**A Review of Hydrogels their Classifications, and Applications**

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**Abstract**

A hydrogel is a three-dimensional network of polymers that can absorb biological fluids and is insoluble in water. A polymer network like that is created via physical crosslinking and chemical crosslinking mechanism. Whereas weak secondary forces make physical hydrogels, covalent forces form chemical hydrogels. There are numerous natural and synthetic polymers used to make hydrogels. The most significant characteristics of hydrogels are swelling, mechanical properties, and their biological properties, all of which have an impact on the hydrogel's morphology and structure. Hydrogel is used in wound dressings, tissue engineering, contact lenses, adsorbent, sensor and in medical applications, because of its water-absorbing properties and structural resemblance to the extracellular matrix (ECM). In this review hydrogels, types of hydrogels, their applications have discussed.

**1 Introduction**

**1.1 hydrogels**

Researchers, over the years, have given different definitions of hydrogels. Such as they are polymeric networks extensively swollen with water and hold onto a substantial amount of water within its structure, but insoluble in water. The hydrophilic functional groups attached to the polymeric network attributes to the absorbance and water retention property in a hydrogel. On the other hand, the cross-links between the polymeric chains attributes to their reluctance to dissolution. Hydrogels can be defined composed of two or more components having a 3-D network of polymeric chains. Hydrophilic gels are interpreted as networks of polymeric chains which are often colloidal gels having water as a medium of dispersion.1,2 Hydrogels are commonly stated as a cross-linked polymeric chains that undergoes swelling in presence of water, and are obtained through a simple reaction between one or more monomers. Its crosslinking allows it to retain its three-dimensional characteristics during its swollen phase.3 Over the past 50 years, hydrogels have drawn a lot of attention because of their extraordinary promise in a variety of applications.4 Hydrogels exhibit flexibility very similar to that of natural tissue due to their capability of carrying large water and fluid contents, such as biological fluids which may resemble biological tissues. Due to this property, a lot of interest has grown in designing the innovative devices through altering their tuneable physicochemical characteristics. Recently, synthetic hydrogels rapidly replaced natural hydrogels having distinct structures that can yield changeable functionality and degradable by additional modification. Relying upon the properties of the components utilized in polymeric network along with the density of the network joints, they can contain various amounts of water in equilibrium.5

The synthesis of hydrogels can be achieved by several chemical ways involving one-step methods like cross-linking of multifunctional monomers, polymerization, and multiple step methods which involves synthesis of polymeric chains containing highly reactive functional groups, which subsequently gets cross-linked with a suitable cross-linking agent. A polymer engineer can formulate polymeric networks possessing a molecular-scale control over structure including cross-linking density with modified features like, biodegradation, mechanical properties, biological and chemical response to stimuli.6

**1.2 Natural Gums based Hydrogels**

In the recent past, the prospected applications of natural gum polysaccharides in a range of fields of water, food, energy, environment, medicine, and biotechnology industries, have gained an eye of research fraternity, because of their accessibility, affordability, structural variety, and exceptional qualities. Natural gums or polysaccharides7 are obtainable from various tree groups, possessing extraordinary properties, including renewable, biodegradable, biocompatible, non-toxic nature and can be easily modified chemically.7 Natural gum-based hydrogels or polysaccharides provide numerous valuable properties compared to synthetic origin. In the recent years they have observed remarkable improvement as a novel alternative because of health, ecological problems and environmental contamination brought on by the unregulated usage of hydrogels made of synthetic polymers.8, 9 Hence, there is a great demand of the materials that don't damage the environment. These hydrophilic polymeric networks are insoluble in water, display higher strength and elasticity.1, 10 They are eminently responsive towards their environment, like any change in, pressure, electric field, solvent composition, pH and temperature.11,12,13 The practical importance of these hydrated polymeric network is greatly developing continuously and are valuable as biomimetic, intelligent, and intelligent materials. They have applications in sensors, actuators and frequently they are being studied as self-oscillating gels.14 Hydrogels termed as Smart networks exhibit a significant physicochemical response towards small changes in the surroundings. These alterations are reversible, and if the trigger is removed, they can go back to their original state.15

**1.3 Classification of Hydrogels**

*Based on source*: They can be of natural or synthetic origins. Natural polymers include polysaccharides like alginate and proteins like collagen and gelatine, starch, cellulose, glucomannan, pectin, hemicellulose, gums, and agarose forming hydrogels. Synthetic polymers including polyethylene glycol (PEG), polyvinyl alcohol (PVA), polyacrylic acid (PAA), polyacrylamide (PAM) that form hydrogels are conventionally synthesized using chemical polymerization methods.2

*Based on polymeric composition* or synthesis techniques:

1. Homopolymer hydrogels have basic structural and functional unit comprising of a single type of monomer in the polymeric network. Their skeletons may be cross-linked, based on the method used for polymerization as well as on the type of monomer.16
2. Copolymeric hydrogels are derived from a variety of monomeric units with at least one hydrophilic component. The polymeric network chains can be arranged in a random, block or alternating configuration. 17
3. Multipolymer interpenetrating polymeric network (IPN) can be synthesized using two separate, cross-linked components of natural or synthetic polymers, confined in a network form. In case of Semi-interpenetrating hydrogel, one polymer is a cross-linked and other polymeric component is a non-cross-linked.18 One straight polymeric chain enters another crosslinked network, and they interact without any chemical bonding.19

*Based on physical and chemical composition:* (I) Non-crystalline (Amorphous) (II) Semicrystalline, a composite of amorphous and crystalline phases. (III) Crystalline.2

*Based on cross-linked networks:* Chemically cross-linked networks have permanent bonding involving covalent interaction while physical networks have transient junctions involving entanglements of polymeric chain involving hydrogen bonds, polar or ionic, hydrophobic type of physical interactions.2

*Based on* *electrical charge*: (I) Neutral (non-ionic), (II) Ionic (including anionic or cationic), (III) Amphoteric having both acidic and basic groups, (IV) Zwitterionic (polybetaines) possess both cationic and anionic functionality in each repeating unit.2

**1.4 Preparation of hydrogels**

Hydrogels can be produced employing natural, synthetic, and composite of both natural and synthetic polymeric materials. Hydrogels have been created by cross-linking polymer chains through chemical alteration, external cross-linking agents, exposure to high energy radiation, and polymerization grafting. In the hydrogel formation chemical cross-linking involve the formation of new covalent bonds between polymeric chains in the hydrogel, where as physical cross-linking involves physical interactions between polymer chains.53 Both chemical and physical methods have their own advantages and disadvantages related with them. Conventional and controlled radical polymerization techniques results hydrogels with various morphologies, size and composition including hollow core-shell particles.54, 55 The most widely used mechanism is free radical polymerization to prepare hydrogels.56, 57 Usually in hydrogel preparation, the gel reactants react with crosslinker (s) to generate 3D-crosslinked networks in presence of radical initiators like potassium persulfate or ammonium persulfate. Free radical polymerization occurs in three main steps: initiation, propagation, and termination58. In the initiation step, free radicals (R●) are produced when an initiator dissociated and then react with other molecules (M) to produce the first radicals M●. In the propagation step highly, reactive free radicals rapidly react with molecules of monomer resulting formation of macroradicals. Usually, termination occurs by combination or disproportionation reaction of free radicals. Various shape of hydrogels like bulk, sphere, and films can be obtained by selecting the appropriate preparation process, raw material, and polymerization condition.47

*Bulk Hydrogels*: Usually, they are smoothly obtained by solution or homogeneous polymerization wherein all the reactants i.e., the monomer (or polymer), initiator, and cross- linker are soluble in the medium. The resultant hydrogel generally takes up the shape of the container in which it has been polymerized and yields a relatively homogeneous hydrogel.59 However, due to the slow diffusion of solute to the adsorption sites within hydrogel it will take long time to reach equilibrium during water treatment.60 Usually, bulk hydrogel is cut into small sized pieces manually or by using food blender to produce small size hydrogel beads for better adsorption efficiency. On the other hand, occasionally a cutting or grinding step could produce hydrogel particles with a fractured morphology and polydispersity.61, 62

*Spherical Hydrogels*: Spherical hydrogel does not require grinding or cutting and thus avoids further morphology destruction and energy consumption. Hydrogel bead is an example of spherical hydrogel with a millimetre diameter. Usually, synthesis of spherical hydrogels involves dropping the monomer or polymer suspension using syringe into a solution thus, the size of the resultant hydrogel bead typically depends on the syringe's diameter. Chitosan, a natural polysaccharide which is biodegradable, nontoxic, odourless, biocompatible and Hydrogel beads are often prepared using biopolymer. When it comes into contact with potassium and sodium cations, it can get crosslinked.63-67

*Hydrogel Films*: Hydrogel composite film appears to hold a lot of potential for practical use. They are simple to make and show robust and repeatable self-healing behaviour in the aqueous medium. Numerous hydrogels have been used as an effective ion-exchange film to purify water. Recently, the direct synthesis of nanofiber hydrogel film has been achieved using the electrospinning technology.38 Some extra components could be added to the hydrogel film either by grafting after polymerization or by combining additive with hydrogel precursor before polymerization to create a specific hydrogel composite with the required qualities.69 Hydrogel film is typically utilized as an active membrane in sensing applications, mainly to give a more hydrophilic surface that is less prone to contamination.65

**1.5 Characterization of Hydrogels**

Numerous characterisation approaches have been utilized for knowing the hydrogel’s physical and chemical properties. The physical properties of polymeric hydrogels determined by the volume fraction, effective molecular weight of the polymeric chain in between two crosslinking junction and on the density of the crosslinking.20 Hydrogels have many properties, such as absorption capacity, permeability, swelling behaviour, optical, surface, and mechanical properties. The nature of the polymer chains and the crosslinking present in the network structures play a significant function in the result of the properties of the hydrogel. All these properties are responsible for making hydrogel a promising material for a wide range of applications.21

*Fourier Transform Infrared Spectroscopy FTIR analysis*: This method provides reliable crosslinking data and gives a notion of the hydrogels' morphology.

*Atomic Force Microscopy (AFM)*: This technique helps to examine the hydrogels' surface morphology. It uses multimode atomic force microscope.

*Network Pore Size:* Various techniques, for instance, mercury porosimetry, Quasi-elastic laser light scattering, equilibrium swelling, electron microscopy, and rubber elasticity measurements experiments are employed to find out the network pore size of hydrogel. This is an important technique for hydrogel characterization.

*X-ray Diffraction*: X-ray diffraction analysis enables one to understand the crystalline and amorphous nature of hydrogel, whether the crystallinity is maintained or was distorted while synthesizing.

*Swelling Behaviour*: To study the potential use as a hydrogel, the specific swelling data studies are employed and it has been successfully studied by numerous researchers.

*Crosslinking and Mechanical Strength*: The crosslinking density inside the network structure of hydrogel determines its mechanical strength. Generally, with increasing crosslinker concentration mechanical strength of the hydrogel also increases.

*Rheology*: It depends on the kind of interactions (entanglement, association, and crosslinks) present in the polymeric network among polymer chains.

All these characterization methods provide important information about the desired crosslinking results, formation of hydrogel. Which can be useful further for various applications.3

**2 Applications of Hydrogel**

The salient features of hydrogels, they are biodegradable, hydrophilic character, biocompatible, less toxic, highly flexible like tissues and easily modifiable. They have good transport properties and the capacity to adapt to changes in the environment, such as those in pH, temperature, or metabolite concentration. Owing to their extraordinary properties, hydrogels are said to have novel applications in a number of fields like drug delivery, wound dressing, agriculture, tissue engineering, water purification, hygiene applications, etc.3,7

Because hydrogels exhibit characteristics that are comparable to those of human soft tissue, they are widely used in biomedical fields, including drug delivery.22-25, gene vectors, tissue engineering26, 27, and biosensors28, 29. Hydrogels meet both material and biological requirements because they have unique characteristics like desired functionality, reversibility, and biocompatibility. They are frequently employed for cell-laden, tissue regeneration, drug delivery, and biosensor.

*Soft Contact Lenses*: It remains one of the most popular uses for hydrogels because of their biocompatibility and mechanical properties. By dissolving the lens's water, hydrogels can be adjusted to match the curvature of the entire eye, allowing atmospheric oxygen to reach the cornea.30 Polyhydroxyethylmethacrylate (PHEMA) was the first ever established synthetic hydrogel as a favourable and great candidate for manufacture of contact lens by Wichterle and Lim (1960).3

*Tissue Regeneration and Tissue Engineering*: The loss or chronic failure of any organ function due to some severe disease or accident necessitates the demand of tissue and organ transplantations. It has becoming more difficult because there are fewer donors available and because of societal, legal, and other norms.31 Tissue engineering has raised hopes for creating a perfect live replacement that mimics the ways in which living tissues perform in the human body.3 Scaffolds act as 3-D artificial templates in which the rebuilding of targeted tissue is cultured to grow. The extremely porosity of hydrogel enables the diffusion of cells during migration, transfer of nutrients and excludes the unwanted products outside of cellular membranes.32 Hydrogels, both natural and synthetic, are utilized as scaffolds in numerous tissue engineering applications, such as the restoration of blood arteries, skin, heart valves, cartilage, and tendons.33 They have been used in a number of biomedical applications, including fillers for scar cosmetic repair7, bladder34, cartilage35, orthopaedic applications36, skin37 and bone38. Polysaccharides based hydrogels that exhibit biocompatibility with tissues which increases their significance in tissue engineering and biomedical applications.

*Wound healing*: Injured skin is covered to avoid bleeding and to protect the wound from environmental infections. Wound dressings are non-toxic, antiseptic, permeable to oxygen, preserve wound moisture, cause minimum damage, eliminates excess exudates and thus fasten the healing process while direct interacting with the wound. A great advantage of gum based hydrogel in wound dressings is that they can easily be applied or removed without interfering with the wound beds.39, 40 Compared to traditional bandages, pads, or gauzes, the mechanical characteristics of hydrogels increase their elasticity and flexibility to adapt with wounds and provide patients with immediate pain relief. They act as a coolant to localized wound in case of burn also reduces the pain and recovers from resultant damage.41, 42 Non-adhesive nature and hydrophilic surface of hydrogels do not allow it to attach with cells therefore causes less pain and discomfort to patient. Hydrogel transparency has a benefit over traditional bandages as it causes less discomfort during peeling it off. Various hydrogels for wound dressings are available, like amorphous gels, gel-impregnated gauzes, plasters or sheets. The development of hydrogel formulations to address different aspects of wound healing and management such as easy dressing, reduction in infection is attaining new heights.43, 3

*Drug Delivery*: Hydrogels' porous structure can act as a matrix for the loading or distribution of pharmaceuticals while also shielding them from harsh environments. Hydrogel targets specific sites like colon as a drug delivery agent and release drug or other nutrients timely. In addition to this hydrogel interacts very less with the drug and other loaded solute hence sustained and prolonged release occurs in the larger fraction comparative to conventional drug delivery systems.7 Because of their special ability to retain large volumes of water, hydrogels are valuable in drug delivery applications that regulate the release of solute over a predetermined length of time. This trait is known as hydrophilicity. Many biomaterials that function through two mechanisms have been investigated for this aim. (1) By adjusting the crosslinker dosage and keeping an eye on the proportion of hydrophilic to hydrophobic monomers, a controlled release of the medication can be accomplished. (2) Hydrogel release large fraction of active drug molecules (protein and peptides) because its interaction with drug is very less. Drug delivery that is targeted and controlled would help with healing and lessen unwanted side effects. Drug release from hydrogel is expressed by a number of processes, including diffusion, chemical control, deswelling, and environmentally responsive release. 3

*Agricultural Applications:* One significant step in achieving sustainable development and growth in agriculture is water management44. Superabsorbent polymeric hydrogels (SPH) derived from natural polysaccharides have gained significance in agriculture due to their remarkable capacity to hold and retain large amounts of water. In dry and semi-arid regions, SPH can be added to the soil to prolong longer moisture retention, enabling crops to tolerate arid weather. In dry and semi-arid soil, hydrogels act as "mini liquid tanks," releasing water into the soil along with the targeted amount of loaded nutrients. Modification in hydrogel properties as required give fertile physical properties of soil.45 The usage natural polysaccharides based SPH is flourishing owing to their biodegradability, durability, high water holding ability, avoid loss of nutrients, nontoxic, and their sustainability compared to synthetic polymer based hydrogels.46 Hydrogels have been used for the prevention of soil erosion over a decade by reduction in soil erosion, increasing water holding capacity, enhancing permeability of finely textured soils, enhance water infiltration among fine-textured agricultural soils. The water-soluble polyacrylamide (PAM) hydrogels form a thin film covering soil surface and are very efficient in preventing soil erosion. This film protect soil surface from washing away during irrigation and retains the optimum water content within the soil system, so that irrigation water can permeate easily.3

*Hydrogel as adsorbent:*  As we all know emerging contaminantsincluding pharmaceuticals, pesticides, industrial chemicals, metal ions, surfactants, and personal care products have elevated worldwide concern for their noteworthy hazard to marine ecosystem and human health. Many of them have no regulatory standards on the effects of chronic exposure due to the lack of information.70 These contaminants are stable under variety of circumstances such as aerobic digestion, heat and light thus they have the potential to build up and harm ecosystems. Therefore, adsorption method has been greatly adopted to treat emerging contaminates as it is really efficient and affordable.71

The use of hydrogel as an adsorbent in pollution management applications is becoming more and more popular. Both the hydrogel adsorbents and the type of adsorbate have a significant impact on the adsorption process. The Freundlich and Langmuir models provide a good interpretation for the adsorption data of emerging contaminants on hydrogels; the kinetic model is often pseudo-second-order. Because of the several interactions that occur between the adsorbate and the adsorbent, such as hydrophobic interaction, hydrogen bonding, ionic or electrostatic interaction, and π–π interaction, hydrogel adsorbents have a great affinity for pollutants. This fluctuates depending on several factors, including pH, the ionic strength of the solution, the chemical makeup of the adsorbent and adsorbate, and more. The surface of the adsorbent will have an ionic charge when the pH of the solution differs from the hydrogel adsorbents' isoelectric point. Ionic adsorbate undergoes simultaneous protonation and deprotonation at varying pH levels, leading to electrostatic interactions between them. Hence, pH is an important factor responsible for adsorption mechanism.47, 3 Many solid and liquid phase removal trials remained tracked for the elimination of pollutants from liquid such as coagulation, biochemical precipitation, adsorption, photodegradation, ion exchange, flocculation, electrochemical treatment, and membrane percolation.48-51 Of all these many methods, adsorption is seen to be superior due to its high efficiency, low effort, and ease of use. Hydrogels are thought to be special for adsorption-based water refining because of their high absorption capacity, low crystallinity, abundance of functional groups, and porous structure. Due to the several significant functional groups that polysaccharides (Gum) include in their structure, hydrogels based on them and graft copolymers have been thoroughly investigated as adsorbents for the removal of contaminants from aqueous environments, including heavy metal ions and organic dyes. The principle advantage of using natural gum-based hydrogels as adsorbents is their biocompatibility, their structure can be easily tailored according to the nature of the pollutant.52 Although hydrogels are found to be superior candidate for the elimination of several aqueous contaminants, including heavy metals, dyes and other emerging contaminates but selective adsorption of contaminates is hardly explored. Therefore, research attempts are required to prepare hydrogels with desired properties, sensitivity, and selectivity toward a specific contaminant. Many hydrogels have been developed with desirable strength and adsorption capacity, but their chemical and biological stability always ignored which needs to be considered for the sustainability and economic viability of wastewater treatment.47

*Hydrogel as sensor of heavy metal ions in environmental and biological sample*: Nonbiodegradable heavy metal ions widespread existence in water are potentially threatening to the ecosystem and living organisms. Hydrogels have been functionalized with many biomolecules, including DNA, to form stimuli-responsive sensors and materials72,73 However, for sensing application most of them rely on hydrogel phase transition or volume change. Because of their high sensor loading capacity, excellent biocompatibility, and extremely low optical background, hydrogels are perfect for optical sensor immobilization. Moreover , hydrogel backbone property such as charge and hydrophobicity can be modified by mixing with different monomers, allowing further control of sensor performance.73 As a transducer material, the stimuli-responsive hydrogel can be utilized to convert a recognition unit's reaction into a physical signal that can be detected by, e.g., quantifying the change of optical length with an optical fibre, observing the resulting change in swelling pressure under isochoric conditions or by measuring the diffracted wavelength of a polymerized crystalline colloidal array. The host-guest interactions in sensing applications have been proven to be a powerful tool. Usually, macrocyclic polyethers, i.e., crown ethers have been proved to be promising candidates in combination with hydrogel facilitated by the generation of highly selective and reversible host-guest complexes with specific alkali and heavy metal cations. Notably, the colorimetric sensing approach has garnered a lot of interest due to its direct visual perception, affordability, speed, and ease of use. Most colorimetric sensors are dispersed in sample solution for full contact with the target chemical to increase sensitivity; however, an uneven and unstable dispersion of the sensors might occasionally result in unsteady detection findings. Chemo sensors can be constructed on solid substrates to circumvent this issue. The choice of solid substrate is crucial since it has a significant impact on the sensor's sensitivity. In the sensor studies, a colorimetric chemo sensor can be formed by the design of molecules that change their colour in sample solution due to an alteration in their molecular structure in the presence of target ions.74 In aqueous conditions, the designed sensor molecule's solubility is crucial. The fact that the sensor cannot dissolve directly in water, although pollutant species, such as anion or cation, are soluble in water, is one of the most significant problems in this research. Additionally, the soluble sensor is meant to be used just once. To deal with such issues, researchers have opted to polymerize molecules that have sensing properties. According to this perspective, the sensor must be easily extracted from the sample solution and insoluble to be utilized again. Hydrogel is the best illustration of a solid support or polymer that is readily extracted from the sample solution through filtration. They are important for various sensing applications as they can be synthesized with good yield, have swelling in water, are reusable and stimuli responsive.74,75

**3 Conclusion**

The presented review demonstrates the literature concerning classification of hydrogels, their properties, and applications. Hydrogels can be integrated into systems and changed into different configurations due to their biocompatibility, sensitivity to external stimuli, and physical and chemical structure. Hydrogel-based chemical and biosensors have advanced significantly in the last several years across a wide range of application areas. The hydrogels have proven beneficial in a variety of disciplines, including energy, environmental remediation, humidity sensing, medicine, soft robotics, and health monitoring, due to its versatile composition, innate properties, and ability to adjust numerous physicochemical parameters.

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