MG in water	Surface MIT detailed	XRD, SEM, UV-Vis, PL, photocurrent	Non-imprinted control; improvable	Dose, cycles; pH missing	S-scheme + selective adsorption	Cycles discussed; data limited	No TOC/COD	No	Kinetic fits; limited validation	Selective degradation in mixtures	Selectivity/scalability brief
(Mbuyazi and Ajibade 2025)	APTES-Fe ₃ O ₄ @BC	Strong toxic-dye removal	Co-precipitation + APTES detailed	XRD, HRTEM, FTIR, UV-Vis, XRF, CHN	Dark/light, ratios, dosages, pH	pH, dose, time, conc. via RSM	ROS via scavengers	5 cycles; minimal drop	No TOC/COD; kinetics addressed	No	ANOVA, R ² , validation thorough	TPB degradation, conc. effects	Scalability, environmental implications

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