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OVERVIEW

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Beyond rules and norms: Heterogeneity, ubiquity, and visibility of groundwaters

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Abstract

Over the last 150 years or so engineers, farmers, scientists, and many others around the globe have gained access to the waters that lie underground with drilling technology, pumps and cheap energy. Since the mid-twentieth century, a massive worldwide proliferation of deep wells has redistributed groundwaters away from springs, seeps, wells, and oases, robbing them of the water that supports local sustainable socionatural relations. The idea and social fact of groundwater has emerged in this history, and has three distinguishing features: heterogeneity, ubiquity, and visibility. The failure to halt depletion has prompted a turn to culture in the hope of governing the liquid sustainably. However, rather than grapple with the complexities and contradictions of heterogeneity, ubiquity, and visibility, these efforts take a rather thin view of culture—as rules, norms, and institutions to be studied, codified and deployed to address the crisis. This instrumental understanding of culture as a set of traits to be selectively used for arresting depletion has not proven effective, however, compelling us to rethink our cultural, political, and economic engagements with groundwater.

KEYWORDS

development, governance, groundwater, political ecology, water cultures

1 | INTRODUCTION

For more than a century and a half deep wells and pumps have provided new points of access to groundwaters, drawing the liquid away from established sources such as springs, wells and oases, as well as the uses of those waters and the human regulatory systems that sustained them. Electric and petroleum-driven pumps enable the extraction of deep waters and their incorporation into intensive capitalist agriculture and urban distribution systems, drying out ancestral sources and rupturing the relations people had developed with them and with each other. This modern emergence of groundwater is propelled and shaped by three complex, contradictory, culturally constructed features of the liquid—its heterogeneity, its ubiquity, and its invisibility—which have facilitated extraction and depletion. Now that the resulting scarcity threatens even the beneficiaries of depletion, they have mounted an effort to conserve the resource. Local understandings and uses of groundwaters that were disrupted, destroyed and rendered invisible by modernist groundwater development are now looked upon favorably as elements to be used for building sustainable governance.

Groundwaters, like rivers (Anderson et al., 2019), are "socially constituted" by humans, and cultural ideas and practices are crucial for understanding these mutual relations. In the second section of the article, I trace the history of groundwater as a modern environmental and cultural object. I suggest that a modern form of groundwater defined by science and law has enabled the historical expansion of cities and capitalist agriculture at the expense of traditional agroecological systems and the multiple groundwaters they depend on. Groundwaters are known, accessed, used and managed culturally and socially, and in the third section I discuss heterogeneity, ubiquity, and visibility: three complex and contradictory features of groundwater that enable its depletion. Groundwater is a key condition of capitalist production, and its looming scarcity has provoked governance efforts that rely heavily on ideas about cultural "rules and norms." I argue that this response fails to address problems associated with heterogeneity, ubiquity and visibility, and fails to recognize groundwater development as dispossession.

2 | THE MODERN DEVELOPMENT OF GROUNDWATER

Our current uses of and knowledge about groundwaters are the product of a long history. For most of the past, interactions with groundwaters occurred at the earth's surface. Throughout the prehistoric southwest United States people dug shallow wells or walled off springs to gain access to, conserve or divert waters found at or just below the surface (Crown, 1987; Haynes, 1999). In Europe, some of the earliest conserved wooden structures are 7000 year old wells (Tegel et al., 2012). It is still common today to excavate the earth around a spring, or in a riverbed, to expose groundwater and create a reservoir for it, a practice that confounds the distinction between surface water and groundwater (Tiki et al., 2011). Farmers in arid and semi-arid areas of the Europe, Africa and Asia have produced water using shallow wells and lifted it to the surface with a variety of devices (Yannopoulos et al., 2015). The most common device is probably the well sweep, known as *shadoof* in Arabic and *bimbalete* in Spanish, which is a see-saw or balance that can be lowered into a well to lift water to the level of the surrounding earth (Palerm-Viqueira, 2002). Other tools for lifting water from the ground include human- or animal-powered water wheels (Glick, 1977; Saadé-Sbieh et al., 2018). The *qanat* or horizontal chain well is a tunnel excavated along the course of groundwater flow, sometimes kilometers in length, that collects water and delivers it downslope by gravity to fields and households (Martinez-Santos and Martinez-Alfaro, 2012; Saadé-Sbieh et al., 2018; Motiee et al., 2006). These are found all over the Mediterranean region and the middle east, as well as in the Americas where they are known as *galerias filtrantes* (Enge & Whiteford, 1989; Palerm-Viqueira, 2004). Small-scale irrigation systems are also built on springs. Oases, where water springs up in otherwise arid conditions, are notable agricultural centers throughout north Africa, the middle east and central Asia (Fragaszy et al., 2021). The oases of southern Tunisia, for example, were made productive using an ingenious social organization that is said to have been established by the scientist Ibn Chabat in the 13th century (Ghazouani, Marleti, et al., 2012). In the Andes of Peru, groundwater emerging as isolated springs has fed sustainable irrigation systems and communities with an organizational structure and a moral economy that has roots in the Inca empire (Trawick, 2001). Similar deep agroecological histories shape society and environment in northern Mexico (Eklund, 2018; Martinez-Saldana, 2012).

Springs, especially thermal and mineral springs, hold special meaning for people, past and present and support rich traditions of social bathing. Singular sources of water that are assigned particular characteristics of smell, taste and feel, as well as powers to clean and heal, springs are often associated with spiritual beings. As the Romans conquered Europe they built bathhouses on these thermal sources, sometimes dedicated to the local deity already associated with the spring, as well as one of their own (Casal García & González Soutelo, 2010). Such is the case of the waters at Bath, England, where the Roman bathhouse was dedicated to the Celtic Sulis and Roman Minerva—a hybrid deity (Gerrard, 2007). Bathhouses were places of socialization, but also of healing, for each spring's waters were considered to have curative properties bestowed by their characteristics. The Romans, following on the Greeks, elaborated a complex conceptual array of spring waters and their associated bathing and drinking cures, which was passed down through Arab scholars to medieval Christians before renaissance and then enlightenment scholars used it as a foundation of modern chemistry and medicine (Coley, 1979, 1982; Porter, 1990; Walsh, 2021). Many springs, such as Lourdes in France, continue to hold deep religious meaning and curative powers for those who seek their waters, as do wells throughout Ireland (Foley, 2010; O'Dell, 2010).

"Modern" is a category used by historians and social scientists to refer to uses and understandings of water that emerged in a historical period characterized by the consolidation of a capitalist socioeconomic system, the rapid growth of technology and industry, the elaboration of scientific method and knowledge, bureaucratic social organization, and other defining features of the last few hundred years.[1] Since about 1850 the widespread use of drilling and pumping technology has provided access to liquid located deeper underground, shifting our conceptualization of groundwater. This accentuated vertical access to and understanding of groundwater was a key part of a modern engagement with water as a uniform, homogeneous substance (Linton, 2010) that displaced myriad, local ideas that the liquid takes specific heterogeneous forms and has both physical and spiritual properties. And, in fact, a singular water was produced as people built increasingly expansive infrastructures to combine diverse waters into one flow and public health systems imposed universal standards on that flow (Bannister & Widdifield, 2014; Gandy, 2002; Melosi, 1999; Walsh, 2021). "Hydrosocial territories" encompassed and incorporated rivers, streams, ponds, wells and other sources into a single disenchanted liquid, at the same time articulating diverse communities and their varied socionatural relationships (Boelens et al., 2016). Water in the modern age of capitalism and technoscience was managed, used, and made "legible" (Scott, 1998) across ever-larger geographical, political and cultural scales through conceptual techniques of abstraction and the assimilation of difference.

The territorial and conceptual integration of the modern hydrosphere took on a vertical dimension when city dwellers and farmers began drilling into the earth. As early as the 11th century residents of Paris tapped shallow confined aquifers to produce water (Jiang et al., 2020), but in the early 19th century the percussion method of drilling enabled a proliferation of much deeper artesian, or "flowing" wells (Garnier, 1822). British geologist William Smith laid the foundations of hydrogeology—the science of groundwater—and his student John Farey pioneered artesian well drilling in the Thames River basin in the first decade of the 19th century (Mather, 2021). By 1840 these wells were common, although efforts to find artesian water often failed due to insufficient knowledge about aquifers. It was in the 1850s, however, when John Snow showed the link between a cholera outbreak and a shallow well in London, that groundwater from deep, confined aquifers became the chosen source of clean water for rapidly growing cities. At the same time, Henry Darcy established modern scientific groundwater hydrology in his studies of the springs that supplied the cities of Europe (Worthington, 2013). During the second half of the 19th century hydrogeology grew in leaps and bounds, aquifers were mapped, wells were perforated in massive numbers for urban and agricultural uses, and motorized pumps came into use for extracting water from them.

In the 150 years that groundwater has been made widely accessible by drills and pumps, it has come to supply more than 40% of all irrigated lands worldwide, and nearly 50% of drinking water. While the effects of this extraction are geographically uneven, aquifers in many of the major food-producing regions of the world are over-exploited, with extraction far exceeding recharge and water levels falling (Famiglietti, 2014). The socioeconomic development that groundwater has supported amounts to a constant spatial redistribution of the liquid and its benefits. Pumping from three-dimensional aquifers has increased overall availability of water for agriculture and urban growth, and has relocated water use away from traditional water sources and infrastructures on or near the surface, such as rivers, springs, canals and wells. Agricultural production escaped the limits of surface water irrigation in arid and semi-arid areas with ample groundwater, such as the southwest United States and northern Mexico (Arax, 2019; Rivas-Sada, 2021; Wolfe, 2017), Spain (Llamas et al., 2015), the high plains of Kansas and Nebraska (Bessire, 2021; Opie et al., 2018), Yemen (Al Qubatee et al., 2017; Handley, 2001) and the north China Plain (Yang et al., 2015). Pumping also increased in established rain-fed agricultural zones, such as western India (Mukherji, 2006; Prakash & Ballabh, 2004; Shah, 2008) and central Mexico (Hoogesteger, 2018).

What is sometimes forgotten in this modern history of groundwater, are the dynamics of capitalism that drive the process forward. Capitalist agriculture and urban development feeds on the rents derived from resources such as land and water (Greco & Apostolopoulou, 2020; Saito, 2017), and the modern use and conceptualization of groundwater took shape on a constantly expanding irrigation frontier characterized by dispossession, colonization, capital investment, and commodity production. For example, in Mexico, United States, Central Asia, Peru, Australia and many other places, groundwater from deep wells came into play alongside the early-twentieth-century buildout of large-dam and canal infrastructure, expanding irrigation in those same areas as well as new ones that did not have ample surface water (Aboites, 2013; Arax, 2019; Bessire, 2021; Obertreis, 2017; Peloso, 1999; Slama, 2020; Walsh, 2008; Wolfe, 2017). Beginning around the 1980s, agricultural capital flowed increasingly toward the globalized production of high-value crops such as vegetables, berries, nuts and tree fruits that benefit from the cleanliness of well water and the temporal and spatial precision with which it can be applied (Zlolniski, 2018). These shifts in capitalist "food regimes" (McMichael, 2009) bring with them changes in the distribution of groundwater use, reshaping hydrosocial territories and relations. The history of urban water use and management can also be explained with the idea of "hydrosocial regimes", which highlights the way that cities expand infrastructures in periods and stages, capturing new sources of groundwater to supply emerging industries and populations (Goldman & Narayan, 2019).

The social redistribution of groundwater (Zwarteveen et al., 2017) that is driven forward by capitalist agriculture concentrates the liquid—and the rents derived from its use—in the hands of the wealthy. Groundwater extraction for agriculture requires a sizeable investment that in turn generates income that can be re-invested to expand extraction. Physically, deeper wells with more powerful pumps suck the resource away from smaller and shallower wells and surface water systems. As shallower wells and irrigation systems dry out, wealthier people with deeper wells monopolize access to groundwater, as well as land. In northern Mexico, for example, richer large landowners utilize groundwater while poor smallholders continue to depend on surface sources and infrastructures that deliver ever-less water precisely because the deep wells get to the resource first (Wolfe, 2017). This is a form of "dispossession" (Harvey, 2004) or enclosure that exacerbates social differentiation (Birkenholtz, 2009; Birkenholtz, 2015; Prakash & Ballabh, 2004; Srinivasan & Kulkarni, 2014; Tetrault & McCulligh, 2018). Accumulation and class formation are thus central to the multifaceted process of depletion. In the zero-sum game of capitalist groundwater redistribution, the rich get richer.

At the same time, since the mid-twentieth century, and often in conjunction with agrarian reform, governments have taken an active role in redistributing groundwater in a way that combats poverty and consolidates state power. Groundwater development has benefitted farmers who previously had no access to traditional irrigation systems, or to the large-scale dam and canal systems built by modernizing states. The presence of subsoil water underneath much of the landscape offers the possibility for more democratic resource use in the sense that farmers excluded from existing surface water schemes because of geography or politics are able to connect directly to the aquifer (Shah, 2005). The ready availability of water at the flip of a switch allows farmers to plant more delicate, high-value crops rather than the basic staples that are better suited to rainfall or flood irrigation. In countries such as India and Mexico, subsidized electricity for rural producers stimulates extraction and inefficient use of groundwater (Badiani et al., 2012; Scott, 2013). In the United States, federal price subsidies to basic commodities such as corn sorghum and soy bolster groundwater use on marginal lands (Sanderson & Hughes, 2019). Closely tied to packages of improved seeds and agrochemicals, government-led groundwater development allows a wider array of rural residents to increase yields, accumulate some wealth, remain on the land, and send their children to school.

Groundwater development has been embraced as a strategy by governments that hope that the wealth generated by depletion will fuel a transition to non-agricultural economic activities (Abderrahman, 2005; Allan, 2007). From this perspective, depletion is an acceptable cost of economic growth, and mentions of a crisis brought on by scarcity are alarmist "red flags" (Massuel & Riaux, 2017). At the same time, groundwater extraction to supply cities has also dewatered both agricultural systems and previous hydrosocial regimes of urban infrastructure (Furlong & Kooy, 2017; Goldman & Narayan, 2019). Regardless of whether one views it positively or negatively, the ecological and social change that groundwater development engenders is so transformative that it has been called a "revolution" (Giordano et al., 2007). Despite the enormity of these changes, groundwater development has been called a "silent" revolution because of the invisibility of deep groundwater to the naked eye (Fornes et al., 2005; Llamas & Martinez-Santos, 2005). Two decades ago, some cautioned that the inevitable end of this groundwater boom through depletion would bring social unrest (Moench, 2002). Other scholars anticipated that the economics of supply and demand would drive an evolutionary transition from development to management as groundwater becomes scarce and those who retain access to it build regulatory institutions to ensure their continued control over the resource (Shah et al., 2003, cited in Hoogesteger, 2018, p. 554). All agree, however, that for the well-being of all involved the "anarchy" (Shah, 2009) of groundwater development and the depletion it has engendered must give way to management (Kemper, 2007), or in more recent parlance, to governance (Closas & Villholth, 2020; Doornbos, 2003; Faysse & Petit, 2012; Zwarteveen et al., 2017).

Despite awareness of the crisis of depletion, groundwater enclosure proceeds apace, protagonized lately by large institutional investors wielding financial capital as much as by the small farmers who are often the subjects of state-led development (Dell'Angelo et al., 2018; Franco et al., 2013). In many cases groundwater "grabbing" is achieved by drilling deeper, but as extraction costs rise with the decline of aquifers, water prospectors search for new sites of access in order lower costs, achieve monopoly rents, and increase profits—an example of what David Harvey calls the "spatial fix" (Harvey, 1991). A telling case is that of wine grape production, which has boomed over the last 30 years in tandem with a reimagination of class and consumption practices around the world (Walsh, 2019). Eyeing handsome profits, investors are draining aquifers in central and southern California to turn previously uncultivated lands into irrigated vineyards (Fairbairn et al., 2021; Volpe et al., 2010; Yelvington et al., 2012). In some cases, the groundwater itself is the object of speculative valuation, and the grapes are grown as an added benefit. The Cadiz project, for example, cultivates grapes on a 34,000-acre property in southern California's blistering Mojave Desert while awaiting the chance to sell groundwater to the City of Los Angeles from the underlying Fenner Basin.[2] In other cases, such as California's Kern Water Bank, investors are as much interested in the empty space in depleted aquifers as they are in the remaining water, for these can be recharged with cheap surplus surface water in wet years to be used or sold for profit during times of scarcity. Regardless of the important environmental justice issues of vertical enclosure, property and unequal access, the literature on (ground)water banking focuses mostly on microeconomics and technical-political management (Maliva, 2014a, 2014b; Miller et al., 2021).

3 | CULTURAL GROUNDWATERS: HETEROGENEITY, UBIQUITY, AND VISIBILITY

The culturally constructed qualities of groundwater have contributed to its development and depletion. Groundwater today is a socionatural object forged by capitalism, and its physical, material qualities are central to our cultural engagement with it. Over the last few decades anthropologists and cognate social scientists have developed a "relational" approach that dissolves the conceptual divide between humans and water (Krause & Strang, 2016; Linton & Budds, 2014). In addition, those working in the traditions of marxist political economy and human ecology offer an expansive literature in political ecology of water (Bakker, 2003; Budds, 2004, Boelens et al., 2016; Johnston, 2003; Loftus, 2009; Martinez-Alier & Rodriguez-Labajos, 2015; Swyngedouw, 2009; Tetrault & McCulligh, 2018; Walsh, 2018). Because it links human and other forms of life to landscapes, infrastructures, climates and an array of other topics, water lends itself to this sort of integrative study; it is a "total social fact" (Orlove & Caton, 2010). Seen this way, groundwaters have culturally constructed but nonetheless material qualities that condition the way humans access, use, manage, value and think about them. In this section I explore three contradictory, culturally constructed features of groundwaters that reflect their social nature and contribute to the history of development and depletion reviewed above. These features are heterogeneity, ubiquity and visibility, and they shape our efforts to govern groundwaters, as will be discussed in Section 4.

3.1 | Heterogeneity

The modern idea of singular, uniform groundwater, like the capitalist hydrosociality that the idea is part of, is strong, pervasive, and in constant expansion. But the more that historians and social scientists look, the more we also see a thriving diversity of human relationships to multiple, heterogeneous groundwaters (Ballestero, 2019a; Barnes & Alatout, 2012; Hamlin, 2000; Hastrup, 2013; Krause & Strang, 2013; Lansing, 2007; Li, 2015; Strang, 2004; Trawick, 2001; Trawick et al., 2014; Walsh, 2018). While this diversity is inherited from the past it thrives and is reproduced in the modern context. In the Mediterranean tradition that has given rise to Euroamerican modernity, authors such as Hippocrates, Galen and Ibn Sina (Avicenna) valued waters for their particular properties (smell, taste, and appearance) and powers (healing maladies, cleaning bodies, and nourishing crops), and considered them to be items within the same genre of things, but not the same thing. Many of these particular water sources emerged from the ground as discrete springs, oases, or wells, but in a way all fresh waters were groundwaters, in that they were seen to gain their specific characteristics from the lands and climates in which they were found (Hamlin, 2000; Hamlin, 2008; Miller, 1962). This climatological view of nature continues to inform the idea that waters have powerful medical uses (Jennings, 2006). Equally rich and diverse traditions can be traced for the Americas (Mundy, 2015; Trawick, 2001) and Australia (McLean et al., 2018; Strang, 2009), for example. For most of recorded human history we know that heterogeneous waters were valued for their specific qualities and uses, and as Jamie Linton (2010) has argued, unifying them physically and conceptually was unthinkable.

Cultural understandings of groundwaters as multiple and heterogeneous are actively reproduced in the modern era. For millennia people have considered the particular taste, feel, and smell of different groundwaters to have important effects on their health, and have sought them out for drinking and bathing (Porter, 1990). The naturally occurring mineral contents of groundwaters distinguish them from other waters, and before the formation of the modern discipline of hydrogeology people nonetheless speculated about how the powers of groundwaters were related to the origins of the springs, oases and well waters they lived with (Fetter, 2004). Sodium springs were used to produce table salt (Ewald, 1985), and effervescent spring waters with dissolved CO_2 such as those from Calistoga and Pellegrino were considered especially helpful for digestion. The modern fields of chemistry and medicine emerged in Europe in the 1700s as a scientific effort to understand the physical basis of Spa cures by identifying their contents (Coley, 1982). In the 19th century, medical entrepreneurs added CO_2 as well as opium, strychnine and other drugs to bottled spring waters, and sold these "soda" waters in pharmacies as tonics and remedies. These carbonated mineral spring waters gave rise to the soft drink industry, which continues to depend heavily on groundwater (Aiyer, 2008; Nash, 2008; Walsh, 2015). The bottled water industry, which emerged in parallel to modern, homogeneous public water and is currently booming, owes much of its momentum to widely held perceptions of the diverse, beneficent, mineral content of groundwaters (Gleick, 2010; Kaplan, 2008). Rather than an obstacle to accumulation, the diversity of groundwaters and their specific use values accentuates their commodification and exchange values (Wilk, 2006).

Groundwaters are generally considered to be freer from anthropogenic contaminants than surface waters, which have more direct contact with wastewater and runoff. This is one reason why spring waters have always been a preferred source of drinking water, and in the industrial age have been marketed in bottled form (Gleick, 2010). Logic would have it that the deeper the waters, the farther they are from the source of anthropogenic pollution. And for this reason, as technology made it possible, cities turned to deep artesian wells and then to deep wells with pumps. Today's urban water systems are highly reliant on deep wells, and 50% of the world's population uses groundwater for drinking (UNESCO, 2015, p. 2). The cleanliness of deep groundwater also makes it especially desirable for irrigating fruits and vegetables that are consumed fresh, particularly those produced for export that must meet international health standards.

Groundwaters can be contaminated by human activity, and so attention to the quality of particular groundwaters considers contamination along with cleanliness; pollution with purity. Latrines, for example, foul shallow groundwaters with biological pathogens, and in agricultural areas nitrates from fertilizers and livestock feedlots percolate into the groundwater (Balazs et al., 2011; Komakech & De Bont, 2018). Dangerous industrial chemicals also pollute groundwaters. Two of the most notorious are hexavalent chromium (documented in the film *Erin Brokavich*) and MTBE, a widely used gasoline additive. But as managed aquifer recharge is increasingly employed to mitigate depletion, nitrates and many other undetected, "emergent", contaminants threaten to enter our groundwaters (Waterhouse et al., 2020). Maintaining health standards for groundwaters is thus a major challenge, despite their relative purity compared with surface waters (Back et al., 2018; Graham & Polizzotto, 2013).

While some geogenic minerals in groundwaters such as carbon dioxide, sodium, sulfur and iron are considered beneficial, arsenic and fluoride are minerals that occur naturally in groundwaters globally and cause serious health problems, including cancer and diabetes (Balazs et al., 2012; Tetrault & McCulligh, 2018). Bangladesh confronts a massive problem with arsenic at unusually shallow levels in its groundwater, which has required a national effort to identify safe wells, provide access to them, and educate people to use them (Caldwell et al., 2003; Crow & Sultana, 2002; Edmunds et al., 2015; Islam, 2014). Arsenic is especially prevalent in deeper, older strata of water, and is thus an additional cost of aquifer depletion that, like most costs associated with groundwaters, are unequally shared across lines of class, race and gender (Balazs et al., 2011; Hoogesteger, 2018; Indu et al., 2007; Sultana, 2011).

The construction and management of large-scale water systems over the last few hundred years requires a deep appreciation of the "contingency" of diverse human-environment relations (Schmidt, 2017), and so multiple heterogeneous groundwaters have emerged in tandem with singular, uniform groundwater. This relation is not one of mutual exclusivity, but rather complementarity and interdependence, as uniformity can only be constructed through the recognition of heterogeneity. To be specific, the production of uniform, clean, modern water requires knowledge about the material specificity of the diverse waters that are brought together in its making (Vogt & Walsh, 2021). Urban water managers routinely blend different sources of water to achieve acceptable levels of organochlorides or total dissolved solids, for example. In addition, capital has re-functionalized longstanding cultural traditions of valuing diverse waters to propel an enormous industry of bottled waters (Gleick, 2010; Kaplan, 2008; Wilk, 2006). The same is true for the spa industry, which continuously adapts its presentation of heterogeneous, powerful groundwaters to the specific consumer demands of the present (O'Dell, 2010). The proliferation of heterogeneous waters conforms to the logic of the diversification of commodities for variegated and segmented markets, a fundamental feature of our modern capitalist economy.

3.2 | Ubiquity

A second culturally constructed characteristic of groundwaters is their extensive distribution in three-dimensional space, a feature of the fluidity of water. While surface waters collect in and flow through low points on a landscape, groundwaters vertically saturate many kinds of geological formations, from sands to fractured hard rock. Groundwaters can thus be accessed via wells throughout the landscape, while surface waters are available to a much more limited number of people who are located near rivers, lakes, and conveyance infrastructures. For this reason, groundwater has been described as a "horizontal" resource, connoting its lateral extension underground and implying decentralized and even democratic access (Hoogesteger & Wester, 2015; Kemper, 2007; Komakech & De Bont, 2018).

This ubiquity of groundwaters enables virtually unfettered, independent access to them by individuals, but a less-recognized social dimension of ubiquity is connectivity. Individual access through wells, springs and oases creates hydrological dynamics that affect all groundwaters, and all the people who make use of them. Our taxonomies and typologies of waters establish units of analysis such as rivers, springs and aquifers that are useful for employing and managing the resource, but they are based on assumptions of separation that should not prevent us from grasping the essential fact that waters flow together; that they are connected to each other and to us. Waters are distributed both on top of and within the earth with varying degrees of connectivity and conductivity that depend on both geology (Pielou, 1998) and human action (Zwarteveen et al., 2017). For example, a river will gain or lose water from the ground of its channel; a spring is where water flows to the surface; rain recharges aquifers. But also, as shown in a long line of historical social science inspired by Julian Steward (1955), Karl Wittfogel (1957b) and others, people have organized in different forms and at various scales to build infrastructures that access, capture, store and transport waters above and below ground.

Ubiquity and individual access to groundwaters results in hydrosocial inequality and injustice. For most of human history contact with groundwaters happened at springs, oases, wells and wetlands on or very near the surface (Balbo et al., 2017; Ghazouani, Molle, & Rap, 2012). By limiting the idea of groundwater, or types of groundwaters, to that substance which can only be reached by drilling and pumping, we exclude from the discussion all those other groundwaters, as well as the agricultural systems and people who depend on them. This is important because the extraction of groundwater for urban development and capitalist agriculture using deep wells and pumps has reduced or eliminated the flow to springs and shallow wells in many places, destroying ecosystems, ancestral agroecologies, and the cultural systems that managed them. Tucson, Arizona's Santa Cruz River once supported a rich riparian ecosystem and small-scale farming, but was turned into a sandy wasteland in less than a century by deep wells that sucked away the groundwater that sustained it (Glennon, 2004). In central California, a landscape of cottonwoods and wetlands suffered the same fate as farming corporations drew down the aquifer that fed the Cuyama River (Slama, 2020). The horizontal "chain wells" in Mexico's Tehuacan Valley that supplied large-scale indigenous irrigated agricultural systems for hundreds if not thousands of years no longer produce water (Enge & Whiteford, 1989). In northern Mexico, the ancestral orchards supporting the town of Cuatrocienegas are now dry due to deep well extraction upriver, and extraction by dairy companies producing alfalfa threatens the pools and endemic flora and fauna of the neighboring United Nations Biosphere Reserve. The traditional irrigation systems of the oases of northern Africa and the Middle East have also been hit hard by groundwater extraction (Caton, 2007; Ghazouani, Marleti, et al., 2012; Mokadem et al., 2018). The physics are simple: when the level of groundwater falls due to pumping, it no longer reaches the surface in the form of springs and seeps. Individualistic extraction enabled by the ubiquity of groundwater has profound and uneven social effects.

While groundwaters seem to be physically ubiquitous and evenly accessible, Zwarteveen et al. (2017) has convincingly argued that the way groundwaters are distributed socially should be approached as a political and economic question of enclosure and dispossession. The metaphor of horizontality has also been questioned by scholars who note that it does not adequately capture groundwaters' "verticality", which is an increasingly important vector of geographical knowledge and resource extraction (Braun, 2000; De Rijke et al., 2016; Scott, 2008). It bears repeating that both horizontal and vertical access to groundwater only became possible over the last 150 years, and enabled a *re*-distribution of groundwater away from longstanding, localized groundwaters and systems.

3.3 | Visibility

A third characteristic of groundwaters that shapes their extraction and governance is visibility, or invisibility (Alley et al., 2016). Giordano (2009) points to the "language of enigma" that casts the liquid as invisible, silent, disordered, unknown and ungoverned. Invisibility is central to the assumption that groundwater is deep water, unconnected to the surface, that inhabits an "inscrutable space" constituted, as Kroepsch and Clifford (2021) explain, by physical, cultural, and political economic factors. However, the invisibility of groundwater only formed into a problem in the modern period. As we have seen, groundwaters in the form of springs, wells and other shallow sources are actually visible at the surface of the earth and have been used and governed in an transparent and sustainable fashion for millenia. The subterranean origins of those well- and spring-waters was the object of speculation until "quantitative" groundwater hydrology—and groundwater exploitation—emerged in the 19th century along with new drilling technologies

(Fetter, 2004; Worthington, 2013). Notably, the earliest widely cited reference to the invisibility of groundwaters is the 1861 judgment of Frazier versus Brown United States, at the dawn of the age of drilling and pumping.[3] Similar geological and legal uncertainty about groundwaters was expressed by scholars in the 1850s and 1860s in Mexico, as the proliferation of artesian wells reduced hydrostatic pressure and flow to existing wells and springs (Walsh, 2018, Chap. 5). Groundwater, as a universal object, came into being along with these new deep wells as an "enigma" that challenged research and regulation, and it remains such today. Management requires measurement, the mantra goes, and over the last 150 years hydrogeology has focused on producing data for models to represent and visualize the geology and flow in groundwater basins (Ballestero, 2019a), part of a regime of "governmentality" for groundwater (Birkenholtz, 2015).

Like quality and distribution, the visibility and invisibility of groundwaters is highly constructed. We cannot see underground, except perhaps by spelunking or sending cameras down mine or well shafts, and even in those cases we would not be able to see an entire aquifer or groundwater basin. Therefore, the "visibility" of these forms of groundwater requires sensing them remotely and creating data-rich scientific models to represent them. These are, again, fundamentally political and economic issues, and as Sally Babidge (2019) has shown for Chile, some social actors and their goals benefit from knowledge and visibility while others benefit from ignorance and invisibility. Another example is California's Sustainable Groundwater Management Act (SGMA), which wisely establishes the need for hydrogeological data as a basis of needed pumping reductions. While a great deal of information exists about critically overdrafted groundwater basins in that state, the idea of a lack of data is repeatedly deployed by those who benefit from unregulated access, and invisibility is actively produced by them through the withholding of, or self-reporting of, historical pumping records. Well metering is a key step toward generating shared data, but it is generally met with resistance. SGMA is based on principles of adaptive management that allow for iterative change as data becomes available, so it would seem that a strong incentive for overlying property owners to not create or provide data is to maximize the amount of water—and economic rents—that can extract during the 20-year implementation period. Groundwater is visible enough to enable individualized appropriation and rapid depletion, but apparently not visible enough for its social regulation.

Along with data, another important issue of visibility concerns which representations of groundwaters are recognized in the politics of distribution, and which are not (Ballestero, 2019b). McLean et al. (2018) show how the rise of modern uses and understandings of groundwater casts a long "shadow" on the cultural diversity of groundwaters, especially those of indigenous peoples, rendering them invisible and facilitating their destruction. Making groundwater visible is thus usually an effort to educate the public in specialized, modern forms of knowing groundwater such as hydrogeology and law, rather than to recognize and incorporate popular understandings and values for groundwaters into management regimes. Andrea Ballestero urges us to consider alternate modes of sensing and representing groundwaters by adopting concepts such "sponge" and "plume" that are more materially accurate metaphors, but also more intelligible to a large number of people beyond those who seek to enclose the resource (Ballestero, 2016). This is an argument for democratizing knowledge about groundwaters, and by extension the regulation and management of those waters, by making both the representations, and the process of generating them, more inclusive. Theorists of common-pool resource management agree that in the most successful and sustainable cases, both resource and representations are intelligible to all those who share them, and are usually generated and adapted by they themselves.

4 | GROUNDWATER GOVERNANCE

Cultural constructions of heterogeneity, ubiquity and visibility are central to the development of groundwaters, but in the search for sustainability more attention is placed on defining "rules and norms" for its use and management. By the 1800s much of the world's freshwaters had well-establish rules for access including forms of individual or collective property. But deep groundwater was new: who owned it and who was allowed to extract it? What relation did it have to streams, rivers, springs, wells, and rain? None of this was clear, and so the modern socionatural object of groundwater was born as an object of legal and scientific inquiry that was distinct from but connected to its heterogeneous manifestations at the surface (Glennon, 2004). Ubiquity and connectivity make possible a process of developmental redistribution that bypasses established uses, governance processes and institutions, and the cultural ideas and practices that sustain them. The invisibility of prior uses and property relations involving groundwaters—a culturally produced "unknowing" of hydrosocial connections (Babidge, 2019)—enabled the long developmental process of enclosure, redistribution and depletion that led to scarcity for all users. While the loss of shallow groundwaters and their agroecologies are often considered to be an acceptable cost of development, the looming threat to capitalist accumulation and social reproduction caused by the demise of this natural condition of production—what O'Connor calls the "second contradiction" of capital (O'Connor, 1998)—has propelled efforts by governments and landowners to conserve the resource.

Because it came into being socially so recently, deep groundwater does not have longstanding cultural institutions in place to manage it collectively. There are some examples of existing governance regimes for shallow groundwaters or surface waters that have succeeded in limiting groundwater extraction to some degree, such as the *huertas* (orchards) of Valencia, Spain (Trawick et al., 2014). Unfortunately, however, participants in these longstanding regimes of governance are usually unable to incorporate new points of access and new users. For example, for more than a thousand years in arid areas of western India deep community step wells supplied domestic water needs, including gardens and orchards. These were remarkable feats of engineering and design that provided resilience in a drought-prone region, had deep religious significance and were important social spaces, especially for women (Park et al., 2020). The amount of water that could be extracted from these wells was limited to that amount that could be carried by hand up and out of these elaborate structures, which sometimes reached a depth of 100 feet (Livingston, 2002). However, in the late 19th century deep wells with motorized pumps were perforated to supplement rainfed agriculture, drying the community step wells. Complicated markets for groundwater emerged, but no physical, social, cultural, or institutional limits to extraction were inherited from the step wells. The oases of northern Africa and the middle east provide many examples of how deep well technology has created the opportunity for some individuals to evade limits that maintain those traditional systems (Fragaszy et al., 2021; Ghazouani, Marleti, et al., 2012).

The bypassing and dismantling of existing cultures of sustainable groundwater use has been abetted by the neoliberal politics in vogue since the 1980s, which in principle reject state regulation in favor of decentralized entrepreneurialism and individual property rights (Budds, 2004). With access to groundwater open to anyone who can afford to extract it, there is quite literally a "race to the bottom" of aquifers in many areas of the world. Uneven spatial and social redistribution of groundwater is a constant process, for depletion causes increased costs of extraction that hurt the poor disproportionately, and concentrates access in the hands of wealthier people with deeper wells. Water moves with gravity and pressure, and although in confined aquifers water can actually move up due to this pressure, pumping often creates cones of depression that redistribute groundwater toward the pumps. Deeper, bigger wells thus often create a gradient, causing water to flow toward them.

Although groundwater development destroys existing sources of shallow groundwaters and their sustainable traditions of use and regulation, it has so far failed to produce effective governance regimes to replace them (Molle & Closas, 2019a). Nation-states that consider groundwater to be national or community property and have centralized water management agencies, such as Iran and Mexico, may formally restrict pumping, but with little compliance or enforcement (Hashemi et al., 2021; Hoogesteger, 2018; Wolfe, 2017). In other places, such as Texas, groundwater is enshrined as a form of private property inherent to land, and state government has little authority to prohibit or reduce pumping, a contrast to neighboring New Mexico, where the law considers groundwater to be a public resource (Emel et al., 1992). However, in Kansas, where there is some legal basis for comprehensive management, the Ogallala aquifer has been mined for more than a hundred years, and the government has not been able to impose pumping restrictions on landowners to stop overdraft (Bessire, 2021; Gibson & Gray, 2016; Sanderson & Hughes, 2019). In California, landowners facing pumping reductions required by the new Sustainable Groundwater Management Act (SGMA) have threatened to sue the state for taking what they consider to be "their" water. While they do not trust the state, neither do they trust each other: in at least five groundwater basins the water users and their agencies have asked the courts to adjudicate their water rights rather than work together to form a plan to reach sustainability. "Cap and trade" schemes, in which the government assigns use rights to a limited amount of groundwater and encourages a market for the resource, have also been frustrated by the reluctance of groundwater users to limit their pumping, and the inability of states to enforce those limits (Castilla-Rho et al., 2019; Crase et al., 2009).

Discussions of groundwater governance usually start with the idea that depletion is a "tragedy of the commons" (Hardin, 1968) caused by individuals maximizing their benefits from an ungoverned resource. Critics of the "tragedy of the commons" argument tend to attack the individualism inherent to that model of socionatural relations, rather than reframing the problem of groundwater management as a wider historical process of dispossession and enclosure. In response to the perceived issue of individualism, scholars and environmental managers distill design principles from existing examples of collective institutions and forms of property and use them to model participatory governance projects for common-pool resources (Agrawal, 2003; Birkenholtz, 2009; Blomquist, 1992; Castilla-Rho et al., 2019; Cleaver & de Koning, 2015; Closas & Villholth, 2020; Faysse & Petit, 2012; Langridge & Ansell, 2018; Ostrom, 1990; Schnegg et al., 2016; Trawick et al., 2014; Wagner, 2012; Wutich, 2009). As a result, governance research develops regimes of property rights for groundwater that make prior dispossessions and enclosures invisible and secure continued, sustainable access to the liquid for capitalist agriculture and urban growth.

In recognition of the failure of structural solutions to groundwater "anarchy", and uncomfortable with individualistic management plans rooted in private property and markets, some scholars have shifted toward a more cultural definition of management institutions. Rather than centralized, state management of water resources, they point to the importance of collaboration among stakeholders in government and civil society, and for a sensitivity to regional environmental and social conditions (Ansell & Gash, 2007; Villholth & Conti, 2018). Local culture and social relations are sometimes cast in a negative light, accused of enabling fraud, bribery and corruption and impeding the function of state institutions and actors (Lopez-Gunn & Martinez-Cortina, 2006). Overall, however, theorists working in the institutional approach promote collective "rules and norms" to ensure effective governance and sustainable use (Trawick et al., 2014; Wutich, 2009; Zwarteveen et al., 2017). These are considered to be diverse and contingent cultural elements, requiring a "polycentric" approach to governance that allows actors to test and choose among a range of available options (Baird et al., 2019; Lubell et al., 2010; Ostrom, 2010).

The turn to culture in groundwater governance is not without its challenges. First, having rejected a leading role for the state as a regulatory agent, the success of collaborative governance is often seen to depend on "voluntary compliance", which "implicitly assumes a certain level of common understanding and knowledge about the resource at stake" (Theesfeld, 2010, p. 137). But is it not precisely the lack of a common understanding of the roots and results of depletion, and the resulting "anarchy" among groundwater users, which is posed as the central problem that culture is to solve? While it is true that structural approaches have not produced sustainability, the spontaneous voluntarism of this formulation of culture seems more of a hope than a plan. Also, a more accurate portrayal of power would recognize that consent is rarely achieved without some degree of coercion, and so compliance is not really voluntary after all (Mann, 2009).

Education offers the possibility that groundwater users will learn to sustainably manage the resource that they share (Weintraub & Christian-Smith, 2017). Education has been successful, for example, in reducing water urban consumption in California. However, participatory polycentric governance can run aground on issues of visibility, data and representations. Wealthy groundwater users can hire experts, and often have training in the agricultural sciences, while less powerful stakeholders face challenges such as the highly technical nature of geohydrology and water law, and busy work and family lives. For example, California's SGMA requires "stakeholder participation," but in most basins here is very little participation of anyone other than large landowners, politicians, water agency officials, hired consultants and NGOs (Dobbin, 2020; Dobbin & Lubell 2021; Méndez-Barrientos et al., 2020). Media coverage contributes to this by underrepresenting the voices, perspectives and interests of the majority of residents and focusing on those of landowners (Bernacchi et al., 2020). Analysis of the first round of groundwater basin Groundwater Sustainability Plans mandated by SGMA shows a general failure of the decentralized, participatory process to adequately provide for the water security of less wealthy and powerful residents (so-called "disadvantaged communities") as well as groundwater dependent ecosystems (GDEs), and reminds us that, along with education, strong and committed oversight is needed to make polycentric governance work for all and not just the few.

The conceptualization of culture as "norms and rules" fails to capture the contradictions and inequalities that enable depletion, nor the fact that governance of groundwaters is a struggle over enclosure, dispossession and redistribution. The view of culture as a set of behavioral guidelines does not help us to understand how power imbalances motivate people to reject or evade norms and rules. Argade and Narayanan (2019), for example, show that concept of culture employed in participatory groundwater governance projects implemented at the behest of the World Bank in Maharashtra, India, did not recognize the deeper cultural and social "undercurrents" that drive extraction to unsustainable levels.

Additionally, the cultural approach to governance should integrate a more robust analysis of political economy, and a sincere effort by social movements and governments to address the links between dispossession, depletion and social inequality (Al Naber & Molle, 2017). Argade and Narayanan (2019) deploy "cultural political economy" to show how participatory governance of groundwater in India reproduces inequality along the lines of class, caste and gender, and to highlight the profound power asymmetries between communities and states. This approach is illuminating, but is principally focused on politics and would benefit from a historical and socioeconomic analysis that recognizes the tensions between agroecologies dependent on groundwaters and capitalist agrarian modes of production that utilize groundwater, as well as struggles among the various rural social classes that make up agrarian capitalism, such as bankers, merchants, small farmers, large farmers, sharecroppers, agricultural laborers and so on. Christian Zlolniski's (2018) work on the struggles of communities of largely indigenous agricultural workers in Baja California to secure access to domestic water succeeds in combining a study of groundwater politics with a wider analysis of production and class formation.

Such an approach could empower efforts by, for example, scholars of California's Sustainable Groundwater Management Act (SGMA) who advocate for the inclusion of "disadvantaged" communities in the participatory governance process stipulated by the law (Dobbin, 2020; Dobbin & Lubell, 2021). Efforts at groundwater "commoning" by environmental justice advocates would be strengthened by public-facing research on the history of groundwater enclosure, or how the agricultural economy generates communities of poor agricultural workers alongside wealthy landowners and investors, or the way that the participatory process of groundwater governance is controlled by agricultural capital and its government allies (Dobbin, 2021). In addition, engaged research should move beyond the "rules and norms" that operate in a negative fashion, and document the positive engagements people have with their groundwaters: cultivating, swimming, soaking, playing, drinking, worshipping, bathing, birdwatching, and so on. These positive hydrosocial relations provide concrete motivation for conserving and protecting groundwaters by giving meaning to the limits of groundwater and providing a reason to abide by them.

5 | CONCLUSIONS

The idea of culture finds its way into groundwater governance in partial and selective ways. It does not usually include, for example, an analysis of dispossession and enclosure, nor of the social groups or classes that win and lose from those processes. Rather, the socionatural relations of subaltern groups who practice sustainable groundwater use and management are distilled into a set of "rules and norms", and then offered as a recipe for moving beyond fundamental socioeconomic conflicts by reaching consensus and compliance among all users. In a sad irony, the proposed solution to capitalist depletion is extracted from the communities that suffer most from it. In practice, however, we find that those who suffer from depletion rarely participate in governance efforts, and that it takes strong activism and a supportive state to make the needs and perspectives of subaltern stakeholders in groundwaters visible in their terms.

According to two leading scholars of the topic, there is currently "no identified satisfactory governance solution" for groundwater (Molle & Closas, 2019a). As some groundwater scholars argue, governance should not be considered the achievement of rule, but rather an ongoing process of negotiating distribution and environmental justice among structurally unequal groups of people (Castro, 2007; Sultana & Loftus, 2020; Taylor et al., 2019; Zwarteveen & Boelens, 2014). To do this we must first recognize that in most of the world today groundwater is a condition of capitalist production, and that to be effective, groundwater management will have to confront fundamental historical processes of dispossession and enclosure. The current self-destructive "anarchy" of groundwater development is not an absence of rule, but rather a laissez-faire rule that enables enclosure, protects the resulting property, and accepts environmental destruction. Heterogeneity, ubiquity and visibility are culturally constructed aspects of groundwater that contribute to this. The developmental bargain that has widened access to groundwater through redistribution has generated prosperity and consolidated rule, but has also exacerbated the problem of depletion that now threatens all groundwater users, with the greatest costs unequally distributed to the poor and the environment. For the most part, the governance schemes that have emerged during the short social life of deep groundwater have supported depletion and its societal beneficiaries, or they have failed. A different engagement by scholars, activists and managers is needed that confronts the complicated and contradictory cultural dimensions of groundwaters, as well as the capitalist political economy that drives depletion in most of the world.

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ENDNOTES

[1] Hydrogeologists, on the other hand, sometimes use the term "modern" to denote groundwater with short subsurface residence times. In this article we use the historical and sociological definition of modern.

[2] https://mojaveproject.org/dispatches-item/the-trouble-with-cadiz/ (Retrieved 12/28/2021)

[3] "[T]he existence, origin, movement and course of [underground] waters, and the causes which govern and direct their movements, are so secret, occult and concealed, that an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would be, therefore, practically impossible." (cited in Mechlem 2016, p. 1).

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study

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FURTHER READING

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