**UNIVERSIDADE FEDERAL RURAL DE PERNAMBUCO**

**PROGRAMA DE PÓS-GRADUAÇÃO EM ETNOBIOLOGIA E CONSERVAÇÃO DA NATUREZA**

INGRID DA SILVA LIMA

# COMO A QUALIDADE DA ÁGUA INFLUENCIA O USO E AS PRÁTICAS ADAPTATIVAS EM COMUNIDADES DO SEMIÁRIDO?

RECIFE-PE

2022

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# COMO A QUALIDADE DA ÁGUA INFLUENCIA O USO E AS PRÁTICAS ADAPTATIVAS EM COMUNIDADES DO SEMIÁRIDO?

Dissertação Apresentada Ao Programa De Pós- Graduação Em Etnobiologia E Conservação Da Natureza (UFRPE, UEPB, UFPE, UPE) como parte dos requisitos para obtenção do título de Mestre

**Orientador**: Thiago Gonçalves-Souza

**Coorientadora**: Ana Haydeé Ladio

**Universidade Federal Rural de Pernambuco**

RECIFE-PE

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## DEDICATÓRIA

*Dedico este trabalho a todas mulheres que antecederam-me, as que estão por vir e a todas que tem sede.*

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**INGRID DA SILVA LIMA**

# COMO A QUALIDADE DA ÁGUA INFLUENCIA O USO E AS PRÁTICAS ADAPTATIVAS EM COMUNIDADES DO SEMIÁRIDO?

Dissertação apresentada ao Programa Pós-Graduação em Etnobiologia e Conservação da Natureza da Universidade Federal Rural de Pernambuco, como exigência para obtenção do grau de Mestre.

Defesa em 24 de maio de 2022

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**RESUMO**

A escassez e a variação da qualidade da água são problemas significativos para a saúde e o bem-estar humano. Seguindo a lógica da maximização ambiental, em locais mais secos, as pessoas tenderiam a investir em irrigação (eficiência) e uso de água de melhor qualidade para compensar o déficit hídrico (disponibilidade). Para entender melhor como os sistemas socioecológicos do semiárido lidam com a questão hídrica, e como a qualidade e acessibilidade afetam o consumo de água e as práticas adaptativas, esta pesquisa realizou uma revisão sistemática guiada pelas seguintes hipóteses: (I) Água a qualidade influencia o desenvolvimento de práticas adaptativas; (II) O acesso à água potável influencia o desenvolvimento de práticas adaptativas; (III) Fatores sociais influenciam o desenvolvimento de práticas adaptativas; (IV) O clima influencia o desenvolvimento de práticas adaptativas. Encontramos com a síntese da literatura: 31 estudos, publicados nos últimos 12 anos (2009-2021) em 13 países, totalizando 3.363 amostras de água. A maioria das amostras de água coletadas são próprias para consumo humano e irrigação, com Excelente (834 ou 27%) e Boa (1.001 ou 29%) representando 56% do total de amostras. O desenvolvimento da agricultura no semiárido é determinado pela variação regional na qualidade e quantidade da água. A relação positiva entre a prática adaptativa e o acesso à água potável, medida neste estudo pelo tamanho da área irrigada, corrobora o Modelo de Máximo Desempenho Ambiental do postulado da Teoria Socioecológica da Maximização. Nas comunidades do semiárido, as variáveis sociais e climáticas tiveram maior impacto no consumo de água e no desenvolvimento de estratégias de adaptação do que a qualidade dos recursos hídricos.

**Palavras-chave**: Adaptação, Evolução Cultural, Segurança hídrica, Resiliência, Sistemas socioecológicos.

**ABSTRACT**

Water scarcity and quality variation are two of the most significant issues to human health and well-being. Following the logic of environmental maximization, in drier places, people would tend to invest in irrigation (efficiency) and usage of better quality water to compensate for the water deficit (availability). o get a better understanding of how the semi-arid region's socio-ecological systems deal with the water issue, and how quality and accessibility affect water consumption and adaptive practices, this research conducted a systematic review guided by the following hypotheses: (I) Water quality influences the development of adaptive practices; (II) Access to potable water influences the development of adaptive practices; (III) Social factors influence the development of adaptive practices; (IV) Climate influences the development of adaptive practices. We found with the synthesis of the literature: 31 studies, published in the last 12 years (2009-2021) in 13 countries, totaling 3,363 water samples. The majority of the water samples collected are appropriate for human consumption and irrigation, with Excellent (834 or 27%) and Good (1,001 or 29%) accounting for 56%of the total samples. The development of agriculture in the semiarid zone is determined by the regional variation in water quality and quantity. The positive relationship between adaptive practice and access to potable water, as measured in this study by the size of the irrigated area, supports the Model of Maximum Environmental Performance of the Social-Ecological Theory of Maximization postulate. In semiarid communities, social and climatic variables had a bigger impact on water consumption and the development of adaptation strategies than the quality of water resources.

**Keywords**: Adaptation, Cultural Evolution, Water Security, Resilience,
Socio-ecological Systems.

## INTRODUÇÃO

A escassez e a variação da qualidade da água são dois dos problemas mais significativos para a saúde e o bem-estar humano (CASSIVI et al., 2019; WHO, 2017). A disponibilidade hídrica envolve a oferta biofísica, a demanda e o acesso à água (FAO, 2017). Embora o acesso à água potável seja uma necessidade fundamental e um direito humano, a desigualdade da água é uma questão importante para a saúde e o bem-estar humanos (ONU, 2015). Estima-se que a demanda da população mundial por água potável dobrará, e que a disponibilidade deste recurso este recurso já sofreu uma redução de 62% desde a década de 1970 (GONÇALVES e ROLIM, 2017; CONSTANTINOV, 2010).

As práticas sustentáveis de gestão da água são vitais para a resiliência contra a escassez de água intensificada pelas mudanças climáticas (SRIVASTAV et al., 2021; CHATURVEDI et al. 2013; HOWARD et al., 2010). A gestão da água (aumentando a capacidade de armazenamento; políticas justas para abastecimento e distribuição de água; e tratamento de fontes alternativas de água) e resiliência agrícola (aumentando a produção e aumentando a renda dos agricultores; garantindo a segurança alimentar e adaptando a agricultura inteligente ao clima) são dois exemplos de práticas adaptativas para lidar com as mudanças nas condições climáticas (Srivastav et al., 2021). O aumento da produção agrícola pode implicar no aumento do consumo de água (FAO, 2017). Diante destas circunstâncias, são necessários sistemas de irrigação eficientes com alta tecnologia que permitam um uso mais racional da água (DAVIS et al., 2017; ALI e TALUKDER, 2008).

Além de ser um dos recursos elementares a vida, a água também é importante para o desenvolvimento social, econômico e ambiental da população humana (CÁCERES, 2002). As pessoas, principalmente os povos originários, atribuem aos recursos hídricos valores culturais pois desenvolvem sistemas de crenças e práticas com rituais e cerimônias que dependem da água (CÁCERES, 2002). As comunidades Mapuches exemplificam a cosmovisão dos recursos hídricos, pois se relacionam com a aǵua de forma respeitosa por acreditarem que os rios e lagos reproduzem o comportamento humano e podem revidar caso sejam degradados (SKEWES et al., 2012).

As mudanças nos padrões de precipitação e temperatura estão aumentando a frequência e a intensidade das secas extremas ao redor do planeta (IPCC, 2019). Por exemplo, a área seca da produção agrícola global experimentou um aumento significativo de 1,109% devido ao aumento da duração da seca (Wang et al, 2018) e 18% da precipitação diária e extremos quentes podem ser atribuídos à temperatura atual de 0,85 °C aumento (FISCHER e KNUTTI, 2015; Chiang et al., 2021). A seca, por sua vez, compromete a economia das comunidades que vivem em regiões semiáridas, onde o saneamento básico e o abastecimento são precários ou inexistentes (ROSEGRANT e CAI, 2002). O investimento no acesso à água de qualidade reduz a vulnerabilidade e a desigualdade social das comunidades (OMS, 2017).

A mudança climática também é um dos fatores que afeta a resiliência dos sistemas socioecológicos (FOLKE e BERKERS, 2003). Os sistemas socioecológicos desenvolvem práticas e tecnologias adaptativas para conviver com as alterações no clima e lidar com a variação dos recursos no ambiente (FERREIRA JÚNIOR et al., 2015; TOMPKINS e ADGER 2003). As comunidades que convivem historicamente com a seca na região semiárida são um exemplo deste processo evolutivo pois desenvolvem práticas adaptativas para captação, purificação e armazenamento dos recursos hídricos (Azevedo et al. 2018).

A vulnerabilidade é uma questão complexa que refere-se a qualquer exposição a ameaças físicas ou socioeconômicas que possam ser mitigadas pela capacidade humana de adaptação (SORG et al., 2018). A vulnerabilidade hídrica pode ser gerada pela superpopulação de uma comunidade e/ou pressão agrícola, com escoamento de agroquímicos e industriais e condições climáticas adversas, dando origem a graves problemas de erosão e degradação da terra (Mateo-Sagasta et al, 2018). Em condições de mudança climática, essas ameaças são exacerbadas, à medida que a temperatura aumenta e os recursos hídricos se tornam mais escassos (NIKOLAOU et al., 2020). A vulnerabilidade do abastecimento de água, por sua vez, é influenciada por uma variedade de fatores, desde as condições físicas até a capacidade de gestão humana (SULLIVAN, 2011). O cálculo da vulnerabilidade à seca requer a análise dos dados de pobreza e meios de subsistência das famílias. Os locais com menores IDH, principalmente em territórios rurais, estão mais vulneráveis aos danos ambientais e sociais causados pelas secas (SATHLER, 2021; SENA et al., 2016). Há estudos que mostram que a gestão eficaz da água depende muito mais de uma governança eficaz do que de regimes hidrológicos (ANDERSON et al., 2019; SULLIVAN, 2011).

O desenvolvimento da agricultura só foi possível devido à gestão da água e práticas de irrigação durante as estações secas (RAMÓN, 1995). A agricultura é a principal fonte de renda para 16% da população que vive na pobreza e vulnerabilidade na região seca (SACHS e REID 2012) e o principal setor de consumo global de água doce e subterrânea para fins de irrigação (FAO, 2017; CHATURVEDI et al., 2013) e o mais vulnerável às mudanças climáticas, particularmente nos países mais pobres (IPCC, 2019; FAO, 2017; XING-GUO et al., 2017; MELKONYAN e ASADOORIAN 2014). A irrigação, também é influenciada por variáveis climáticas, como temperatura e precipitação local (CUNHA et al., 2015; KURUKULASURIYA et al., 2011; SEO, 2011), regiões com menos chuvas tendem a investir na prática de irrigação para mitigar a escassez de água (ALAM, 2015).

Essa prática é usada para mitigar os efeitos negativos das mudanças climáticas e da escassez de água nas plantações, além de aumentar a produtividade agrícola (CUNHA et al., 2015). A irrigação é a principal prática adaptativa utilizada por agricultores em regiões áridas (CUNHA et al., 2015; SEO, 2011; MAGRIN et al., 2007) que demonstra a capacidade dos sistemas socioecológicos de se adaptarem a distúrbios ambientais como a escassez de água. A prática de irrigação pode ser estimada com base na área potencial de irrigação e na necessidade de água por hectare (GARROTE et al., 2015). O tamanho irrigado por hectare afeta a renda familiar e o tamanho da população de uma área, seja ela úmida ou seca (KURUKULASURIYA e MENDELSOHN, 2007). Diversas entidades e grupos de pesquisa dedicam-se a entender quais fatores influenciam a qualidade da água usada para o consumo humano e irrigação (KARUNANIDHI et al., 2021; WHO, 2011). Ações e campanhas de gestores públicos e privados dos recursos hídricos também estimam uma redução do consumo doméstico, setor responsável por 10 % do uso da água do planeta (FAO, 2017). Contudo, as estratégias comprometidas com a segurança hídrica deveriam estar focadas na agricultura e indústria, setores responsáveis por 90% do uso e contaminação da água superficial e subterrânea da terra (FAO, 2017).

Embora o acesso aos recursos hídricos seja claramente um pré-requisito, as formas como eles podem ser entregues e usados variam consideravelmente dentro e entre os países (GOMEZ et al., 2019; GONZÁLEZ-GÓMEZ et al., 2020). Variando de normas e práticas locais tradicionais que remontam a gerações, até os mais recentes acordos internacionais baseados na ciência, a governança da água é a chave para apoiar as vidas e os meios de subsistência das comunidades locais (MELO et al, 2018).

As terras secas abrigam 2,3 bilhões de pessoas, o equivalente a 1/3 da população mundial (SACHS e REID, 2013). As comunidades, especialmente em regiões áridas, selecionam estratégias para responder às mudanças climáticas e garantir a segurança do uso dos recursos naturais (ALBUQUERQUE, 2006). Observações, estudos e pesquisas recentes sugerem que onde os aquíferos estão secando e a água da chuva é cada vez mais imprevisível, muitas comunidades lidam e até se preparam para a escassez de água (ZOBEIDI et al., 2022; MALEKSAEIDI e KARAMI, 2013). Combinando água salgada e doce, aumentando os intervalos entre irrigações para lidar com a escassez de água, coletando água em lagoas e aumentando a profundidade dos poços (ZOBEIDI et al., 2022), com tecnologias de conservação de água focadas no consumo inteligente de energia, minimizando o fracasso das culturas por meio do aumento uso de variedades locais tolerantes à seca (GEBRU et al., 2020; ALTIERI et al., 2017) e melhorando a captação e coleta de água para fornecer controle e independência dos recursos hídricos (TOLOSSA et al., 2020; BAGUMA et al., 2010).

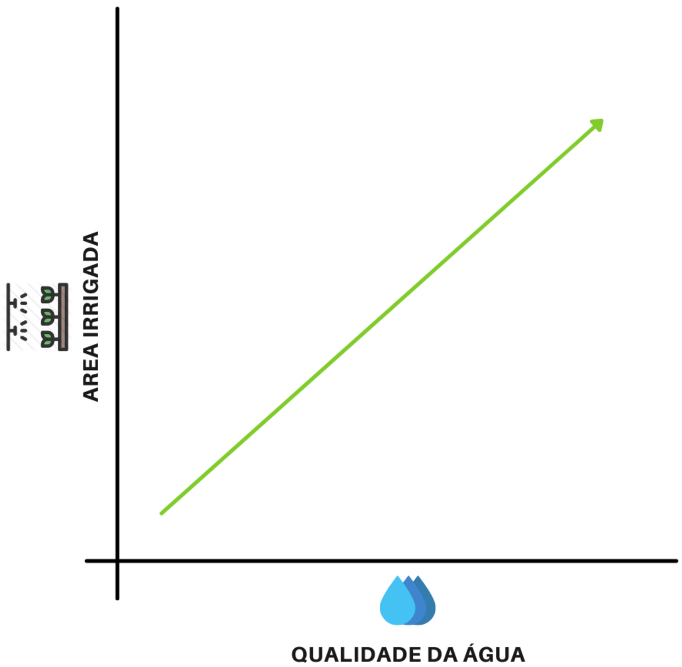
Em termos de qualidade da água, as soluções comumente criadas são: armazenamento de água, conservação e reciclagem de água, abertura de poços e tratamento de água domiciliar são algumas das técnicas domésticas para lidar com o abastecimento insuficiente de água (ABUBAKAR, 2018). Tanto no cenário atual quanto no futuro, o custo de tornar a água aproveitável além de depender das condições sociais econômicas, tende a ser menor que os benefícios trazidos à comunidade. Nas últimas décadas, tem havido um esforço crescente em investigar como a gestão das comunidades rurais e urbanas afeta a qualidade da água (BLACKSTOCK et al., 2010; MACLEOD et al., 2007). A falta de uma perspectiva cultural e comportamental sobre o manejo adaptativo da água na agricultura, por outro lado, pode limitar a precisão dos modelos de previsão da qualidade da água (BLACKSTOCK et al., 2010). O aumento dos impactos climáticos terá consequências negativas para a qualidade da água, aumentando o escoamento, alterando os regimes de temperatura e fluxos extremos

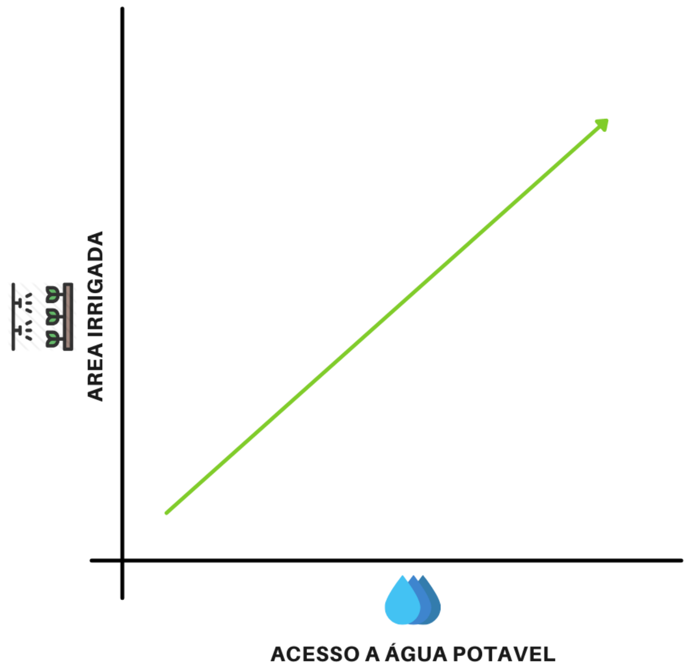
(BATES et al., 2008). As comunidades precisarão mitigar os riscos das mudanças climáticas e se adaptar às suas dificuldades para fortalecer sua resiliência (LUMB et al., 2011). Seguindo o conceito de maximizar o uso dos recursos (ALBUQUERQUE et al., 2019), as pessoas tendem a investir em estratégias adaptativas (custo) focadas na captação, tratamento e gestão para usar a água de melhor qualidade (benefício).

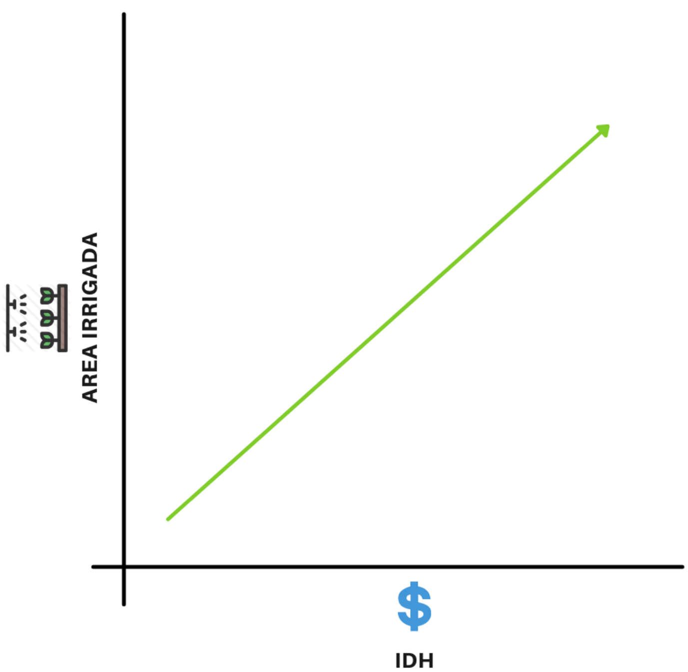
Contudo, abordagens sociais, ecológicas e econômicas também são necessárias para entender e solucionar a crescente crise hídrica global. A integração da abordagem ecológica e social é necessária para entender os processos e mecanismos que atuam na segurança hídrica dos sistemas socioecológicos (BIGGS et al., 2021; PREISER et al., 2018). Além das variáveis ambientais, fatores sociais como renda, educação e expectativa de vida também influenciam a seleção e uso do recurso, gerando heterogeneidade na população (SHACKLETON et al., 2021; LACUNA-RICHMAN, 2002; GODOY et al., 1995).

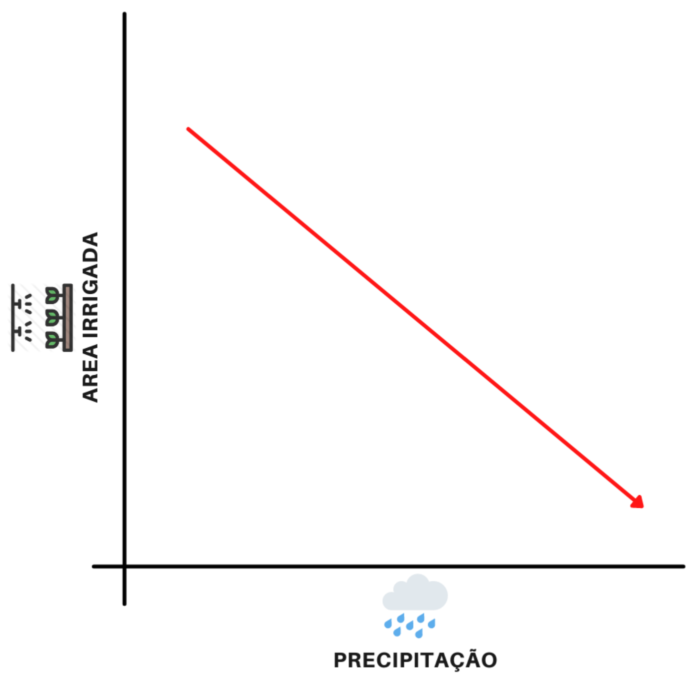
A Teoria Socioecológica da Maximização sugere que os sistemas socioecológicos são construídos e organizados por meio de processos cognitivos (aprendizagem e transmissão social) e práticas comportamentais efetivas que contribuem para a sobrevivência de grupos humanos (ALBUQUERQUE et al., 2019). De acordo com o Modelo de Máximo Desempenho Ambiental desta teoria, a introdução de práticas adaptativas em sistemas socioecológicos não é aleatória e as pessoas seguem a lógica de redução de custos e maximização de benefícios para selecionar e usar os recursos naturais (ALBUQUERQUE et al., 2019) . Por exemplo, estudos indicam que o uso de recursos naturais pode ser influenciado por sua disponibilidade espacial, domínio utilitário e que uma diminuição em sua eficiência pode ser compensada por um aumento de disponibilidade (ALBUQUERQUE et al., 2019; GONÇALVES et al., 2016). O uso de recursos tende a ser maximizado onde a disponibilidade e a eficiência estão positivamente correlacionadas (ALBUQUERQUE et al., 2019). Seguindo a lógica da maximização ambiental, em locais mais secos, as pessoas tenderiam a investir em irrigação (eficiência) e uso de água de melhor qualidade para compensar o déficit hídrico (disponibilidade).

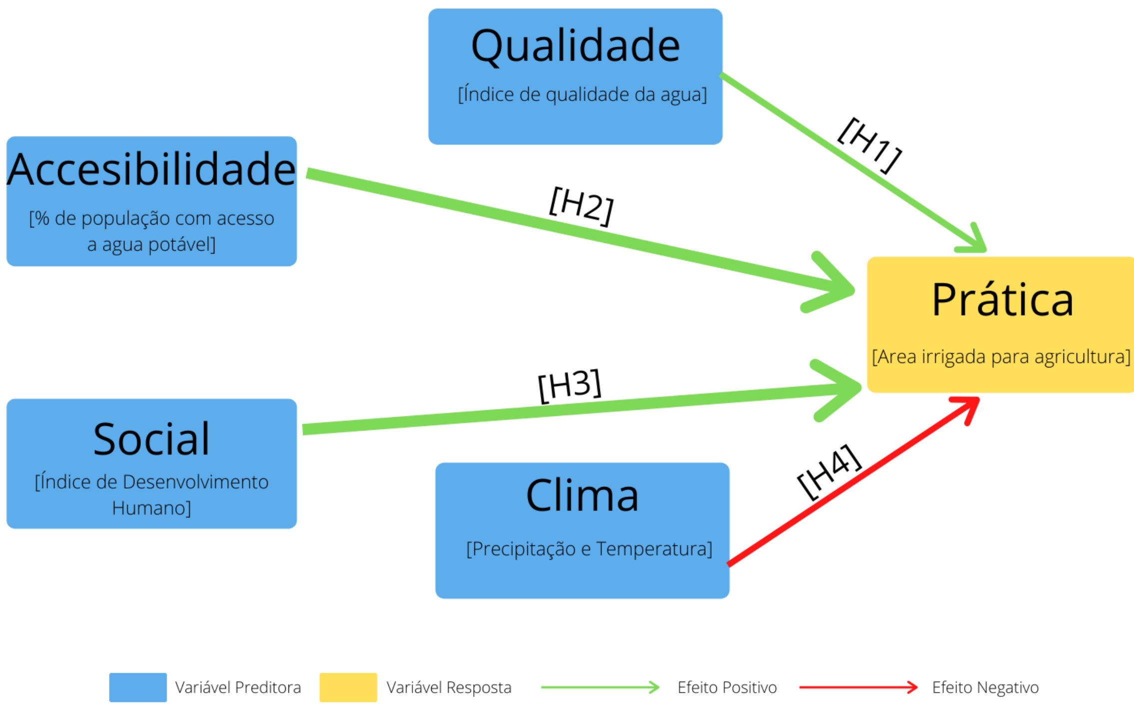
Para entender melhor como os sistemas socioecológicos do semiárido lidam com a questão hídrica, e como a qualidade e acessibilidade afetam o consumo de água e as práticas adaptativas, esta pesquisa realizou uma revisão sistemática guiada pelas seguintes hipóteses: (I) Água a qualidade influencia o desenvolvimento de práticas adaptativas; (II) O acesso à água potável influencia o desenvolvimento de práticas adaptativas; (III) Fatores sociais influenciam o desenvolvimento de práticas adaptativas; (IV) O clima influencia o desenvolvimento de práticas adaptativas.





Qualidade
[Índice de qualidade da agua]
Accesibilidade
[% de população com acesso a agua potável]
Social
[Índice de Desenvolvimento Humano]
Clima
[Precipitação e Temperatura]
Prática
[Area irrigada para agricultura]
[H1]
[H2]
[H3]
[H4]
Variável Preditora
Variável Resposta
Efeito Positivo
Efeito Negativo

# CAPÍTULO I: FUNDAMENTAÇÃO TEÓRICA

## CRISE HÍDRICA

As terras secas ocupam 41% da superfície do planeta e são habitadas por 3 bilhões de pessoas (IPCC, 2019; FAO, 2017). A escassez hídrica é uma das características sociais e ambientais históricas das regiões secas do mundo (FAO, 2017). Estas zonas áridas foram moldadas por uma combinação de baixa precipitação, secas e ondas de calor, bem como pela ocupação e ação antrópica, como uso de fogo, pastagem de gado, coleta de produtos florestais madeireiros e não madeireiros e cultivo do solo (FAO, 2017). Estas regiões são classificadas pelo índice de aridez (IA), criado pelo Programa das Nações Unidas para o Meio Ambiente (PNUMA) que usa a razão entre a precipitação média anual e a evapotranspiração potencial para categorizá-las em: hiper-áridas, terras áridas, terras semi-áridas e terras sub-húmidas secas.

As regiões áridas do planeta são as mais afetadas pelas mudanças climáticas (IPCC, 2019). As predições dos relatórios atuais estimam que o declínio na produtividade causado pelo aumento da desertificação afeta cerca de 500 milhões de pessoas que vivem em zonas áridas (IPCC, 2019). Os distúrbios no regime das chuvas e temperatura já causam perdas econômicas e na agricultura, diminuindo os ganhos dos cultivos nas áreas secas (IPCC, 2019).

A crescente demanda pela disponibilidade e acessibilidade da água segura para o consumo são um dos maiores desafios enfrentados pela população humana (CASSIVI et al., 2019; OLIVEIRA, 2017; SENA et al., 2016). O acesso a água de qualidade agrava a vulnerabilidade das comunidades e acentua a desigualdade social (SENA et al., 2016). A precarização do abastecimento de água potável influencia a saúde pública (ROJAS, 2002). Doenças relacionadas à contaminação da água vitimizam e adoecem milhares de pessoas em todo mundo. Compreender e quantificar como a relação entre a oferta e demanda de recursos naturais, a economia e a dinâmica social modulam a segurança hídrica, energética e alimentar é fundamental para manutenção do bem estar, saúde e economia das comunidades rurais e urbanas (BIGGS et al., 2015; MELO et al., 2020).

Diversas ações em todo mundo estão focadas em responder as questões socioeconômicas e ambientais causadas pelo aumento dos períodos de seca e estiagens. E na compreensão dos processos que influenciam a confiança e percepção dos consumidores sobre a qualidade das fontes de água potável disponíveis (DORIA, 2009; SILVANO et al., 2007; MORALES et al., 2020). Diversos índices de qualidade da água são usados no monitoramento espacial e temporal dos recursos hídricos pois reduzem diversos parâmetros físico-químicos em equações que facilitam a interpretação dos gestores públicos e privados (TORRES et al., 2009).

No entanto, no setor da água existem inúmeros indicadores de qualidade da água e estresse hídrico, mas a maioria deles são indicadores únicos usados para diferentes propósitos. Alguns exemplos disso são o 'Índice de Sustentabilidade da Água Canadense' também conhecido 'Índice de Qualidade da Água' (WQI) e o 'Índice de Vulnerabilidade Climática', o último integra os fatores regionais de vulnerabilidade e analisa cenários de mudanças globais para examinar futuros prováveis (SULLIVAN, 2011). O WQI foi adotado pelo Programa Ambiental das Nações Unidas (PNUMA) em 2007 como base para o Índice Global de Qualidade da Água Potável (GDWQI) e é a medida mais comum nos relatórios dos países sobre a água utilizada para consumo humano e irrigação (KARUNANIDHI et al., 2021; ROJAS, 2002). Oxigênio dissolvido, pH, turbidez, sólidos totais dissolvidos, nitratos, fosfatos e metais estão entre as métricas de WQI mais utilizadas (LUMB et al., 2011).

## ADAPTAÇÃO DE SISTEMAS SOCIOECOLÓGICOS

O conceito de Sistemas socioecológicos (SES) foi concebido na década de 1990 para entender a interação dos sistemas humanos e naturais (BERKES, 1989). A integração em várias escalas espaciais e temporais dos sistemas ecológicos e sociais é uma das principais características dos sistemas socioecológicos (BERKES e FOLKE, 2003; BIGGS et al., 2021). Fatores socioeconômicos, históricos, culturais, ecológicos e psicológicos interferem no funcionamento dos sistemas socioecológicos (SOUSA et al., 2019).

Uma das características dos sistemas sócio-ecológicos é a capacidade de adaptação aos distúrbios ambientais. As sociedades humanas desenvolvem saberes e práticas focados na otimização da obtenção e uso dos recursos naturais disponíveis em diferentes paisagens e condições ambientais (BERKES et al., 2000). O conceito de resiliência aplicado nos sistemas sócio-ecológicos indica o quanto as populações humanas são flexíveis e inovam para conviverem com as mudanças ambientais (FOLKE, 2006; ALBUQUERQUE et al., 2019). A resiliência dos sistemas socioecológicos pode ser uma ferramenta eficaz na conservação da natureza e tradições culturais, devido ao seu enfoque nos processos que atuam na seleção de estratégias usadas para lidar com os distúrbios ambientais (JÚNIOR et al., 2015).

A Etnobiologia é um ramo da ciência que nos últimos 30 anos investiga os processos adaptativos que regem as relações dinâmicas entre os sistemas humanos e naturais (BERKES et al., 2000; SOCIETY OF ETHNOBIOLOGY, 2020). A etnobiologia integra teorias de diversas abordagens científicas, principalmente dos ramos das ciências sociais e biológicas (ALVES e ALBUQUERQUE, 2014). Por exemplo, a ecologia humana é uma das teorias que a etnobiologia usa para entender como a interação com os processos naturais afetam a mente e distribuição da espécie humana (BUBOLZ E SONTAG, 2009; BEGOSSI, 2014). Entre as principais variáveis que a etnobiologia mensura para entender o comportamento humano e os processos de interação social estão: os aspectos associados à transmissão do cultural (SOLDATI, 2014), gênero e idade (TORRES-AVILEZ et al., 2014), etnia, renda e escolaridade (MEDEIROS et al., 2014) e status social (REYES-GARCÍA E GALLOIS, 2014).

A abordagem interdisciplinar da etnobiologia ganha ainda mais destaque no contexto das mudanças ambientais e culturais (WOLVERTON, 2013; VANDEBROEK et al., 2020). A etnobiologia fornece campo teórico e prático direcionados as demandas das sociedades, os problemas ambientais, a conservação da diversidade biológica e cultural, abrangendo todas as escalas: locais, regionais e global (WOLVERTON, 2013; VANDEBROEK et al., 2020). Uma das principais prioridades da etnobiologia é integrar o conhecimento ecológico local e o conhecimento científico, com base na ética socioambiental e na complexa relação pessoas-natureza (VANDEBROEK et al., 2020).

A Resiliência dos sistemas sócio-ecológicos é uma das áreas que influencia a Teoria Socioecológica da Maximização (TSM) que foi proposta em 2019 para entender os padrões que regem o comportamento humano em relação a seleção e uso dos recursos naturais (ALBUQUERQUE et al., 2019). Segundo os pressupostos da TSM a interação em diversos contextos sociais e ambientais entre as pessoas e a natureza é resultante da combinação entre a eficiência e disponibilidade do recurso (ALBUQUERQUE et al., 2019). Para garantir a sobrevivência, os sistemas socioecológicos maximizam os benefícios (por exemplo, uma planta com propriedades medicinais) e reduzem os custos (por exemplo, aquisição d e um recurso) (ALBUQUERQUE et al., 2019). Por exemplo, estudos indicam que o uso de recursos naturais pode ser influenciado por sua disponibilidade espacial, domínio de utilidade e que uma diminuição em sua eficiência pode ser compensada por um aumento de disponibilidade (Albuquerque et al., 2019; GONÇALVES et al., 2016). O uso de recursos tende a ser maximizado onde a disponibilidade e a eficiência dos recursos estão positivamente correlacionadas (ALBUQUERQUE et al., 2019).

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**CAPÍTULO 2 -** How do water quality and access affect socio-ecological system adaptation in the semiarid region?

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## HOW DO WATER QUALITY AND ACCESS AFFECT SOCIO-ECOLOGICAL SYSTEM ADAPTATION IN THE SEMIARID REGION?

Lima S. Ingrid, Ladio H. Ana, Gonçalves-Souza Thiago

**ABSTRACT**

Water scarcity and quality variation are two of the most significant issues to human health and well-being. Following the logic of environmental maximization, in drier places, people would tend to invest in irrigation (efficiency) and usage of better quality water to compensate for the water deficit (availability). To get a better understanding of how the semi-arid region's socio-ecological systems deal with the water issue, and how quality and accessibility affect water consumption and adaptive practices, this research conducted a systematic review guided by the following hypotheses: (I) Water quality influences the development of adaptive practices; (II) Access to potable water influences the development of adaptive practices; (III) Social factors influence the development of adaptive practices; (IV) Climate influences the development of adaptive practices. We found with the synthesis of the literature: 31 studies, published in the last 12 years (2009-2021) in 13 countries, totaling 3,363 water samples. The majority of the water samples collected are appropriate for human consumption and irrigation, with Excellent (834 or 27%) and Good (1,001 or 29%) accounting for 56%of the total samples. The development of agriculture in the semiarid zone is determined by the regional variation in water quality and quantity. The positive relationship between adaptive practice and access to potable water, as

measured in this study by the size of the irrigated area, supports the Model of Maximum Environmental Performance of the Social-Ecological Theory of Maximization postulate. In semiarid communities, social and climatic variables had a bigger impact on water consumption and the development of adaptation strategies than the quality of water resources.

## 1 INTRODUCTION

Water scarcity and quality variation are two of the most significant issues to human health and well-being (Cassivi et al. 2019; Who, 2017). Water availability involves the biophysical supply, the demand, and access to water (FAO, 2017). While access to safe drinking water is a fundamental need and right, water inequality is a major issue to people (UN, 2015). Around the world, 800 million people are hungry, with four million facing serious water insecurity (Maxfield, 2020). According to recent reports, nearly 80% of those who must use dangerous and unprotected water sources live in rural areas (FAO, 2017). Water and food security are addressed in two of the United Nations' seventeen Sustainable Development Goals (SDG) (UN, 2015). They aim to increase nutrition and promote sustainable agriculture (SDG 2), as well as ensuring that everyone has access to safe drinking water and sanitation (SDG 6) (UN, 2015).

Changes in precipitation patterns and rising temperatures are increasing the frequency and intensity of extreme droughts around the planet (Ipcc, 2019). For example, due to increased drought duration, the global agricultural production dry area increased by 1.109% (Wang et al, 2018), and 18% of daily precipitation and hot extremes can be attributed to the current 0.85 °C temperature increase (Fischer and Knutti, 2015; Chiang et al, 2021). Also, drought compromises the economy of communities living in semi-arid regions, where basic sanitation and supply are precarious or non-existent (Rosegrant and Cai, 2002). Access to quality water reduces the vulnerability and social inequality of communities (Who, 2017).

Agriculture is the primary source of income for the 16% of the population who live in poverty and vulnerability in the dry region (Sachs and Reid 2012) and the principal sector of consumption of global freshwater and groundwater for irrigation purpose (Fao, 2017; Chaturvedi et al. 2013) and the most vulnerable to climate change, particularly in the poorest countries (Ipcc, 2019; Fao, 2017; Xing-Guo et al. 2017; Melkonyan and Asadoorian 2014). Sociological systems develop practices and technologies to adapt to living with environmental changes (Tompkins and Adger 2003).

Sustainable water management practices are vital for resilience against water scarcity intensified by climate change (Srivastav et al. 2021; Chaturvedi et al. 2013; Howard et al. 2010). Water management (by increasing storage capacity; fair policies for water supply and distribution; and treatment alternative sources of water) and agriculture resilience (by increasing production and raising farmer income; ensuring food security and adapting climate smart agriculture) are two examples of adaptive practices to deal with changes in climatic conditions (Srivastav et al. 2021). The increase in agricultural production may imply an increase in water consumption (FAO, 2017). In consideration of this circumstance, is needed are efficient irrigation systems with high technology that allows a more rational use of water (Davis et al, 2017; Ali and Talukder, 2008).

Irrigation is the major adaptive practice used by farmers in arid regions (Cunha et al. 2015; Seo, 2011; Magrin et al. 2007) that demonstrates socio-ecological systems' ability to adapt to environmental disturbances such as water scarcity. The irrigation practice could be estimated based potential irrigation area and per-hectare water requirement (Garrote et al, 2015). The irrigated size per hectare has an effect on family income and population size of an area, whether it is wet or dry (KURUKULASURIYA and MENDELSOHN, 2007). Irrigation systems include surface, sprinkler, spot, and sub-irrigation, and they vary based on climate diversity, crops, energy availability, conditions and water efficiency (Allen et al. 2020). This practice is used to mitigate the negative effects of climate change and water scarcity on crops while also increasing agricultural productivity (Cunha et al. 2015). Irrigation, on the other hand, is also influenced by climatic variables such as local temperature and precipitation (Cunha et al. 2015; Kurukulasuriya et al., 2011; Seo, 2011), regions with the least rainfall have a tendency to invest in the practice of irrigation to mitigate water scarcity (Alam, 2015).

Vulnerability it's a complex issue related to any exposure to physical or socioeconomic threat which can be mitigated by human capacity for adaptation (Sorg et al, 2018). Water vulnerability could be generated from overpopulation of a community and/or farming pressure, with agrochemical and industrial runoff and harsh weather conditions giving rise to severe problems of erosion and land degradation (Mateo-Sagasta et al, 2018). Under conditions of climate change, these threats are exacerbated, as temperature rises and water resources become more scarse (Nikolaou et al, 2020).

Water supply vulnerability is influenced by a variety of factors, from physical conditions to human management capabilities (Sullivan, 2011). Calculating drought vulnerability requires the analysis of poverty and household livelihood data. In addition to environmental variables, social factors such as income, education and life expectancy also influence the selection and use of resource, generating heterogeneity in the population (Shackleton et al. 2021; Lacuna-Richman, 2002; Godoy et al. 1995). Places with lower Human Development Index (HDI), mainly in rural territories, are more vulnerable to environmental and social damage caused by droughts (Sathler, 2021; Sena et al, 2016). There are studies that show that  effective water management is much more dependent on effective governance than on hydrological regimes (Anderson et al, 2019; Sullivan, 2011).

While access to water resources is clearly a prerequisite, the ways these can be delivered and used vary considerably both within and between countries (Gomez et al, 2019; González-Gómez et al, 2020). Ranging from traditional local norms and practices dating back through generations, to the latest state-of-the-art science-based international agreements, water governance is a key to supporting the lives and livelihoods of local communties (Melo et al, 2018).

Drylands are home to 2.3 billion people, equivalent to 1/3 of the world's population (Sachs and Reid, 2013). Communities, especially in arid regions, select strategies to respond to climate change and ensure the security of natural resources use (Albuquerque, 2006). Recent observations, studies and research suggest where aquifers are drying up and rainwater is increasingly unpredictable many communities cope and even prepare for water scarcity (Zobeidi et al, 2022; Maleksaeidi and Karami, 2013), in irrigation management included changing irrigation time, using unconventional water, combining saline and freshwater, increasing inter-irrigation intervals to cope with water scarcity, water collection in ponds, and increasing wells depth (Zobeidi et al, 2022), with water conservation technologies focous on smart energy consumption, minimizing crop failure through increased use of drought-tolerant local varieties (Gebru et al, 2020; Altieri et al, 2017), and improve water catchment and harvesting to provide independent control of water resources (Tolossa et al, 2020; Baguma et al, 2010).

In terms of the water quality, commonly created solutions are: water storage, water conservation and recycling, boreholes, and home water treatment are some of the household techniques for dealing with insufficient water supply (Abubakar, 2018). In both current and future scenarios, the cost of making water usable must be lower than the benefits and that it also depends on the community's structural-economic constraints. In recent decades, there has been a growing focus on how the management of rural and urban communities management affects water quality (Blackstock et al, 2010;

Macleod et al., 2007). The lack of a cultural and behavioral perspective on adaptive agricultural water management, on the other hand, may limit the accuracy of water quality prediction models (Blackstock et al, 2010). Increased climate impacts will have negative consequences for water quality by increasing runoff, changing temperature regimes, and extreme flows (Bates et al., 2008). Communities will need to mitigate climate change risks and adapt to its difficulties in order to strengthen their resilience (Lumb et al, 2011). Following the concept of maximizing the use of resources (Albuquerque et al., 2019), people tended to use better quality water sources and invest in adaptive strategies for their collection, treatment, and management.

Social-Ecological Theory of Maximization suggests that social-ecological systems are constructed and organized through cognitive processes (social learning and transmission), and behavioral effective practices that contribute to the survival of human groups (Albuquerque et al., 2019). According to the Model of Maximum Environmental Performance of this theory, the introduction of adaptive practices into social-ecological systems is not random and people follow the logic of cost reduction and benefit maximization to select and use natural resources (Albuquerque et al., 2019). For example, studies indicate that the use of natural resources can be influenced by their spatial availability, utility domain and that a decrease in its efficiency could be compensated by an increase in availability (Albuquerque et al., 2019; Gonçalves et al, 2016). Resource use tends to be maximized where resource availability and efficiency are positively correlated (Albuquerque et al., 2019). Following the logic of environmental maximization, in drier places, people would tend to invest in irrigation (efficiency) and usage of better quality water to compensate for the water deficit (availability).

One of the obstacles in overcoming the water crisis is the gap between the socio-ecological systems adaptive strategies and the reports on water quality that are measured by physico-chemical and microbiological parameters instead to analyzing the people's adaptive practices developed for dealing with water scarcity. Several water quality indices are used in the spatial and temporal monitoring of water resources as they reduce many physical-chemical parameters in equations that facilitate the interpretation of public and private managers (Torres et al. 2009). However, in the water sector there are numerous indicators of water quality and water stress, but most of these are single indicators used for different purposes. Some examples of this are the 'Canadian Water Sustainability Index' also known 'Water Quality Index' (WQI) and the 'Climate Vulnerability Index', the last integrates the regional factors of vulnerability, and analyzes global change scenarios to examine probable futures (Sullivan, 2011). The WQ was adopted by the United Nations Environmental Program (UNEP) in 2007 as a basis for the Global Drinking Water Quality Index (GDWQI) and is the most common measure in countries' reports on water used for human consumption and irrigation (Karunanidhi et al, 2021; Rojas, 2002). Dissolved oxygen, pH, turbidity, total dissolved solids, nitrates, phosphates, and metals are among the most regularly utilized WQI metrics (Lumb et al, 2011). The cost of making water usable must be lower than the benefits and that it also depends on the structural-economic constraints of the community.

To get a better understanding of how the semi-arid region's socio-ecological systems deal with the water issue, and how quality and accessibility affect water consumption and adaptive practices, this research conducted a systematic review guided by the following hypotheses (Figure 1): (I) Water quality influences the development of adaptive practices; (II) Access to potable water influences the development of adaptive practices; (III) Social factors influence the development of adaptive practices; (IV) Climate influences the development of adaptive practices.

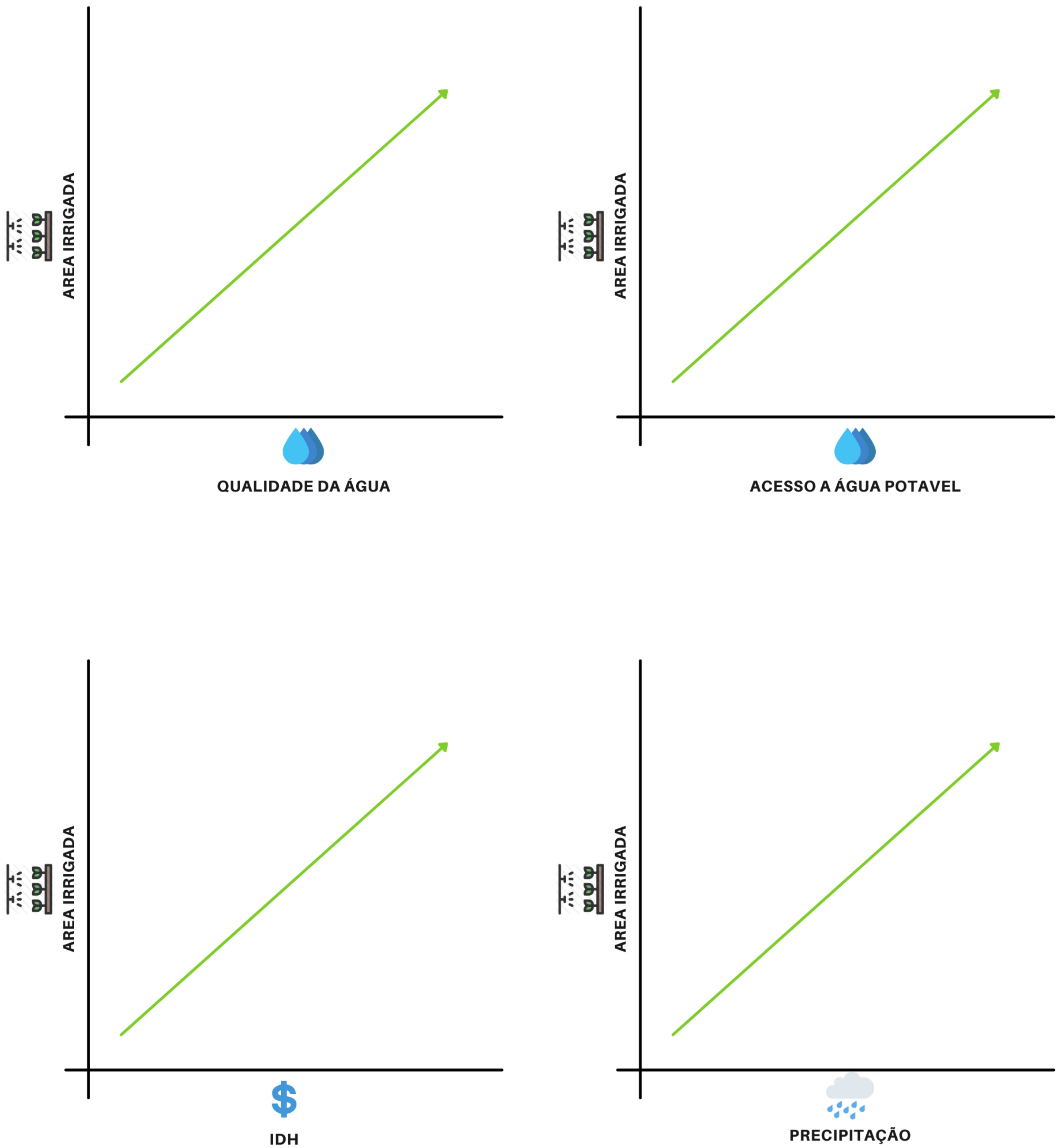
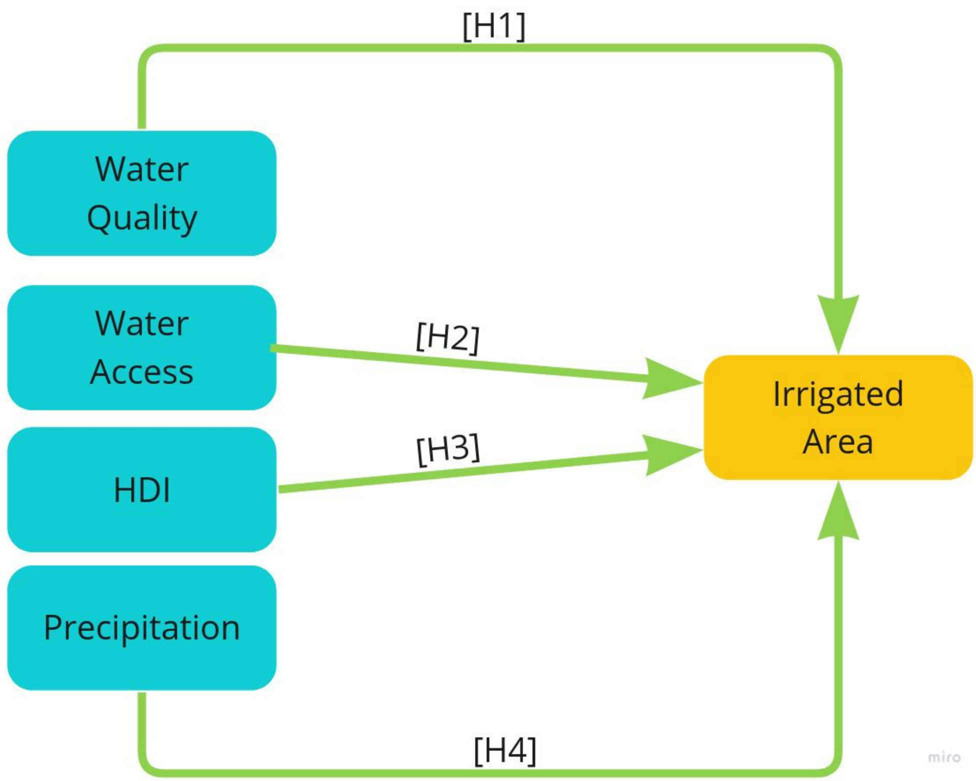



**Figure 1**

Hypothesis 1 - Prediction 1: (a) Water quality has a positive relationship with the irrigated area. Hypothesis 2 - Prediction 2: (b) Access to potable water has a positive relationship with the irrigated area. Hypothesis 3 -

Prediction 3: (c) The HDI has a positive relationship with the irrigated area. Hypothesis 4 - Prediction 4: (d) Precipitation has a negative relationship with the irrigated area.




Legend: Predictor variable [blue], response variable [orange], and [green arrow] positive effect.

## 2 MATERIALS AND METHODS

### 2.1 Study area

The chosen studies are in the semiarid region (Figure 2), which has a climate with an average annual precipitation of 200-500 mm and an average temperature of 18-0 °C. The latitude of the studies ranged from 5° to 46° and the longitude from 7° to 111°. The continent that published the most on the subject was Asia (24 papers), followed by Africa (5 papers), America (1 paper) and Europe (1 paper). The HDI of the study locations ranged from 0.837 in Saudi Arabia, considered high, to 0.514 in Nigeria, considered low. The study sites had total irrigated areas ranging from 2,000 hectares in Kenya to 5 million hectares in India.

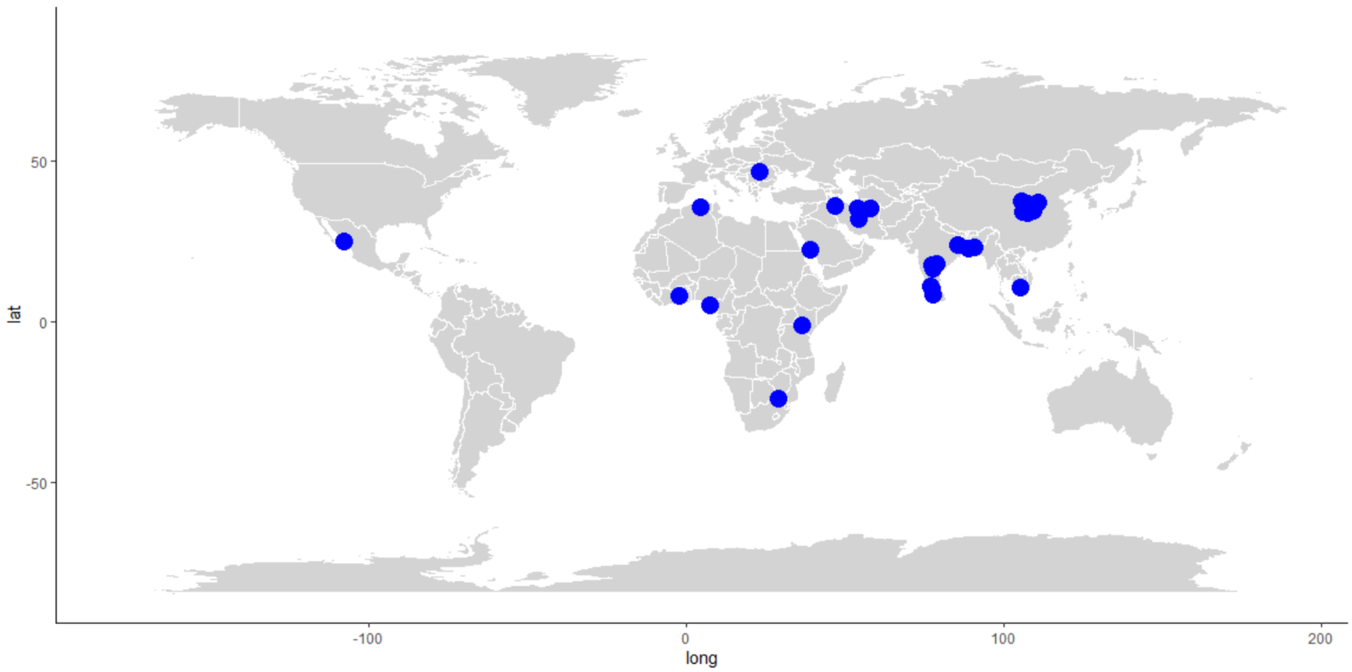



**Figure 2**
Study area map.Distribution of water quality publications in the semiarid region from 2009 to 2021.

2. 2 Systematic review

This study used the nine phases of the PRISMA protocol (Moher et al, 2015) to conduct a synthesis of the literature on the quality and use of water in the semi-arid region (Figure 3): I elaboration of the research question, (ii) study search, (iii) study selection, (iv) data extraction, (v) study bias risk, (vi) synthesis of results, (vii) examination of the quality of evidence, (viii) writing of results, and (ix) publishing (Figure 3).

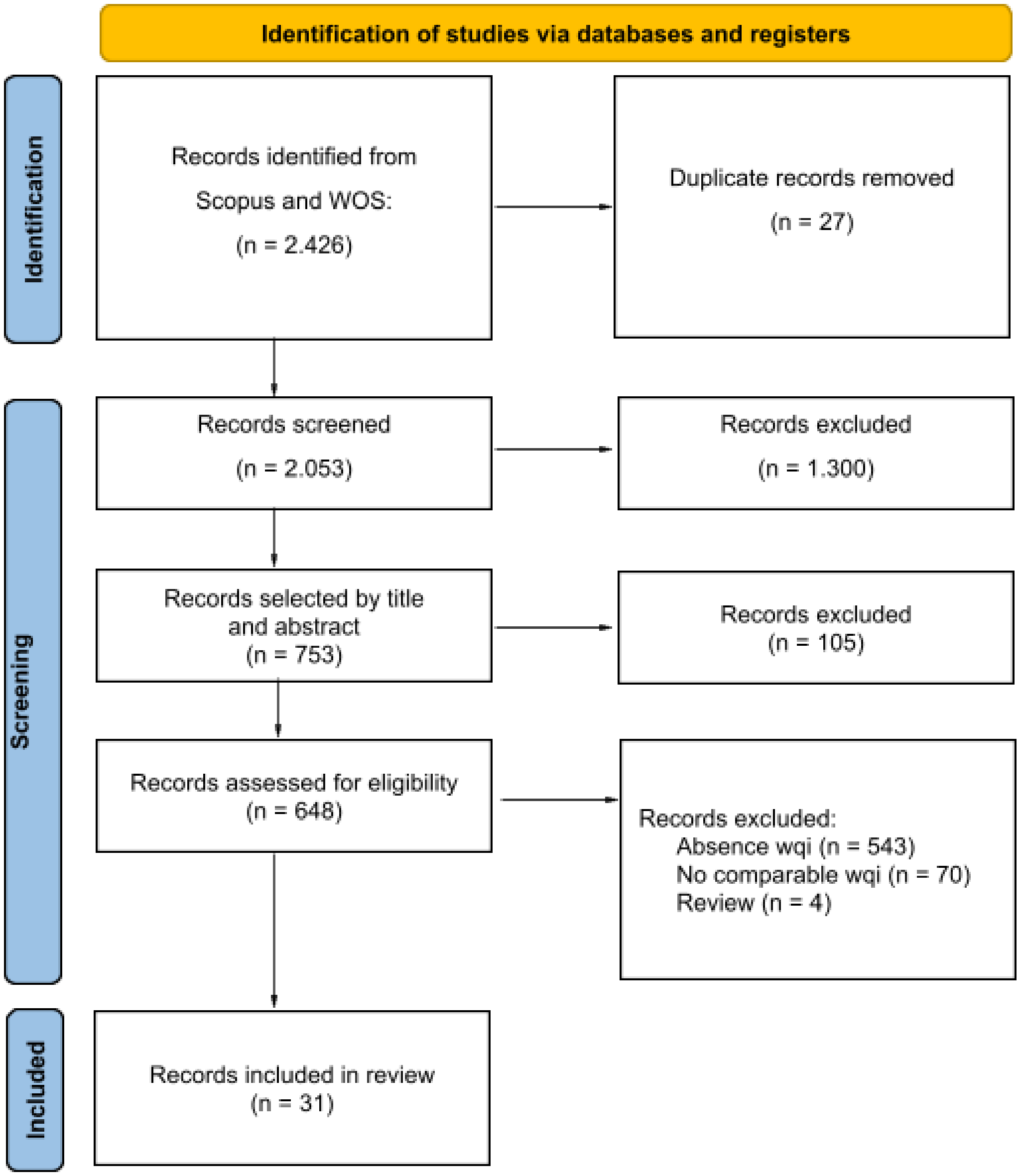



**Figure 3**
Prisma flow diagram.

The following keywords were used in the title, abstract and keywords filters to conduct the search: (water quality) AND (semiarid OR arid) AND (human OR people*OR communit*) AND (Index OR WQI) AND (drink* OR irrigat* OR agriculture). The following databases were used to select studies: Scopus and Web of Science (WOS). The selected studies meet the following eligibility criteria: (i) they must be peer-reviewed research on water quality in the semi-arid region, and (ii) they must include at least one quantitative measure of water quality (predictor variable) and use (response variable). In addition, the following exclusion criteria were used: (i) Bibliographic reviews and (ii) water quality studies with no quantitative data. There was no date or language filter. The variables temperature and precipitation average were estimated and indicated a posteriori using the year of publication and sampling of the research.

Following the extraction and examination of titles and abstracts, duplicates were removed and publications were excluded based on the eligibility criteria. The data was categorized based on the risk of bias criterion: number of people in the region (despite the fact that the population of municipalities ranged from 28,000 in Iran to 81 million in India, none of the studies interviewed the populace regarding the quality of irrigation water); water source selection criteria (the selected studies collected samples of water used in irrigation); data collection methods and sampling methods (he selected studies used the same measure of water quality index). The studies' risk of bias will be analyzed by evaluating and categorizing them into three risk categories: low (there is one risk of bias in the study: moderate (there are two risks of bias in the study); high (there are more than two risks of bias in the study).

2.3 Analysis

In this paper, we used Generalized Linear Models (GLMs) to determine which factors have an impact on water use in 13 countries from 2009 to 2021. Operational variables were categorized as follows: Accessibility (percentage of the country's population with access to drinking water from the FAO's AQUASTAT database (www.fao.org/aquastat/)); Quality (number of studies samples classified as suitable for human consumption); Use (frequency of citation of water uses by category: Human consumption, Agriculture, Livestock, Industry, Domestic); Adaptive practice (size in hectares of irrigated area of study site from the FAO's AQUASTAT database (www.fao.org/aquastat/)). The water was categorized using the Water Quality Index (WQI) which standardizes the physical, chemical and biological parameters according to its concentration and creates a scale ranging from 0>300, with: Excellent (0-50) and Good (50-100) are indicated for human consumption; Poor (100–200) and Very poor (200–300) can be used for human consumption and irrigation after treatment; and Unsuitable for drinking/Irrigation purpose (>300) even after treatment they cannot be used. The first standardized dimension of the PCA of the Water Quality Index (WQI) of papers was used as a proxy for water quality in our models.

Using the R programming language, the analyses were carried out in three stages: exploratory, model construction and testing. The following packages were used for the development of exploratory analyzes: tidyverse (data exploration and transformation), FactoMineR, factoextra, psych, and corrplot (for exploratory PCA analysis), vegan (standardization and transformation of Multidimensional Analysis), and ggplot2 (for graphical visualization of the data). To create and choose models related to factors that influence the development of adaptive practice, the following packages were used: DHARMa (diagnosis of Generalized Linear Models), performance (GLM overdispersion analysis), MASS (fitting the Model distribution), piecewiseSEM (non-normal distribution analysis) and gridExtra (graphical visualization of the models).

The Human Development Index (HDI) is classified according to the variation in income, education and life expectancy, their score varies from 0 to more than 800, where: low human development (0 - 0.550), medium human development (0.550–0.699), high human development (0.700–0.799) and very high human development (0.800 or greater). The first models considered social variables (access to potable water, population size, HDI, Gini, GDP) and climate variables (mean annual temperature and precipitation) as possible predictors of the development of adaptive practice measured by the size of the irrigated area of the sampling locations, but the assumptions of normal distribution were not attended with this model, which indicated a high overdispersion problem with a value of 559263.6, far beyond the appropriate threshold of 1.5. The chosen model (Figure 4 and Figure 5) had a normal distribution, homogeneity of variance, and no residue overdispersion, and it was composed of the social variables (access to potable water, population size and HDI) and climate variables (mean annual temperature and precipitation) and  overdispersion averages its out at around 1.560679. Variables having a p.value >0.05 that don't demonstrated statistical significance were eliminated from the model. In addition to the significant value, the model was chosen based on the assumptions of normality, independence, and residual overlapping. Generalized Linear Models (GLM) were created to analyze the non-normal data of the discrete and dependent variable related to the size of the irrigated area of Hypotheses I and II, using multiple logistic regression and estimation of the parameters of the Poisson distribution using Maximum Likelihood (ML). The link between the predictor variables (Quality and Accessibility) and the response variables was utilized to choose the most appropriate model and evaluate the predictions of hypotheses I and II using analysis of variance (ANOVA) (Use and Adaptive Practice).

Hypotheses III and IV were tested using unconstrained multivariate exploratory analyses to validate the association between categorical variables related to water use. An unrestricted multivariate analysis, principal component analysis (PCA), was used to see how the predictor variables water quality and consumption change in different places in the semi-arid region (31 sampling units). The most important water sources in the semi-arid region for coping well with the binary matrix were identified using correspondence analysis (CA), transformed with chi-square. The studies (predictor variables) are in the lines, and the source categories (response variables) are in the columns of this chi-square-transformed correlation matrix.

## 3 RESULTS

### SYSTEMATIC REVIEW

We found with the synthesis of the literature: 31 studies, published in the last 12 years (2009-2021) in 13 countries, totaling 3,363 water samples. In recent decades, there has been an upsurge in the number of publications in this field. Aims and Scopes of Periodics that published on water quality in the semiarid region from 2009 to 2021 are focused on Sustainable (23 Journals), Environmental (20 Journals) , Development (18 Journals) , Human (17 Journals) , Water (13 Journals) , Management (13 Journals) , Health (11 Journals) , Biology (10 Journals), Pollution (9 Journals) and Social (9 Journals) (Figure 4). The most numerous publications on this subject are from India (10 papers) and China (6 papers).

WATER USE

Most of the publishing is focused on studies of irrigated areas (26 papers or 84%), and few on non-irrigated areas (5 papers or 16%). And these studies are mainly rural areas (61%). Regarding the nature of the source, (93%) of the water samples were collected from groundwater bodies. In addition, the articles identified five distinct types of water use: human consumption (31), agriculture (29), domestic (19), industrial (11) and livestock (4). In terms of agriculture, the studies identify 26 different categories of crops, the main ones were: Corn (6), Rice (3), Sugarcane (3),Tomato (3), Cotton (2) and Sorghum (2).

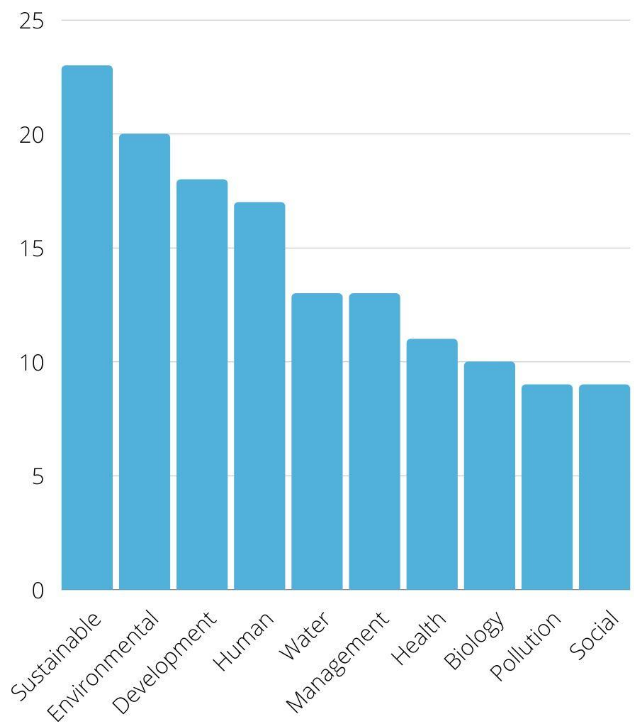



**Figure 4**
Aims and Scopes of Journals that published on water quality in the semiarid region from 2009 to 2021.

WATER QUALITY

The main findings of the synthesis on the quality and use of water in the semiarid region suggest that the majority of the water samples obtained in the published works are adequate (with Excellent (834 or 27%) and Good (1,001 or 29%) accounting for 56% of the total), and that human consumption is the primary use of water in the semiarid region, followed by irrigation for agriculture. According to Principal Components Analysis (PCA) of water quality by region, samples classed as Excellent (<50) and Good (50-100), respectively, explain 41% and 25% of the total variation in the data. In 18 investigations (10 rural and 8 urban), water quality was rated as suitable for human consumption and irrigation, indicating that there is a uniform distribution of water quality between rural and urban areas (Figure 5).

However, in 44% of the studies the water quality was classified as unsuitable for consumption and irrigation: Poor (675 or 19%) and Very Poor (421 or 12%). The use of water for human consumption or irrigation is not recommended in 432 studies or 13% of the samples. None of the studies indicated that the water is treated or purified before being used.

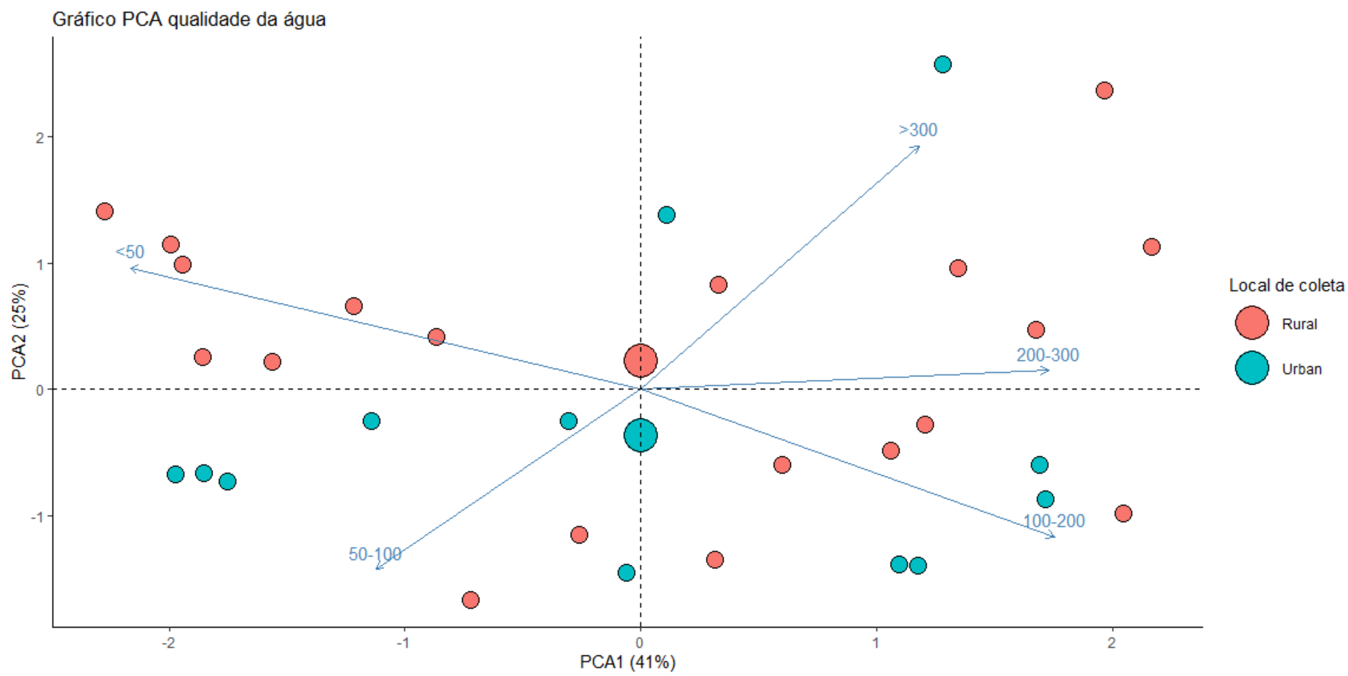



**Figure 5**
PCA of water quality by region.

WATER QUALITY INFLUENCES THE DEVELOPMENT OF ADAPTIVE PRACTICES

The water quality samples collected in the experiments do not show statistical significance in the model and did not contribute to the variance in area size (p.value=0.96, $R^2$=0.25), contrary to what was predicted by Hypothesis I (which predicted a positive association between quality and adaptive practice.

ACCESS TO POTABLE WATER INFLUENCES THE DEVELOPMENT OF ADAPTIVE PRACTICES

On the other hand, the prediction of Hypothesis II that predicted a positive association between the percentage of the population with access to clean water and the size of the irrigated area was confirmed (p.value= 0.0003, $R^2$= 0.05) (Figure 6).

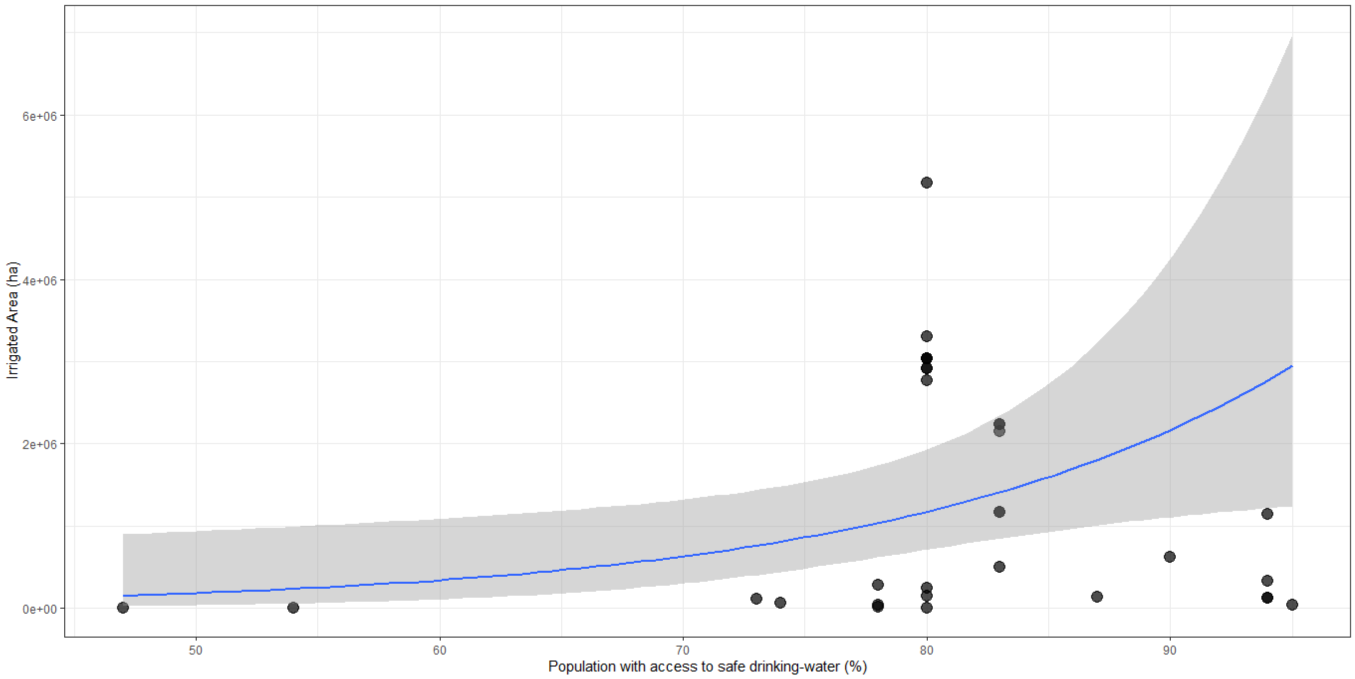



**Figure 6**
Model Result of Hypothesis 2 - Prediction 2: (b) Access to potable water has a positive relationship with the irrigated area.

SOCIAL FACTORS INFLUENCE THE DEVELOPMENT OF ADAPTIVE PRACTICES

The human development index varies significantly based on the semiarid communities. The HDI variable had a negative impact on adaptive practice, and the largest irrigated area values were centered in the medium and low category of Education, Health, and Income. (p.value= 0.002, $R^2$= - 0.23) (Figure 7).

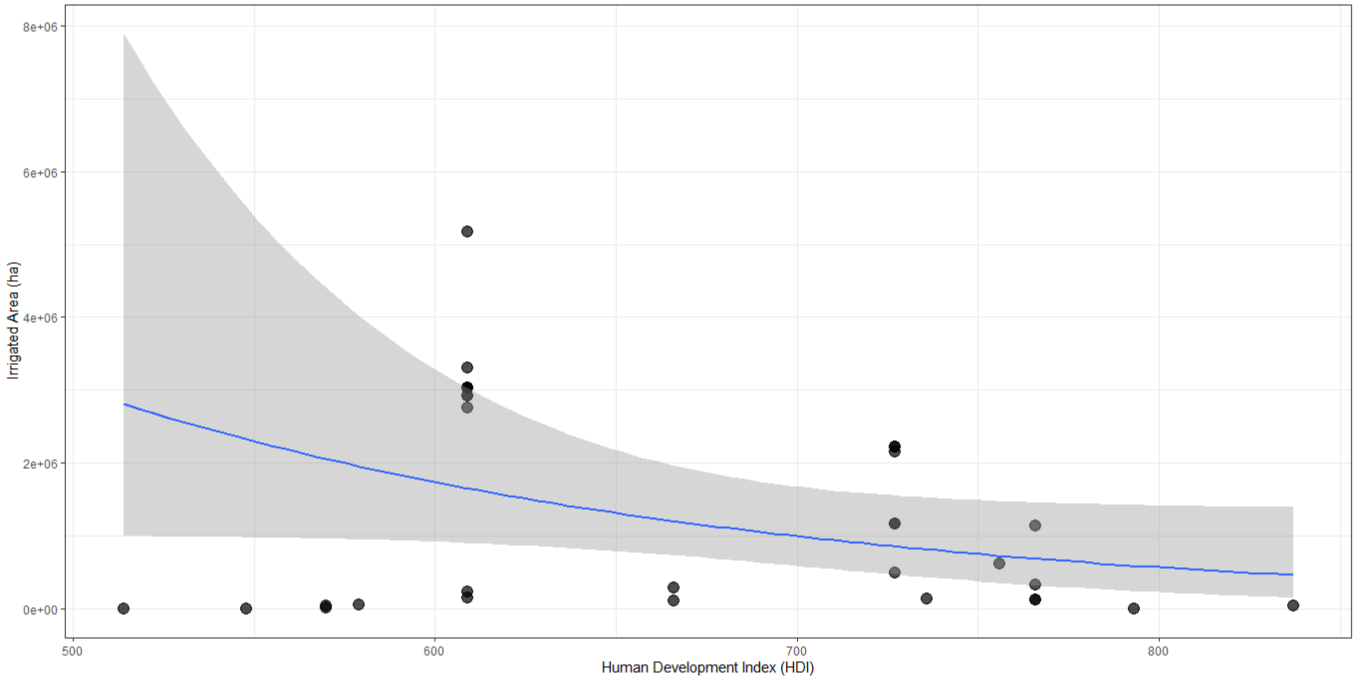



**Figure 7**
Model Result of Hypothesis 3 - Prediction 3: (c) The HDI has a negative relationship with the irrigated area.

## CLIMATE INFLUENCES THE DEVELOPMENT OF ADAPTIVE PRACTICES

Regarding the predictions of the hypothesis that the climate would affect the adaptive practice of irrigation in the semiarid region, on the one hand the annual average temperature did not contribute to the variation in the size of the irrigated area (p.value= 0.52, $R^2$=0.29). While the average annual precipitation, in turn, was statistical significance and had a negative relationship with the size of the irrigated area, as the regions with the lowest rainfall were the ones that invested the most in the size of the irrigated area (p.value= 0.0009, $R^2$= - 0.13) (Figure 8).

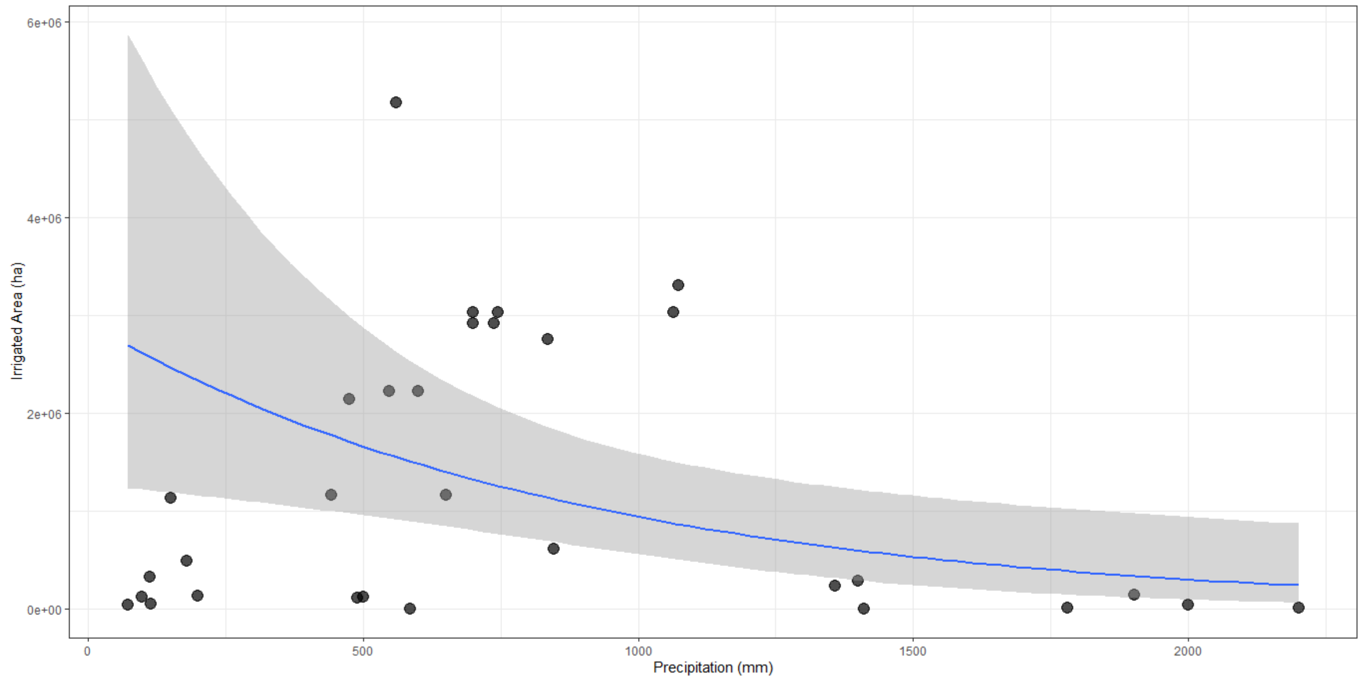



**Figure 8**
Model Result of Hypothesis 4 - Prediction 4: (d) Precipitation has a negative relationship with the irrigated area.

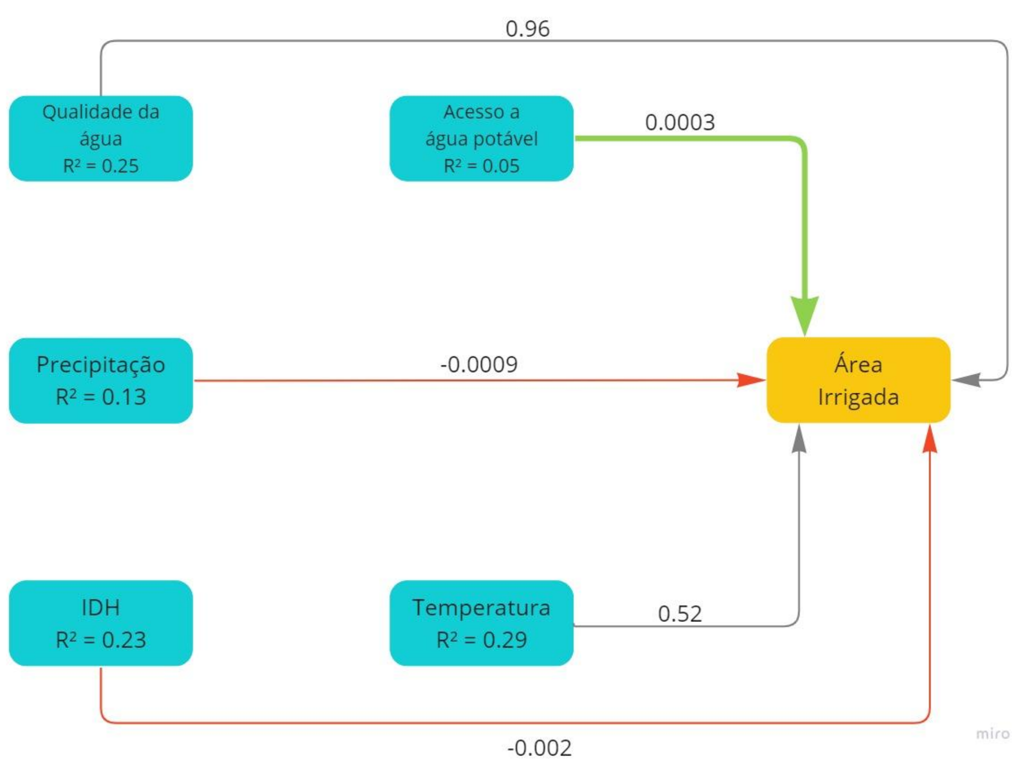



**Figure 9**
Model statistics of Hypotheses.

## 4 DISCUSSION

Concerns over maintaining water resources could explain the rise of WQI scientific literature around the world (Alves, 2014; Espejo et al, 2012). One of the variables that may have affected the publication of papers in journals with a focus on sustainability is the desire to achieve global goals and sustainable development. Countries such as China and India lead the world ranking of publications on the quality and use of water in the semiarid region because they already facing water scarcity, which leading to food scarcity and endanger the public water supply in your territories (Alves, 2014; Singh et al., 2011; Wu et al., 2012).

The semiarid region's vast domain of areas receiving some type of irrigation has found in this study demonstrates that communities in this region are creating adaptive strategies for dealing with the increasing drought and decrease in rainfall (Silva et al, 2021). The wide dependence that semiarid communities have on underground sources found in this review reflects that the rural communities are beginning to face water scarcity, leading to a high dependence on groundwater for public and agricultural supply (Magesh and Chandrasekar, 2013).

In a scenario of water scarcity, water quality has not shown to influence the variation of the irrigated area in semiarid communities. When there is a scarcity of water, people prefer to utilize whatever water is available without regard for its quality. Modern approaches such as including nutrients in the water and purification treatment could improve irrigation with low water quality (Abubakar, 2018; Assouline et al, 2015). Due to the lack of data in the papers on adaptation practices focusing on the collection, storage, and purification of water used in irrigation, we are unable to influence the adaptive strategies established to maximize water use in arid locations. The cost of making water usable must be considered in works on water quality and use to improve the predictive capacity of models on water security in semiarid communities.

The size of the irrigated area in the semiarid region was positively influenced by the percentage of the population with access to drinking water, as predicted in hypothesis II. Communities in the semiarid region are even more dependent on groundwater sources to provide their livelihood, through consumption and use in agriculture irrigation (Adimalla, 2019). The association between these variables implies that semiarid communities invest in access to drinking water to maximize their agricultural gains by increasing the size of the irrigated area in order to satisfy increased needs for water and food.

The variation in income distribution, degree of urbanization and education obstruct the access and selection of natural resources, generating vulnerability and heterogeneity in socio-ecological systems (Biggs et al., 2021; Robinson et al., 2019; Reyes-García et al., 2013). The negative relationship between the HDI and adaptive practice may be another indication that in the worst environmental and social circumstances people create solutions to guarantee their survival. Because in the most vulnerable situations of low education, income and life expectancy, semiarid communities maximize water use by increasing the size of the irrigated area.

Following the logic of environmental maximization, in drier places, people would tend to invest in irrigation (efficiency) and usage of better quality water to compensate for the water deficit (availability). The negative association between rainfall and the extent of the irrigated area identified in this study's model suggests that semiarid communities are developing adaptive strategies to respond to climate change rainfall patterns. Temperature was expected to have a positive effect on the development of adaptive practice (Lyimo et al, 2010), however this climate variable had no impact on the irrigated area size variation. This finding may indicate that in semiarid areas, increased warming has a smaller impact on water resilience than reduced rainfall.

This development of strategies to adapt to climate disturbances is one of the determining factors for the resilience of socio-ecological systems (Albuquerque et al., 2019; Faulkner et al., 2018; Delgado-Serrano et al., 2017). The sustainable management of water used in irrigation is critical to address the increase in drought and the decline in the quality and quantity of groundwater and surface water sources (Priyan, 2021; Steffen et al., 2015; WEF, 2015; Griggs et al., 2013; Scanlon et al., 2012; Oki, 2006).

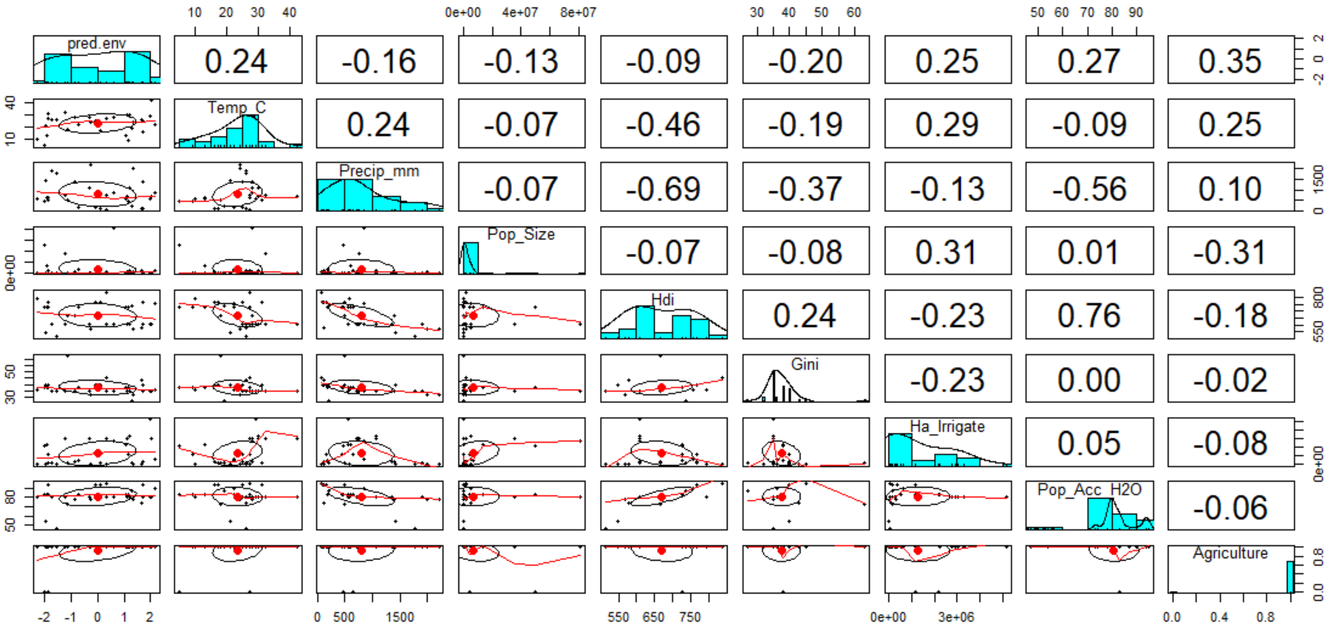
## 5 CONCLUSION

Our research contributes to water security by demonstrating how water access influence socio-ecological system adaptations in the semiarid region. The process related to water use and development of adaptive strategies in the semiarid region communities have a greater influence of social and climatic variables than the availability and quality of water resources. The development of agriculture in the semiarid zone is determined by the regional variation in water availability. And the positive relationship between adaptive practice and access to potable water, as measured in this study by the size of the irrigated area, supports the Model of Maximum Environmental Performance of the Social-Ecological Theory of Maximization postulate (Albuquerque et al, 2019).

## Open Research

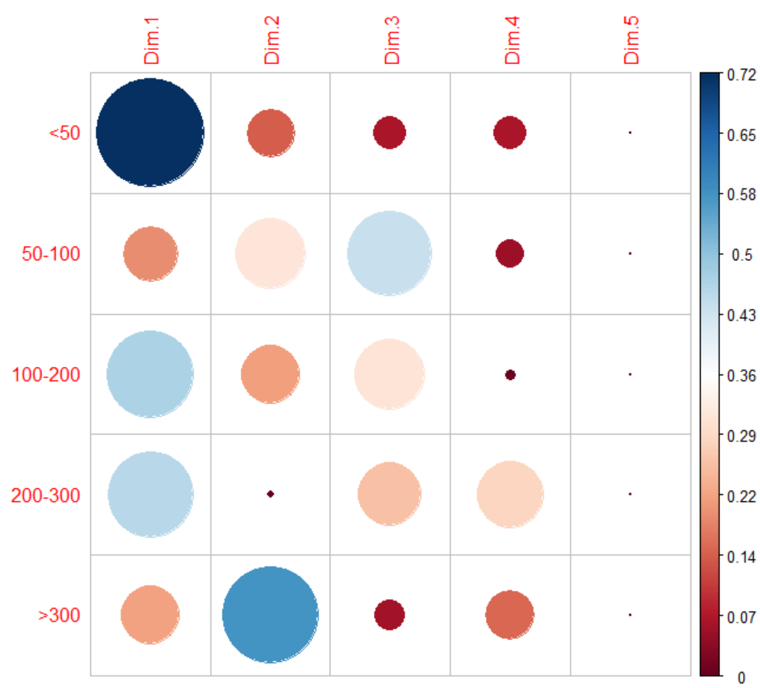
https://github.com/IngridLimaS/Semiarid-Water-Project

## Supporting Information




## Annex 1

Correlation coefficients of the variables used in the models.



## Annex 2

Correlation of the variables used in the models.

| Área Irrigada | Acesso | Hdi | Prec. | Tam.Pop | Temp. | WQI |
|---|---|---|---|---|---|---|
| p.value | 0.0003 | 0.002 | 0.0009 | 0.31 | 0.52 | 0.96 |
| $R^2$ | 0.05 | -0.23 | -0.13 | 0.37 | 0.29 | 0.25 |

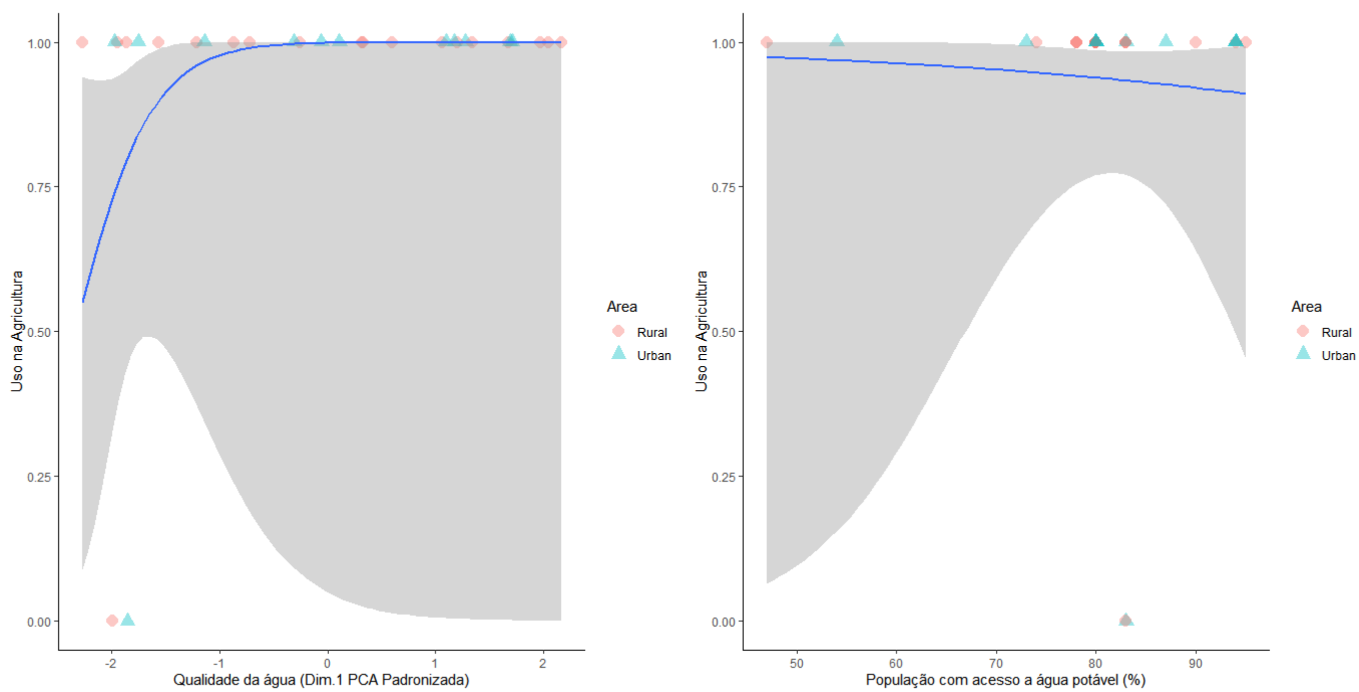
## Annex 3

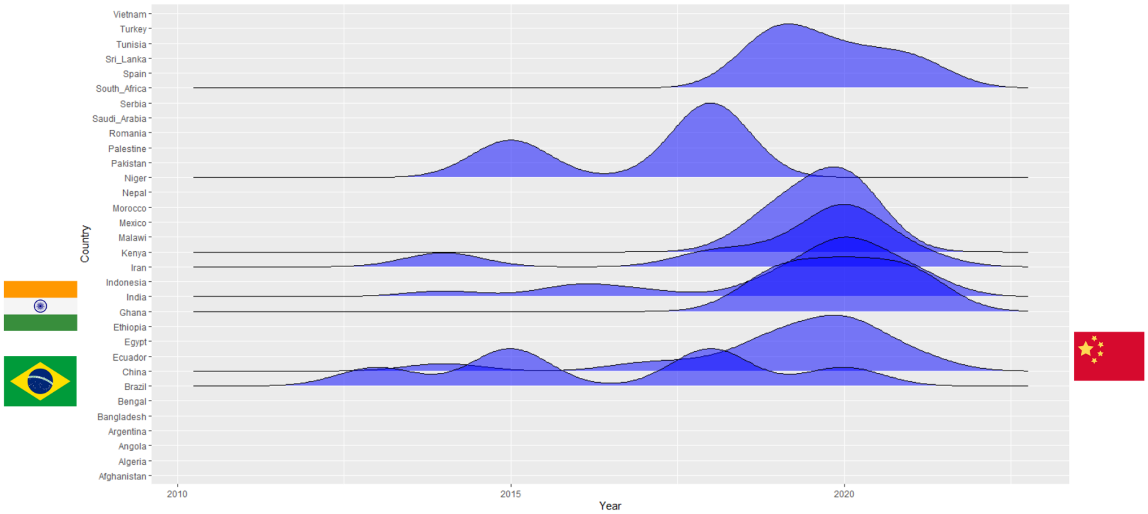
Correlation of the variables used in the models.

Legend: WQI (water quality index); Pop (Population size); Temp (Average temperature in the year of data collection); Prec (Average of precipitation in the year of data collection).

## Annex 4

Model of water use.






**Annex 5**

Countries that published the most on water quality and use in the semiarid region from 2009 to 2021.

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## CAPÍTULO 3 - CONSIDERAÇÕES FINAIS

### PRINCIPAIS CONCLUSÕES

A preocupação com a manutenção dos recursos hídricos pode explicar o aumento da literatura científica do WQI em todo o mundo. O vasto domínio do semiárido de áreas que recebem algum tipo de irrigação encontrado neste estudo demonstra que as comunidades desta região estão criando estratégias adaptativas para lidar com o aumento da seca e diminuição das chuvas. Quando há escassez de água, as pessoas preferem utilizar qualquer água disponível sem levar em conta sua qualidade.

O investimento no acesso à água potável pode maximizar os ganhos agrícolas, e aumentar o tamanho da área irrigada para satisfazer as necessidades crescentes de água e alimentos das comunidades do semiárido. A relação negativa entre o IDH e a prática adaptativa indica que nas piores circunstâncias ambientais e sociais as pessoas criam soluções para garantir sua sobrevivência. Porque nas situações mais vulneráveis de baixa escolaridade, renda e expectativa de vida, as comunidades do semiárido maximizam o uso da água aumentando o tamanho da área irrigada. A associação negativa entre a precipitação e o tamanho da área irrigada sugere que as comunidades do semiárido estão desenvolvendo estratégias para se adaptar as mudanças climáticas. A gestão sustentável da água utilizada na irrigação é fundamental para enfrentar o aumento da seca e o declínio na qualidade e quantidade das fontes de água subterrânea.

### CONTRIBUIÇÕES TEÓRICAS E/OU METODOLÓGICAS DA DISSERTAÇÃO/TESE

Nossa pesquisa contribui para a segurança hídrica ao demonstrar como o acesso à água influencia as adaptações do sistema socioecológico no semiárido. O processo relacionado ao uso da água e desenvolvimento de estratégias adaptativas nas comunidades do semiárido tem maior influência de variáveis sociais e climáticas do que a disponibilidade e qualidade dos recursos hídricos.

O desenvolvimento da agricultura no semiárido é determinado pela variação regional da disponibilidade hídrica. E a relação positiva entre a prática adaptativa e o acesso à água potável, medida neste estudo pelo tamanho da área irrigada, corrobora o Modelo de Máximo Desempenho Ambiental do postulado da Teoria Socioecológica da Maximização (Albuquerque et al, 2019).

PRINCIPAIS LIMITAÇÕES DO ESTUDO

Devido à falta de dados nos artigos sobre práticas de adaptação com foco na coleta, armazenamento e purificação da água usada na irrigação, não conseguimos influenciar as estratégias adaptativas estabelecidas para maximizar o uso da água em locais áridos.

PROPOSTAS DE INVESTIGAÇÕES FUTURAS

O custo de tornar a água aproveitável deve ser considerado em trabalhos de qualidade e uso da água para melhorar a capacidade preditiva de modelos de segurança hídrica em comunidades do semiárido.

ORÇAMENTO (CUSTO DO PROJETO)

Devido a reformulação do projeto no início da Pandemia da Covid-19, não houveram custos com deslocamento, estadia e campo.

**ANEXOS**

Código usado nas análises:

https://github.com/IngridLimaS/Semiarid-Water-Project