

Advances in materials for fog harvesting: A comprehensive review of conventional, bioinspired, and advanced functional materials

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ABSTRACT

Water scarcity is affecting many nations worldwide, and countries including Jordan, Saudi Arabia, and India are among those affected. Fog harvesting has emerged as a promising passive approach for atmospheric water collection, particularly in arid and semi-arid regions where conventional freshwater resources are limited. The performance of fog-harvesting systems is strongly governed by the material, surface and structural characteristics of the collector, which determine fog-droplet interception, adhesion, coalescence, transport, and drainage. Over the past two decades, research has progressed from conventional mesh collectors toward engineered materials and bioinspired surfaces designed to overcome the limitations of conventional systems. This review provides a comprehensive assessment of materials used for fog harvesting, covering developments from 2006 to 2026. Conventional metallic and polymeric meshes, including stainless steel, aluminum, copper, polyethylene, polypropylene, and nylon, are first reviewed in terms of their material properties, wettability, durability, cost, and water-collection performance. The review then examines advanced material strategies, including surface coatings, hydrophilic–hydrophobic patterns, superhydrophobic and superhydrophilic surfaces, electrospun nanofibers, and micro/nano-structured surfaces. Particular attention is given to bioinspired materials and architectures derived from cactus spines, spider silk, Namib desert beetles, and pitcher plants, as well as emerging fractal and triply periodic minimal surface (TPMS) structures. The comparative analysis demonstrates that material performance cannot be evaluated solely on fog-droplet capture; efficient water harvesting requires a balance between capture, droplet mobility, coalescence, shedding, drainage, mechanical stability, environmental durability, and manufacturability. The review identifies the transition from passive interception-based meshes toward multifunctional, surface-engineered, and bioinspired materials as a major technological development in fog harvesting.

Keywords: water scarcity, climate change, atmospheric water, fog harvesting, bioinspired mesh, triply periodic minimal surface, nanofibers.

INTRODUCTION

Water scarcity is hitting many nations worldwide; countries including Jordan, Saudi Arabia, India, Turkmenistan and Pakistan are among these countries (Bozorg-Haddad et al., 2019; Shan et al., 2020). Population impacted with severe water

scarcity is about 4 billion people (Mekonnen & Hoekstra, 2016). Water scarcity (WS) is a critical global challenge threatening environmental sustainability, economic development, and human well-being (Khan et al., 2024; Mukherjee et al., 2019). WS affects the climate, agriculture, groundwater, population growth, economic

and social stability (Mukheibir, 2010). The WS threats require integrated water resource management, technological innovation, and climate-resilient strategies to ensure sustainable freshwater availability (Khan et al., 2024; Lindner & Stamm, 2025). Climate change also plays a main role in intensifying WS by causing droughts, floods, and increasing evaporation (Nairizi, 2017; Sivakumar, 2010; Tabari, 2020). Atmospheric water (AW) has become an important, decentralized water resource for drinking water and irrigation (Inbar et al., 2020; Zhang et al., 2022). Although the amount of AW is small compared to other freshwater resources (0.04%), AW is continuously renewed which makes it a viable source of water (Ahrestani et al., 2023). AW harvesting is divided into dew point passive harvesting, active harvesting using mechanical cooling, desiccant type and fog water harvesting (Jarimi et al., 2019).

Fog water harvesting captures liquid fog droplets (typically 10–50 μm), while dew harvesting collects water through the condensation of atmospheric water vapor on surfaces (Boutracheh et al., 2024). The fog harvesting processes including impaction, interception and collection play valuable roles in maximizing the collection efficiency and the water yield (-Sánchez & Mulligan, 2025). The fog harvesting may be affected by various factors including in-situ fog, droplet-size and droplet-to-mesh surface interactions (Ura et al., 2021). In the last two decades research in the area of water harvesting and fog water harvesting has been intensified (Sartipizadeh et al., 2025). Research has progressively moved from conventional mesh collectors toward engineered surfaces, biomimetic materials, functional coatings, nanostructured materials, and three-dimensional architectures.

The development of fog-harvesting technology can therefore be viewed as a transition from simple passive interception toward integrated control of droplet capture, adhesion, coalescence, transport, shedding, and drainage (Jiang et al., 2023). This development has placed materials and surface engineering at the center of recent fog-harvesting research.

This paper reviews developments in the fog-harvesting field, especially during the last two decades (2006–2026), with particular emphasis on materials, surfaces, structural characteristics, and their influence on fog-droplet collection and drainage. An intensive review has been performed to capture important technological developments

in fog harvesting, reduce the time required by researchers working in this field, and contribute to the faster development and implementation of fog harvesting for drinking-water and irrigation applications (Boutracheh et al., 2024).

FOG HARVESTING COLLECTOR MATERIALS

Fog harvesting (FH) is affected by many factors including (Guo & Liu, 2025):

- Material-related factors such as mesh type, size, material, orientation, coating and surface characteristics (hydrophobic and hydrophilic).
- Environmental-related factors such as fog density, droplet size, wind speed, relative humidity and ambient temperature.
- Structural and design factors such as collector installation angle, orientation and height.

These factors are strongly coupled. Consequently, improving one material property does not necessarily result in a proportional increase in the overall water yield. Fog harvesting initially relied heavily on traditional Raschel mesh systems (Wang et al., 2023). Polymeric meshes remain attractive because of their low cost, low weight, availability, and ease of installation.

The materials commonly used include polyethylene (PE), high-density polyethylene (HDPE), polypropylene (PP), and nylon. Traditional polypropylene and polyethylene Raschel meshes were originally used extensively in agricultural applications and subsequently adopted for large-scale fog collectors (Castellano et al., 2008). These materials are generally characterized by low cost, wide availability, UV resistance, and reasonable outdoor durability. Their water collection performance ranges depending on fog conditions (Alzahrani & Abdelbaki, 2025).

Metallic materials such as copper, aluminum, and stainless steel are particularly attractive for applications exposed to relatively high wind speeds (Nikbakht, & Heyhat, 2026). However, metallic meshes are generally heavier and more expensive and may require stronger structural support. Table 1 shows a comparison of traditional materials in fog harvesting. In order to improve water collection efficiency, durability, and cost-effectiveness, continuous developments in FH materials were made. Technology has evolved through several generations of materials.

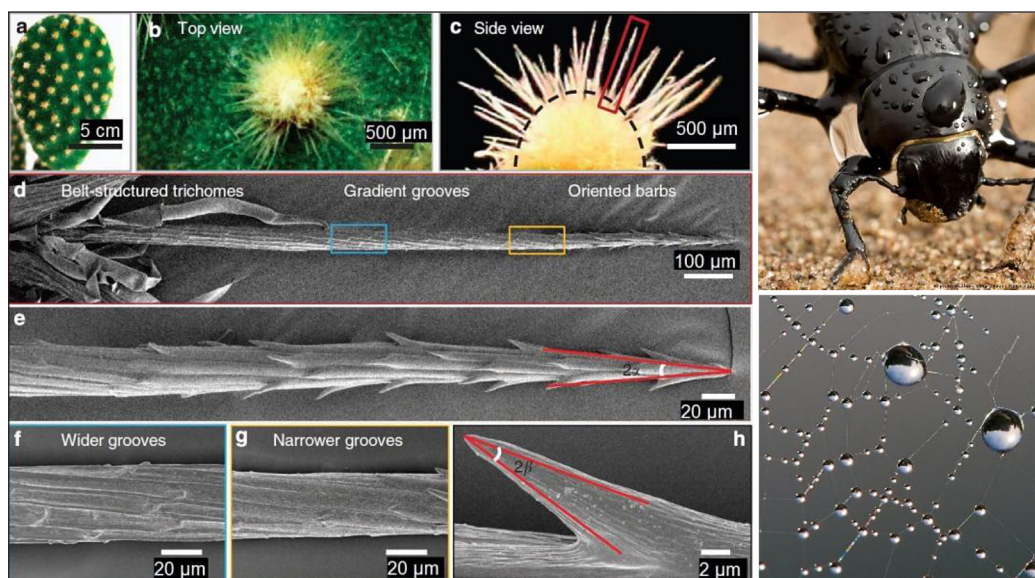
Table 1. Traditional materials in fog harvesting systems

Mesh material	Composition & structure	Typical water yield / efficiency	Advantages	Limitations	References
HDPE Raschel mesh (standard fog nets)	Warp-knitted polyethylene (sometimes polypropylene) ~35% shade cloth	~3–10 L/m ² -day in good fog conditions (field averages); typical collection efficiency often low (~1–2% raw capture)	Low cost, widely available, lightweight	Moderate efficiency; hydrophobic surface can delay drainage	Di Bitonto et al., 2025
Polypropylene / plastic nets	Plastic shade/mesh similar to Raschel	Similar to HDPE (3–10 L/m ² -day typical in field deployments)	Affordable, accessible	Not optimized for fog capture	Hadba et al., 2024
Nylon mesh	Synthetic polyamide mesh	Not widely quantified in field studies; expected similar to basic plastic meshes	Better intrinsic wettability than HDPE/PP	UV degradation over time; data sparse	Knapczyk-Korczak et al., 2020
Stainless steel mesh (coated)	Metal (e.g., SS304/316) with hydrophobic coatings (e.g., MIT-14)	Higher relative capture vs HDPE; up to ~40% more collection at moderate winds in trials; some advanced designs aim at ~10–12 L/m ² -day in very favorable conditions	Strong, durable; better performance across wind speeds	Heavier, higher cost; requires stronger support	Fernandez et al., 2018

BIOMIMETIC SURFACE MATERIALS

In recent years, researchers have increasingly studied natural fog-harvesting organisms such as the Namib Desert beetle, cactus spines, and spider silk. These studies initiated a major transition toward biomimetic materials and surfaces (Amjad et al., 2026). Bioinspired collectors incorporate engineered surface properties such as hydrophilic and hydrophobic regions, micro- and nanoscale textures, and directional water transport. These characteristics can promote faster

droplet nucleation, improve drainage, and reduce re-evaporation losses. Significant water collection improvements compared with conventional Raschel meshes have been reported under laboratory conditions (Rajaram et al., 2016). Biomimetic surface engineering is one of the fastest-growing research areas in fog harvesting. Instead of relying solely on mesh geometry, researchers engineer the surface chemistry and micro/nano-structure of collectors by mimicking organisms that have evolved to collect water efficiently in arid environments (Xiao & Guo, 2021; Yu et al.,

**Figure 1.** Surface structure of a cactus spine showing how its tiny barbs and grooves are arranged (Ju et al., 2012)

2022). These bio-inspired surfaces enhance droplet nucleation, capture, transport, coalescence, and drainage, thereby significantly improving water collection.

Fog harvesting technology is strongly inspired by organisms that have evolved to capture and transport atmospheric water in dry environments. Their surfaces combine micro/nanostructures, wettability differences, curvature, and surface-energy gradients to collect tiny fog droplets and move them toward a storage or absorption region. The Namib Desert beetle survives in one of the driest environments by harvesting fog. It is characterized by hydrophilic bumps (0.5–1 mm), hydrophobic wax-covered background. Water condenses on bumps. Droplets grow and roll toward the beetle's mouth (Nørgaard & Dacke, 2010).

Cactus spines collect fog through conical geometry, Laplace pressure gradient and surface energy gradient. Water moves naturally from the sharp tip toward the stem. It is characterized by passive directional transport, rapid drainage, and the prevention of flooding (Yi et al., 2019). Spider silk contains spindle knots, periodic joints and alternating wettability. Water droplets migrate automatically toward the spindle knots (Wang & Guo, 2024). Pitcher plants possess slippery liquid-impregnated surfaces (SLIPS). They are characterized by extremely low adhesion, rapid droplet removal, anti-fouling and self-cleaning, which inspired the development of lubricant-infused fog collectors (Li et al., 2020).

Hydrophilic bumps on hydrophobic backgrounds

The surface combines two complementary mechanisms:

- Hydrophilic regions – increase droplet nucleation rate, retain droplets during the initial growth stage and promote coalescence (Gao et al., 2026).
- Hydrophobic regions – this reduces contact angle hysteresis, minimizes droplet pinning and accelerates droplet removal, exposing fresh nucleation sites (Wang et al., 2015).

This combination significantly increases the overall water collection rate compared with uniformly hydrophilic or uniformly hydrophobic surfaces (Hou et al., 2018). Researchers have reproduced this design using several fabrication techniques including photolithographic patterning, laser surface texturing, plasma surface treatment, inkjet printing of hydrophilic coatings, selective chemical functionalization, microcontact printing and electrospun nanofiber membranes with patterned wettability (Akuoko & Kwon, 2024).

Various materials have been used including PTFE, PDMS, fluorinated silica nanoparticles, TiO₂ coatings, ZnO nanostructures and graphene oxide composites. They are characterized by high fog capture efficiency, rapid droplet shedding, reduced flooding of the collector surface, continuous regeneration of condensation sites, improved

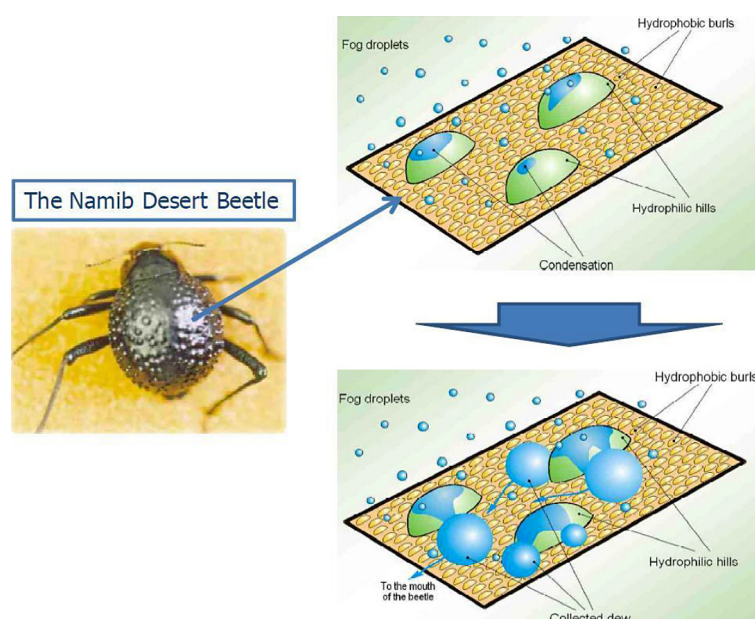


Figure 2. Beetle's back (elytra) surface made of hydrophilic hills/bumps surrounded by hydrophobic regions/burls (Parker & Lawrence, 2001)

self-cleaning performance and passive operation without external energy (Table 2).

Table 3 summarizes different biomimetic approaches for fog harvesting inspired by nature. The Namib beetle uses hydrophilic bumps to improve water collection, while the cactus spine and spider silk use special structures to both collect and efficiently transport water droplets. SLIPS uses a lubricant layer that provides excellent drainage of collected water. Surfaces combining hydrophilic bumps with a hydrophobic background can provide very high water collection and good drainage. Overall, these biological inspirations show how surface structure and wettability can be designed to improve both fog capture and water removal in artificial fog-harvesting systems (Yu et al., 2022).

Advanced functional materials and surface technologies

Functional coatings provide an effective method for modifying the surface properties of conventional collector materials without completely replacing the supporting mesh. The coating strategies discussed in the literature include:

- nanoparticle coatings;
- metal-oxide coatings;
- polymer thin films;

- graphene-based coatings;
- silica nanostructures;
- hydrophilic coatings; and
- hydrophobic or superhydrophobic coatings (Sartipizadeh et al., 2025).

Their principal objective is to modify surface energy, wettability, nucleation, droplet adhesion, and shedding. From approximately 2015 onward, researchers have increasingly focused on modifying collector surfaces rather than replacing the complete mesh structure (Ielo et al., 2021; Jin et al., 2022; Schneider et al., 2021). Researchers have investigated nanoparticle coatings, metal-oxide coatings, polymer thin films, graphene-based coatings, and silica nanostructures (Lu et al., 2026).

These materials aim to increase condensation and control droplet adhesion and removal. Surface engineering provides a means of modifying wettability and droplet mobility without necessarily changing the underlying structural mesh. Micro- and nanostructuring can increase effective surface area and alter the interaction between fog droplets and the collector. Such structures may influence nucleation, adhesion, coalescence, and droplet mobility.

Hybrid and composite meshes have become increasingly important in recent research (Bintein et al., 2023). Examples include dual-layer meshes

Table 2. Basic characteristics of hydrophilic bumps on hydrophobic backgrounds and their performance

Key characteristic	Performance
High fog capture efficiency (wettability gradient + 3D structure)	~693.3 mg cm ⁻² h ⁻¹ at a 5 cm collection distance (Chen et al., 2026).
Rapid droplet shedding & self-cleaning (high-contrast wetting patterns)	~60% improvement over pristine Pyrex glass (Kostal et al., 2018).
Continuous condensation site regeneration (3D-printed hybrid wettability)	366.2 g m ⁻² h ⁻¹ (Lin et al., 2025).
Passive operation & high efficiency (multi-bioinspired patterns)	~5.3 g cm ⁻² h ⁻¹ , which is 1.8× higher than previous star-shaped patterns (Yu et al., 2017).
Reduced flooding (multi-bioinspired: beetle + cactus + spiderweb)	20.17 L m ⁻² day ⁻¹ ; 68.64% higher than superhydrophilic surface and 229.38% higher than superhydrophobic surface (Li et al., 2024; Qi et al., 2025).
Dual-directional water transport (tri-layered composite membrane)	3.55 g cm ⁻² h ⁻¹ (Zhang et al., 2025).

Table 3. Biomimetic-inspired surfaces with their collection and drainage enhancements

Biomimetic inspiration	Surface feature	Collection enhancement	Drainage enhancement	Reference
Namib beetle	Hydrophilic bumps	High	Moderate	Parker & Lawrence, 2001
Cactus spine	Conical gradient	High	Very high	Jiang et al., 2023
Spider silk	Periodic spindle knots	High	Very high	Zheng et al., 2010
SLIPS	Lubricant layer	Moderate	Excellent	Chen et al., 2022
Hydrophilic bumps + hydrophobic background	Wettability contrast	Very high	High	Al-Khayat et al., 2017

with different pore sizes, composite polymer–metal fiber structures, and electrospun nanofibers supported on conventional Raschel mesh.

Other approaches include laser-patterned collectors, 3D-printed collectors, and bioinspired hierarchical structures. These systems aim to simultaneously optimize fog interception, water transport, droplet growth, and drainage. Hybrid materials combine the advantages of two or more material classes. Examples include polymer–metal structures, dual-layer meshes, electrospun nanofibers supported by conventional mesh, and hierarchical bioinspired materials (Yin et al., 2017). Such systems are particularly promising because the structural material can provide mechanical support while the functional surface provides improved wetting and droplet transport.

Recent research has also explored smart and sustainable materials (Batisha, 2015), including recycled polymers, biodegradable materials, self-cleaning coatings, and anti-icing surfaces (Cannio et al., 2024; Wang et al., 2025). These developments seek to reduce maintenance requirements and improve long-term performance while addressing environmental concerns associated with conventional polymeric collectors. Future material development should consider not only water yield but also environmental impact, service life, maintenance requirements, and end-of-life disposal. Researchers recognized that flat meshes have limited interaction with airflow. Consequently, new structures including three-dimensional knitted meshes, multilayer meshes, spacer fabrics, curved collectors, and conical collectors have been investigated (Zefrehei et al., 2022). These structures can provide greater effective surface area, modify airflow through the collector, reduce blockage caused by accumulated water, and improve performance under varying wind conditions.

Harp collectors use vertical wires or fibers arranged similarly to the strings of a harp (Shi et al., 2020). Their low solidity can allow high airflow penetration while providing effective droplet interception. Their relatively open structure may also facilitate drainage and reduce the blockage associated with conventional dense meshes. Fractal collectors provide multiscale architectures that can increase effective interaction with fog droplets while maintaining pathways for airflow and drainage. Their potential arises from combining different length scales within one architecture.

Spider-web-inspired structures incorporate interconnected fibers and localized droplet

collection regions. Their design is inspired by the ability of natural spider silk to combine water capture with directional transport (Zheng et al., 2010). Three-dimensional lattice collectors provide a larger effective collecting structure than conventional planar meshes. Additive manufacturing can provide control over the geometry, porosity, and orientation of these structures (Charoensook et al., 2024). Triply periodic minimal surface (TPMS) structures, including gyroid, diamond, and schwarz-P architectures, provide continuous three-dimensional pathways for airflow and water transport. Their geometry allows the material architecture itself to participate in fog capture, airflow management, and drainage. Recent research has therefore considered TPMS structures as potential next-generation water-harvesting architectures (Wu et al., 2026). However, their practical application remains dependent on manufacturing cost, structural durability, scalability, and field validation.

Electrospinning enables the production of fibers with diameters ranging from tens of nanometers to a few micrometers (Ganesh et al., 2017; Mishra et al., 2019; Xue et al., 2019). Materials such as polyvinylidene fluoride (PVDF), polyacrylonitrile (PAN), polyvinyl alcohol (PVA), and nylon have been investigated for nanofiber-based fog collection (Knapczyk-Korczak et al., 2020).

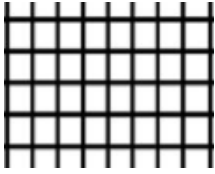
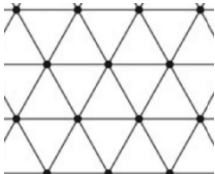
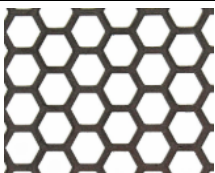
Electrospun structures provide extremely high surface area, high potential capture efficiency, and tunable pore size. However, their practical application requires consideration of mechanical stability, manufacturing complexity, and long-term environmental durability.

COLLECTOR GEOMETRY AND STRUCTURAL CHARACTERISTICS

Although this review focuses on materials, material performance cannot be separated completely from collector geometry. Fiber diameter, pore size, porosity, shade coefficient, and structural configuration determine how the material interacts with fog and airflow (Park et al., 2013).

Mesh geometry determines how efficiently fog droplets are captured and drained while air passes through the collector (Table 4). The principal capture mechanisms include inertial impaction, interception, and gravitational drainage (Saha et al., 2022).

Table 4. Various mesh geometries for fog harvesting systems

Mesh geometry	Description	Aperture shape	Performance notes	References
Square mesh	Orthogonal weave with uniform square openings; often woven from metal		Balanced capture but higher blockage and pressure drop at high SC. Used as baseline in many experiments	Elshennawy et al., 2023; Renon, & Jeanningros, 2025
Rectangular mesh	Orthogonal openings with unequal width/height; typically woven sieve types		Often used experimentally; tends to block less flow than square due to directional pores, with moderate fog capture	Ghosh et al., 2017, Rajaram et al., 2016
Triangular mesh	Equilateral triangle openings; can appear in knitted or engineered meshes		Higher interception potential per unit area due to angled fibers, but may incur higher aerodynamic resistance	Verbrugghe, & Khan, 2023
Hexagonal mesh	Honeycomb-like openings; minimal intersections per area		Often yields better aerodynamic efficiency and smoother flow with good capture per unit shade coefficient	Elshennawy et al., 2022; Zhang et al., 2023
Raschel mesh	Knitted polypropylene mesh with triangular pattern and sloped fibers; widely used in large fog collectors		Field standard due to good drainage and balanced performance; foam-like structure enhances droplet coalescence and runoff	Rivera & Lopez-Garcia, 2015

The main governing parameters include:

- fiber diameter, which influences droplet capture probability;
- pore size, which controls the penetration of small droplets;
- porosity, which affects airflow;
- solidity ratio or shade coefficient; and
- overall mesh structure.

Advanced geometries have also been developed using biological inspiration. These include cactus-inspired tapered structures, aerodynamic kirigami meshes, harp collectors, and other three-dimensional structured meshes (Table 5), (Zhang, X. et al., 2022). The shade coefficient (SC), sometimes called the solidity ratio, is one of the most important design parameters in fog harvesting collectors. It represents the fraction of the collector area occupied by fibers (Elshennawy et al., 2023):

$$SC = \frac{\text{Fiber area}}{\text{Total mesh area}} \quad (1)$$

A low SC allows fog to pass through without sufficient interception, while a high SC blocks airflow and causes aerodynamic bypass. Therefore, an optimum value exists (Yang et al., 2025). Typical shade coefficients for various traditional materials are shown in Table 6.

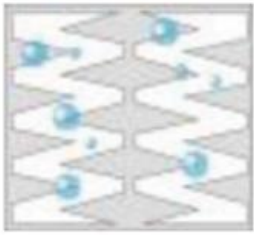
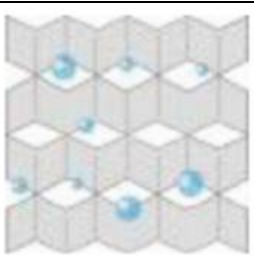
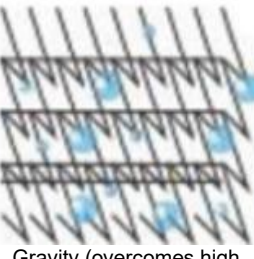
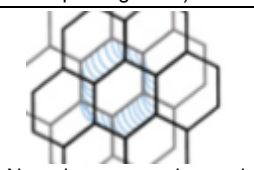
A major trend in the literature from approximately 2010–2026 is that the optimum shade coefficient is no longer considered a universal value (e.g., 50%) (Mukhopadhyay et al., 2023). Instead, the optimal SC depends strongly on collector geometry:

$$\eta_{total} = f(SC, \eta_a, \eta_d, \eta_r, \text{geometry}) \quad (2)$$

where: η_a – aerodynamic efficiency, η_d – droplet deposition efficiency, η_r – drainage efficiency.

Consequently, advanced geometries such as harp, fractal, spider-web, and TPMS collectors often achieve equal or better water yields than conventional Raschel meshes while operating at

Table 5. Bio-inspired fog harvesting meshes (Bai et al., 2024)

Mesh geometry	Mechanism	Advantages	Limitations
2D cactus kirigami mesh with tapered needles (Bai et al., 2020)	 Laplace pressure + gravity	Simple to manufacture using CNC cutting	Practically untested, mechanical stability at high wind speeds
3D cactus mesh with tapered needles (Cheng et al., 2021)	 Laplace pressure + gravity	Reduced clogging, boost Laplace effect with wettability gradients	Cost, practically untested
3D aerodynamic kirigami mesh (Li et al., 2025)	 Aerodynamic + gravity	Simple to manufacture, high collection efficiency	Practically untested, mechanical stability (at high wind speeds)
Advanced harp / meshes (Nagor, 2026)	 Gravity (overcomes high pinning force)	Improved droplet control potential without wire tangling, no need for costly coatings	Cost, practically untested
Other 3D/structured meshes	 Non-planar or engineered structures (e.g., intertwined hex patterns)	Often enhance both airflow and capture; sometimes outperform traditional meshes in field and laboratory	Aqualonis "FogHa-TiN" and other proprietary structured meshes (Fernandez et al., 2018)

significantly lower shade coefficients (Shi et al., 2018). This shift from optimizing SC alone to optimizing geometry-driven transport mechanisms is one of the central developments in modern fog-harvesting research. Table 7 summarizes the various geometries/shapes of fog collectors with their shade coefficients.

The aerodynamic efficiency ranges in Table 8 are literature-derived approximate ranges, because depends strongly on wind speed, droplet size distribution, collector dimensions, Reynolds number, and mesh porosity. Therefore, values should be interpreted as comparative performance indicators rather than universal constants.

Table 6. Various mesh geometries for fog harvesting systems: traditional materials

Period	Collector type & material	Typical shade coefficient (%)	Design philosophy	Collection performance	Recommended reference(s)
1960s–1980s	Early wire screens, galvanized steel	20–35	Maximize airflow through mesh	Low	Schemenauer & Cereceda, 2025
1980s–1990s	Raschel mesh collectors, polyethylene	35–50	Balance interception and ventilation	Moderate	Fessehaye et al., 2014
1990s–2005	Large fog collectors	35–50	Balance interception and ventilation		Fernandez et al., 2018
2005–2015	Aerodynamic and biomimetic studies, functionalized polymer fibers	40–60	Improve aerodynamic collection efficiency	Very high	Alzahrani & Abdelbaki, 2025
2015–2020	Theoretical optimization studies, coated metallic mesh	45–60	Best compromise between interception and bypass flow	Very high	Ghosh, & Ganguly, 2020; Moazzam et al., 2018

Table 7. Shade coefficients for various collector shapes and geometries

Geometry / shape	Shade coefficient equation	Parameters	Reference
General geometry	$SC = \frac{A_{proj}}{A_{frontal}}$	A_{proj} : projected solid area	Rivera et al., 2011; Elshennawy et al., 2023
Porosity-based method	$SC = 1 - \varepsilon$	ε : porosity (open-area fraction)	Rivera et al., 2011; Azeem et al., 2020
Circular fibers (square arrangement)	$SC = 1 - \left(1 - \frac{d}{s}\right)^2$	d : fiber diameter, s : pitch	Rivera et al., 2011
Thin-fiber approximation	$SC \approx \frac{2d}{s}$	$d \ll s$	Rivera et al., 2011
Square fibers	$SC = 1 - \left(1 - \frac{w}{s}\right)^2$	w : fiber width	Derived from the square-mesh formulation (Elshennawy et al., 2023)
Rectangular strips	$SC = 1 - \left(1 - \frac{b}{s_x}\right)\left(1 - \frac{b}{s_y}\right)$	b : strip width	Derived from the rectangular mesh equations (Elshennawy et al., 2023)
Elliptical fibers	$SC = 1 - \left(1 - \frac{d_{proj}}{s}\right)^2$	d_{proj} : projected width	Rivera et al., 2011
Triangular fibers	$SC = 1 - \left(1 - \frac{w_{proj}}{s}\right)^2$	w_{proj} : projected width	Geometric form derived from the triangular mesh treatment of (Elshennawy et al., 2023)
Diamond-mesh (raschel nets)	$SC = 1 - \frac{A_{open}}{A_{cell}}$	Cell geometry	Elshennawy et al., 2023
Perforated plates	$SC = 1 - \frac{N\pi d_h^2}{4A_{plate}}$	N : holes, d_h : hole diameter	Rivera et al., 2011; Azeem et al., 2020
Harp collectors	$SC = \frac{A_{blocked}}{A_{total}} = \frac{Nd}{W}$, $A_{blocked} = NdH$, $A_{total} = WH$	N : wires, d : wire diameter, W : collector width	Almasi et al., 2011; Sohom et al., 2011
Chevron (V-shaped) collectors	$SC = \frac{2A_{panel}\cos\theta}{A_{frontal}}$	θ : panel angle	Ghosh et al., 2020; Amjad et al., 2026; Jin, 2019; Sharifvaghefi, & Kazerooni, 2021
Zigzag collectors	$SC = \frac{\sum A_{projected}}{A_{frontal}}$	Projected segments	Derived from projected-area methodology used in collector-shape optimization studies.
Conical fibers	$SC(z) = \frac{d(z)}{s}$	$d(z)$: variable diameter	Ju et al., 2013
Branched structures	$SC = \frac{\sum A_{proj,i}}{A_{frontal}}$	Branch projections	Biomimetic tree-like collectors; projected-area method reported in bio-inspired fog harvesting literature
Fractal structures	$SC = \frac{A_{solid}}{A_{frontal}}$	Image/CAD analysis	Numerical image-analysis method used in fractal collector studies; SC obtained from CAD/image processing
Spider-web structures	$SC = 1 - \varepsilon$	Measured porosity	Zheng et al., 2010
3D lattice structures	$SC = \frac{A_{proj}}{A_{frontal}}$	CAD projection	Additive-manufactured fog collectors; projected-area calculation from CAD models (Kaindu et al., 2025)
TPMS structures (gyroid, diamond, schwarz-p)	$SC = 1 - \frac{A_{void}}{A_{frontal}}$	Void fraction from CAD	Recent TPMS water-harvesting studies in <i>Additive Manufacturing, Materials & Design</i> , and <i>Advanced Functional Materials</i> ; CAD-derived porosity calculations (Wu et al., 2021)

Table 8. Reported aerodynamic efficiencies for various mesh geometries

Mesh geometry	Typical shade coefficient (%)	Approximate penetration range	Reference
Single raschel mesh	35–50	0.30–0.60	Schemenauer & Cereceda, 1994; Hadba et al., 2020; Rivera et al., 2011
Double raschel mesh	40–55	0.40–0.70	Rivera 2011; Fessehayee et al., 2014
Woven wire mesh (circular fibers)	40–60	0.50–0.80	Mekonnen & Hoekstra, 2016; Qi et al., 2025
Square mesh	35–55	0.45–0.75	Mekonnen & Hoekstra, 2016
Rectangular mesh	35–60	0.55–0.85	Elshennawy et al., 2023
Triangular mesh	35–55	0.45–0.75	Elshennawy et al., 2023
Hexagonal mesh	35–60	0.60–0.90	Elshennawy et al., 2023
Perforated plate	20–70	0.30–0.65	General screen-flow theory (Rivera et al., 2011)
Harp collector	10–45	0.70–0.95	Park et al., 2013; Shi et al., 2020
Inclined harp collector	10–40	0.75–0.95	Park et al., 2013; Jiang et al., 2023
Chevron (V-shaped)	20–60	0.60–0.90	Silva et al., 2024
Zigzag collector	20–60	0.55–0.85	CFD-based fog collector studies
Conical fibers (cactus-inspired)	15–50	0.60–0.90	Jiang et al., 2023
Spider-web collector	10–40	0.70–0.90	Biomimetic web studies (Jiang et al., 2023)
Branched / tree-like collector	15–50	0.60–0.90	Nature-inspired collector literature
Fractal collector	10–50	0.70–0.95	Fractal fog harvesting studies
3D lattice collector	15–60	0.60–0.95	Additive manufacturing studies (Bitonto et al., 2025)
TPMS (gyroid, diamond, schwarz-p)	20–70	0.50–0.95	Recent TPMS water-harvesting studies (Garzon et al., 2026; Renon & Jeanningros, 2025)
Hybrid mesh–harp collector	25–55	0.70–0.95	Emerging studies (2020–2026) (Shi et al., 2020)

A widely utilized model for aerodynamic efficiency was developed by de Rivera (Yang et al., 2025):

$$\eta_a = \frac{SC}{SC + \sqrt{C_o/C_d}} \quad (3)$$

where: C_o – pressure-drop coefficient of the mesh,
 C_d – drag coefficient of the collector.

Alternative form using porosity:

$$SC = 1 - \varepsilon \quad (4)$$

The equation can be written as:

$$\eta_a = \frac{1 - \varepsilon}{(1 - \varepsilon) + \sqrt{C_o/C_d}} \quad (5)$$

where: ε – mesh porosity.

Rivera employed the mesh pressure-drop coefficient from screen-flow theory:

$$C_o = 1.3SC + \left(\frac{SC}{1 - SC} \right)^2 \quad (6)$$

This equation is commonly used for woven and Raschel meshes (Elshennawy et al., 2023).

CONCLUSIONS

The design of fog-harvesting materials increasingly requires simultaneous control of surface properties and structural characteristics. Conventional materials remain attractive because of their low cost, availability, mechanical strength, and durability. However, advanced surface engineering, including hydrophilic, hydrophobic, superhydrophobic, and hybrid-wettability surfaces provides greater control over droplet nucleation, mobility, and removal. Bioinspired approaches based on cactus spines, Namib Desert beetles, spider silk, and pitcher plants further demonstrate the potential of combining wettability gradients, hierarchical structures, and low-adhesion surfaces to enhance both collection and drainage. Recent fractal, micro/nanostructured, and TPMS-based materials represent a further transition toward multifunctional fog collectors that integrate capture and water transport within the same material architecture. The future of fog-harvesting materials lies in developing durable, scalable, low-cost, and sustainable materials that integrate capture, transport, and drainage.

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REFERENCES

- Ahrestani, Z., Sadeghzadeh, S., & Emrooz, H. B. M. (2023). An overview of atmospheric water harvesting methods, the inevitable path of the future in water supply. *RSC advances*, 13(15), 10273-10307.
- Akuoko, S. Y., & Kwon, K. S. (2024). Fabrication and applications of nature-inspired surfaces with selective wettability. *Langmuir*, 40(31), 15969-15995.
- Al-Khayat, O., Hong, J. K., Beck, D. M., Minett, A. I., & Neto, C. (2017). Patterned polymer coatings increase the efficiency of dew harvesting. *ACS Applied Materials & Interfaces*, 9(15), 13676-13684.
- Almasi, A., Nosraty, H., & Mirdehghan, S. A. (2025). Fog collection improvement using harp structures formed from hairy yarns. *Scientific Reports*, 15(1), 44710.
- Alzahrani, A. S., & Abdelbaki, A. M. (2025). Fog harvesting implementation as a sustainable water source: a feasibility study in Al-Baha, Saudi Arabia. *Journal of Umm Al-Qura University for Engineering and Architecture*, 1-21.
- Amjad, M., Nguir, M., Ma, X., & Wen, D. (2026). Recent advances in bioinspired 3D printed surface architectures for enhanced condensation and fog harvesting. *npj Clean Water*, 9(1), 54.
- Azeem, M., Guérin, A., Dumais, T., Caminos, L., Goldstein, R. E., Pesci, A. I., ... & Dumais, J. (2020). Optimal design of multilayer fog collectors. *ACS applied materials & interfaces*, 12(6), 7736-7743.
- Azeem, M., Noman, M. T., Amor, N., Ali, H. M. A., & Kashif, M. (2026). Innovations in Membrane Technology for Water Harvesting from Fog: A Review. *Sustainability (2071-1050)*, 18(9), 4307.
- Bai, H., Zhao, T., Wang, X., Wu, Y., Li, K., Yu, C., et al. (2020). Cactus kirigami for efficient fog harvesting: simplifying a 3D cactus into 2D paper art. *Journal of Materials Chemistry A*, 8(27), 13452-13458.
- Batisha, A. F. (2015). Feasibility and sustainability of fog harvesting. *Sustainability of Water Quality and Ecology*, 6, 1-10.
- Bintein, P. B., Cornu, A., Weyer, F., De Coster, N., Vandewalle, N., & Terwagne, D. (2023). Kirigami fog nets: how strips improve water collection. *npj Clean Water*, 6(1), 54.
- Boutracheh, H., El Bouhaddioui, M., & Moumen, A. (2024, October). Current research priorities on fog harvesting as a clean water resource: a bibliometric approach. In: *E3S Web of Conferences*, Vol. 489, p. 05002. EDP Sciences.
- Bozorg-Haddad, O., Zolghadr-Asli, B., Sarzaeim, P., Aboutalebi, M., Chu, X., & Loáiciga, H. A. (2020). Evaluation of water shortage crisis in the Middle East and possible remedies. *Journal of Water Supply: Research and Technology—AQUA*, 69(1), 85-98.
- Cannio, M., Boccaccini, D. N., Caporali, S., & Taurino, R. (2024). Superhydrophobic materials from waste: innovative approach. *Clean Technologies*, 6(1), 299.
- Castellano, S., Mugnozza, G. S., Russo, G., Briassoulis, D., Mistriotis, A., Hemming, S., & Waaijberg, D. (2008). Plastic nets in agriculture: A general review of types and applications. *Applied Engineering in Agriculture*, 24(6), 799-808.
- Charoensook, D., Nipu, S. M. A., Girish, A., He, Q., Cheng, S., Chapman, K., et al. (2024). Three-dimensional printing of bioinspired hierarchical structures for enhanced fog collection efficiency in 3D space via vat photopolymerization. *Biomimetics*, 9(12), 734.
- Chen, K., Du, C., Yu, Y., Ji, D., Zhou, C., & Yang, S. (2026). Biomimetic wettability-gradient copper foam with hierarchical metal-organic framework and hydrophobic silane heterostructure for durable high-efficiency fog harvesting. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 140047.
- Chen, K., Tao, Y., & Shi, W. (2022). Recent advances in water harvesting: A review of materials, devices and applications. *Sustainability*, 14(10), 6244.
- Cheng Y, Zhang S, Liu S, Huang J, Zhang Z, Wang X, Yu Z, Li S, Chen Z, Zhao Y, Lai Y, Qian X, Xiao C, Fog catcher brushes with environmentally friendly slippery alumina microneedle structured surface for efficient fog-harvesting, *Journal of Cleaner Production* (2021), doi: <https://doi.org/10.1016/j.jclepro.2021.127862>.
- de Dios Rivera, J. (2011). Aerodynamic collection efficiency of fog water collectors. *Atmospheric Research*, 102(3), 335-342.
- de Dios Rivera, J., & Lopez-Garcia, D. (2015). Mechanical characteristics of Raschel mesh and their application to the design of large fog collectors. *Atmospheric Research*, 151, 250-258.
- Di Bitonto, M. G., Rodríguez Torres, N. M., Caruana, R., Angelotti, A., Guilizzoni, M., & Zanelli, A. (2025). Experimental analysis on fog harvesting by means of bi- and three-dimensional meshes: a laboratory study. *The Journal of The Textile Institute*, 116(7), 1207-1219.
- Elshennawy, A. A., Abdelaal, M. Y., Hamed, A. M., & Awad, M. M. (2023). Evaluating mesh geometry and shade coefficient for fog harvesting collectors. *Water Resources Management*, 37(15), 6107-6126.

24. Elshennawy, A. A., Awad, M. M., Abdelaal, M. Y., & Hamed, A. M. (2022). Fog collection: materials, techniques, and affecting parameters—A review. *Scientific Journal*, 2(2), 102-127[‡]
25. Fernandez, D. M., Torregrosa, A., Weiss-Penzias, P. S., Zhang, B. J., Sorensen, D., Cohen, R. E., ... & Bowman, M. (2018). Fog water collection effectiveness: Mesh intercomparisons. *Aerosol and Air Quality Research*, 18(1), 270-283[‡]
26. Fessehaye, M., Abdul-Wahab, S. A., Savage, M. J., Kohler, T., Gherezghiher, T., & Hurni, H. (2014). Fog-water collection for community use. *Renewable and Sustainable Energy Reviews*, 29, 52-62[‡]
27. Ganesh, V. A., Ranganath, A. S., Baji, A., Raut, H. K., Sahay, R., & Ramakrishna, S. (2017). Hierarchical structured electrospun nanofibers for improved fog harvesting applications. *Macromolecular Materials and Engineering*, 302(2), 1600387[‡]
28. Gao, S., Wu, S., Wu, L., Deng, Z., & Chen, Y. (2026). Accelerating droplet coalescence to enhance condensation by electrowetting-on-dielectric. *International Journal of Heat and Mass Transfer*, 256, 127986[‡]
29. Garzon, L., Ferrandiz Bou, S., Rayón Encinas, E., Abril, P., & Cobos Maldonado, C. (2026). Mechanical characterisation of stereolithography-printed TPMS scaffolds: geometry and density property relationships. *Progress in Additive Manufacturing*, 1-15[‡]
30. Ghosh, R., & Ganguly, R. (2017). Harvesting water from natural and industrial fogs—opportunities and challenges. *Droplet and spray transport: paradigms and applications*, 237-266
31. Ghosh, R., Ganguly, R. (2020). Fog harvesting from cooling towers using metal mesh: Effects of aerodynamic, deposition, and drainage efficiencies. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, 234(7), 994-1014[‡]
32. Ghosh, R., Patra, C., Singh, P., Ganguly, R., Sahu, R. P., Zhitomirsky, I., & Puri, I. K. (2020). Influence of metal mesh wettability on fog harvesting in industrial cooling towers. *Applied Thermal Engineering*, 181, 115963[‡]
33. Guo, J., Guo, Z., & Liu, W. (2025). Bio-Inspired Wettability Integrated System for Environmentally Adaptable Fog Harvesting. *Advanced Materials Technologies*, 10(5), 2401352[‡]
34. Hadba, L., Bitonto, M. G. D., Oliveira, M., Mendonça, P., Zanelli, A., & Silva, L. T. (2024). A nature-inspired green-blue solution: Incorporating a fog harvesting technique into urban green wall design. *Sustainability*, 16(2), 792[‡]
35. Hou, Y., Shang, Y., Yu, M., Feng, C., Yu, H., & Yao, S. (2018). Tunable water harvesting surfaces consisting of biphilic nanoscale topography. *ACS nano*, 12(11), 11022-11030[‡]
36. Idelchik, I. E. (1995). Handbook of hydraulic resistance. In: *Fuel and Energy Abstract*, Vol. 4, No. 36, p. 302.
37. Ielo, I., Giacobello, F., Sfameni, S., Rando, G., Galletta, M., Trovato, V., et al. (2021). Nanostructured surface finishing and coatings: Functional properties and applications. *Materials*, 14(11), 2733[‡]
38. Inbar, O., Gozlan, I., Ratner, S., Aviv, Y., Sirota, R., & Avisar, D. (2020). Producing safe drinking water using an atmospheric water generator (AWG) in an urban environment. *Water*, 12(10), 2940[‡]
39. Jarimi, H., Powell, R., & Riffat, S. (2020). Review of sustainable methods for atmospheric water harvesting. *International Journal of Low-Carbon Technologies*, 15(2), 253-276[‡]
40. Jiang, Y., Machado, C., & Park, K. C. K. (2023). From capture to transport: A review of engineered surfaces for fog collection. *Droplet*, 2(2), e55.
41. Jin, T., Peydayesh, M., Li, M., Yao, Y., Wu, D., & Mezzenga, R. (2022). Functional coating from amyloid superwetting films. *Advanced Materials*, 34(51), 2205072[‡]
42. Jin, Y. (2019). Designing Surfaces for Enhanced Water Condensation and Evaporation. KAUST Research Repository. <https://doi.org/10.25781/KAUST-0601A>.
43. Ju, J., Bai, H., Zheng, Y., Zhao, T., Fang, R., & Jiang, L. (2012). A multi-structural and multi-functional integrated fog collection system in cactus. *Nature Communications*, 3(1), 1247[‡]
44. Ju, J., Bai, H., Zheng, Y., Zhao, T., Fang, R., & Jiang, L. (2013). Bioinspired Conical Copper Wire with Gradient Wettability for Continuous and Efficient Fog Collection. *Advanced Materials*, 25(42), 5937–5942. <https://doi.org/10.1002/adma.201301876>.
45. Kaindu, J. K., Olejnicki, L. E., Kennedy, B. S., & Boreyko, J. B. (2025). Anti-clogging and anti-tangling fog harvesting with 3D-printed mesh-harp hybrids. *Journal of Materials Chemistry A*, 13(27), 22039-22046.
46. Kennedy, B. S., & Boreyko, J. B. (2024). Bioinspired fog harvesting meshes: a review. *Advanced Functional Materials*, 34(35), 2306162[‡]
47. Khan, T., Samiullah, M., Rouf, I., Sultana, S., Rahman, S., Rahman, B., & Khanum, R. (2024). The nexus of water scarcity and climate change: understanding interconnected challenges and formulating resilient strategies. *Int J Environ Sci*, 7(3), 57-68[‡]
48. Knapczyk-Korczak, J., Szewczyk, P. K., Ura, D. P., Bailey, R. J., Bilotti, E., & Stachewicz, U. (2020). Improving water harvesting efficiency of fog collectors with electrospun random and aligned Polyvinylidene fluoride (PVDF) fibers. *Sustainable materials and technologies*, 25, e00191[‡]
49. Kostal, E., Stroj, S., Kasemann, S., Matylitsky, V., & Domke, M. (2018). Fabrication of biomimetic fog-collecting superhydrophilic–superhydrophobic surface micropatterns using femtosecond lasers. *Langmuir*, 34(9), 2933-2941[‡]

50. Li, D., Li, C., Xiao, M., Zhang, M., Li, J., Yang, Z., ... & Zhao, X. (2025). Sustainable solutions for water scarcity: a review of electrostatic fog harvesting technology. *Communications Engineering*, 4(1), 34.
51. Li, J., Zhou, Y., Wang, W., Du, F., & Ren, L. (2020). A bio-inspired superhydrophobic surface for fog collection and directional water transport. *Journal of Alloys and Compounds*, 819, 152968.
52. Li, M., Xie, S., Tian, G., Chen, G., & Guo, Z. (2024). Biomimetic leaf-shaped wedge structure with mixed wettability for fog harvesting. *ACS Applied Materials & Interfaces*, 16(32), 42931-42941.
53. Lin, C. Y., Teng, T. A., Chang, H. K., & Chen, P. Y. (2025). Desert beetle-inspired hybrid wettability surfaces for fog collection fabricated by 3D printing and atmospheric pressure plasma treatment. *Biomimetics*, 10(3), 143.
54. Lindner, A., & Stamm, J. (2025). Integrating Climate Change Adaptation and Water Resource Management: A Critical Overview. *Standards*, 5(1), 4.
55. Lu, X., Liu, X., Zhang, Q., Liu, R., & Luo, J. (2026). Robust anti-fogging coatings based on silicate-PVA composites: achieving high transparency, hydrophilicity, durability and self-cleaning. *Progress in Organic Coatings*, 214, 110005.
56. Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. *Science advances*, 2(2), e1500323.
57. Mishra, R. K., Mishra, P., Verma, K., Mondal, A., Chaudhary, R. G., Abolhasani, M. M., & Loganathan, S. (2019). Electrospinning production of nanofibrous membranes. *Environmental Chemistry Letters*, 17(2), 767-800.
58. Moazzam, P., Tavassoli, H., Razmjou, A., Warkiani, M. E., & Asadnia, M. (2018). Mist harvesting using bioinspired polydopamine coating and microfabrication technology. *Desalination*, 429, 111-118.
59. Mosa, M., Radwan, F., Al-Ghobari, H., Fouli, H., & Alazba, A. A. (2024). Impact of varied fog collector designs on fog and rainwater harvesting under fluctuating wind speed and direction. *Earth Science Informatics*, 17(1), 617-631.
60. Mukheibir, P. (2010). Water access, water scarcity, and climate change. *Environmental Management*, 45(5), 1027-1039.
61. Mukherjee, S., Patel, A. K., & Kumar, M. (2019). Water scarcity and land degradation nexus in the Anthropocene: reformations for advanced water management as per the Sustainable Development Goals. In *Emerging Issues in the Water Environment during Anthropocene: A South East Asian Perspective* (pp. 317-336). Singapore: Springer Singapore.
62. Mukhopadhyay, A., Datta, A., Dutta, P. S., Datta, A., & Ganguly, R. (2024). Droplet morphology-based wettability tuning and design of fog harvesting mesh to minimize mesh-clogging. *Langmuir*, 40(15), 8094-8107.
63. Nagor, R. O. N. (2026). Simulation Design and Analysis of a Fog Catcher with Harp and Cylindrical Brush Assembly. Available at SSRN 6830786.
64. Nairizi, S. (2017). Drought and water scarcity. *International Commission on Irrigation and Drainage: New Delhi, India*.
65. Nikbakht, S., & Heyhat, M. M. (2025). Experimental study of folded metal mesh for efficient fog harvesting. *Scientific Reports*, 15(1), 19367.
66. Nørgaard, T., & Dacke, M. (2010). Fog-basking behaviour and water collection efficiency in Namib Desert Darkling beetles. *Frontiers in Zoology*, 7(1), 23.
67. Park, K. C. (2013). *Physico-chemical hydrodynamics of droplets on textured surfaces with engineered micro/nanostructures* (Doctoral dissertation, Massachusetts Institute of Technology).
68. Parker, A. R., & Lawrence, C. R. (2001). Water capture by a desert beetle. *Nature*, 414(6859), 33-34.
69. Pérez-Sánchez, J., & Mulligan, M. (2025). Catching Clouds: Mapping the Potential of Fog Water Harvesting in La Palma (Canary Islands). *Earth Systems and Environment*, 1-19.
70. Qi, X., Fang, X., Wang, Y., Chen, X., Mi, L., Liu, W., & Cui, H. (2025). Water collection and transport on bioinspired surface integrating beetles, spider webs, and cactus spines. *Langmuir*, 41(9), 6174-6185.
71. Rajaram, M., Heng, X., Oza, M., & Luo, C. (2016). Enhancement of fog-collection efficiency of a Raschel mesh using surface coatings and local geometric changes. *Colloids and Surfaces A: Physico-chemical and Engineering Aspects*, 508, 218-229.
72. Renon, C., & Jeanningros, X. (2025). A numerical investigation of heat transfer and pressure drop correlations in Gyroid and Diamond TPMS-based heat exchanger channels. *International Journal of Heat and Mass Transfer*, 239, 126599.
73. Saha, A., Datta, A., Mukhopadhyay, A., Datta, A., & Ganguly, R. (2022, December). Time-dependent droplet detachment behaviour from wettability-engineered fibers during fog harvesting. In *Conference on Fluid Mechanics and Fluid Power* (pp. 463-471). Singapore: Springer Nature Singapore.
74. Sartipizadeh, P., Mohammadzadeh, M. R., Antonini, C., & Akbari, R. (2025). Enhanced fog water harvesting on superhydrophobic steel meshes. *Advanced Engineering Materials*, 27(13), 2402378.
75. Schemenauer, R. S., & Cereceda, P. (1994). The role of wind in rainwater catchment and fog collection. *Water International*, 19(2), 70-76.
76. Shan, V., Singh, S. K., & Haritash, A. K. (2020). Water crisis in the Asian countries: status and future trends. *Resilience, response, and risk in water systems: Shifting management and natural forcings paradigms*, 173-194.
77. Sharifvaghefi, S., & Kazerooni, H. (2021). Fog

- harvesting: combination and comparison of different methods to maximize the collection efficiency. *SN Applied Sciences*, 3(4), 516.
78. Shi, W., De Koninck, L. H., Hart, B. J., Kowalski, N. G., Fugaro, A. P., van der Sloot, T. W., ... & Boreyko, J. B. (2020). Harps under heavy fog conditions: superior to meshes but prone to tangling. *ACS Applied Materials & Interfaces*, 12(42), 48124–48132.
 79. Silva-Llanca, L., Carvajal, D., Larraguibel, D., & González, B. (2024). A CFD study of the aerodynamic efficiency of V-shaped fog water collectors. *International Journal of Heat and Fluid Flow*, 107, 109382.
 80. Sivakumar, B. (2011). Global climate change and its impacts on water resources planning and management: assessment and challenges. *Stochastic Environmental Research and Risk Assessment*, 25(4), 583–600.
 81. Sohom Goswami, Ravi M. Sidhpuria, Sameer Khandekar; Effect of Droplet-Laden Fibers on Aerodynamics of Fog Collection on Vertical Fiber Arrays. *Langmuir* 19 December 2023; 39 (50): 18238–18251. <https://doi.org/10.1021/acs.langmuir.3c02022>.
 82. Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports*, 10(1), 13768.
 83. Ura, D. P., Knapczyk-Korczak, J., Szewczyk, P. K., Sroczyk, E. A., Busolo, T., Marzec, M. M., ... & Stachewicz, U. (2021). Surface potential driven water harvesting from fog. *Acs Nano*, 15(5), 8848–8859.
 84. Verbrugghe, N., & Khan, A. Z. (2023). Water harvesting through fog collectors: a review of conceptual, experimental and operational aspects. *International Journal of Low-Carbon Technologies*, 18, 392–403.
 85. Wang, Q., & Guo, Z. (2024). Durability improvement strategies for wettable fog harvesting devices inspired by spider silk fibers: a review. *Nanoscale*, 16(44), 20405–20433.
 86. Wang, S., Liu, H., Liu, G., Song, P., Liu, J., Liang, Z., ... & Ren, G. (2025). Green Superhydrophobic Surfaces: From Natural Substrates to Sustainable Fabrication Processes. *Materials*, 18(18), 4270.
 87. Wang, Y., Zhang, J., Marcotte, A. R., Karl, M., Dye, C., & Herckes, P. (2015). Fog chemistry at three sites in Norway. *Atmospheric Research*, 151, 72–81.
 88. Wang, Y., Zhao, W., Han, M., Xu, J., & Tam, K. C. (2023). Biomimetic surface engineering for sustainable water harvesting systems. *Nature Water*, 1(7), 587–601.
 89. Wu, J., Yin, K., Xiao, S., Wu, Z., Zhu, Z., Duan, J. A., & He, J. (2021). Laser fabrication of bioinspired gradient surfaces for wettability applications. *Advanced Materials Interfaces*, 8(5), 2001610.
 90. Wu, X., Wang, S., Zhao, J., Li, J., Sun, Y., Cui, P., ... & Xu, X. (2026). Fully-Printed TPMS-Architected Hygroscopic Lattices for High-Yield Solar-Powered Atmospheric Water Harvesting. *Advanced Functional Materials*, e77027.
 91. Xiao, Y., Guo, Z. (2021). Recent advances in biomimetic surfaces inspired by creatures for fog harvesting. *New Journal of Chemistry*, 45(45), 21125–21150.
 92. Xue, J., Wu, T., Dai, Y., Xia, Y. (2019). Electrospinning and electrospun nanofibers: methods, materials, and applications. *Chemical Reviews*, 119(8), 5298–5415.
 93. Yang, X., Li, S., Wang, X., Qian, X., Zhang, S. (2025). Bio-inspired fog harvesting fabric materials: Principle, fabrication, engineering applications and challenges. *Journal of Bionic Engineering*, 22(3), 1014–1038.
 94. Yi, S., Wang, J., Chen, Z., Liu, B., Ren, L., Liang, L., Jiang, L. (2019). Cactus-inspired conical spines with oriented microbarbs for efficient fog harvesting. *Advanced Materials Technologies*, 4(12), 1900727.
 95. Yin, K., Du, H., Dong, X., Wang, C., Duan, J. A., & He, J. (2017). A simple way to achieve bioinspired hybrid wettability surface with micro/nanopatterns for efficient fog collection. *Nanoscale*, 9(38), 14620–14626.
 96. Yu, Z., Yun, F. F., Wang, Y., Yao, L., Dou, S., Liu, K., et al. (2017). Desert beetle-inspired superwettable patterned surfaces for water harvesting. *Small*, 13(36), 1701403.
 97. Yu, Z., Zhu, T., Zhang, J., Ge, M., Fu, S., & Lai, Y. (2022). Fog harvesting devices inspired from single to multiple creatures: current progress and future perspective. *Advanced Functional Materials*, 32(26), 2200359.
 98. Zefrehei, A. A., Sheikhzadeh, M., & Pishavar, A. R. (2022). Evaluation of the geometrical parameters of collector mesh on the fog collection efficiency. *Journal of Industrial Textiles*, 51(2 Suppl), 3466S–3492S.
 99. Zhang, M., Liu, R., & Li, Y. (2022). Diversifying water sources with atmospheric water harvesting to enhance water supply resilience. *Sustainability*, 14(13), 7783.
 100. Zhang, Y., Yang, X., Wang, S., Liu, J., Liu, X., Chan, K., & Liu, J. (2023). Multifunctional superhydrophobic copper mesh for efficient oil/water separation and fog collection. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 657, 130603.
 101. Zhang, Y., Zhang, X., Xun, H., Gao, H., Xu, Y., Zhou, H., Niu, H. (2025). Environmentally friendly nanofiber/nylon mesh composite membrane driven by dual-asymmetric wettability for high-efficiency fog-water harvesting. *Applied Surface Science*, 164288.
 102. Zhang, X., Gan, L., Sun, B., Liu, Z., Liao, G., & Shi, T. (2022). Bio-inspired manufacturing of superwetting surfaces for fog collection and anti-icing applications. *Science China Technological Sciences*, 65(9), 1975–1994.
 103. Zheng, Y., Bai, H., Huang, Z., Tian, X., Nie, F.-Q., Zhao, Y., Zhai, J., Jiang, L. (2010). Directional water collection on wetted spider silk. *Nature*, 463, 640–643.