Climate Change and Transboundary Aquifiers: Necessitating Legal Reforms for Climate-Resilient Transboundary Aquifier Management.

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TBA – Transboundary Aquifers

TWAP - Transboundary Water Assessment Programme

GGRETA - Groundwater Resources Governance in Transboundary Aquifers

ISARM - Internationally Shared Aquifer Resource Management)

UNESCO – United Nations Education Science and Cultural Organisation

SDM – Sustainable Development Management

UN – United Nations

UNECE – United Nation Economic Commission for Europe.

EU – European Union

IWL – International Water Law

TAS – Transboundary Aquifer System

IAH - International Association of Hydrogeologists

TARM - Transboundary Aquifer Resources Management

WFD – Water Framework Directive

MAR – Managed Aquifer Recharged

NSAS- Nubian Sandstone Aquifer System

IAEA-International Atom Energy Agency

JASAD-NSAS- Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System

BDS-Basin Development Strategy

CCAI-Climate Change Adaptation Initiative

IWRM- Integrated Water Resource Management

FMMP- Flood Management and Mitigation Program

RFMMC-Regional Flood Management and Mitigation Centre

MDEWS-Mekong Drought Early Warning System

DMP- Drought Management Program

SHDS- Sustainable Hydropower Development Strategy

HSAP- Hydropower Sustainability Assessment Protocol

IWT- Indus Water Treaty

MRC- Mekong River Commission

LUC – Land Use Chnage

GRACE - Gravity Recovery and Climate Experiment

UNECE - United Nations Economic Commission for Europe

OAS - Organization of American States

UNESCO – INWEB - United Nations Educational, Scientific and Cultural Organization - International Network of Water-Environment Centres for the Balkans

SEF - Socio-Economic Framework

IGRAC - International Groundwater Resources Assessment Centre

GRAPHIC - Groundwater Resources Assessment under the Pressures of Humanity and Climate Change

GSMN - Global Soil Moisture Network

SIDA - Swedish International Development Cooperation Agency

RBMP - River Basin Management Plan

PoM - Programme of Measures

RBD - River Basin District

WBI - World Bank Institute

ICJ – International Court of Justice

SAP - Subsidiary Action Program

SVP - Shared Vision Program

Chapter 1: Introduction

A significant problem for many people worldwide is water scarcity. Over half of the world's population—roughly four billion people—do not have appropriate access to clean drinking water for at least one month of the year. [1] According to estimates, 57% of the world's population will live in areas with acute water scarcity by 2050. The use of groundwater, which makes up 20%[2] of all water used worldwide, is substantial since it is a vital resource with 70 times more freshwater than surface water. [3] But both its quantity and quality have decreased, immensely taxing the world's ability to manage its water resources. All facets of life, from residential to industrial, depend on groundwater in dry or semi-arid areas with few surface streams and precipitation. [4] However, its quantity and quality have declined, placing enormous pressure on global water resource management. In arid or semi-arid regions, where surface streams and precipitation are scarce, groundwater is used for all aspects of life, from domestic to industrial purposes. Overusing groundwater can lead to depletion of water cycle, which hinders economic development and creates various challenging situations related to health, education, and agriculture. Therefore, safeguarding groundwater is of primary importance, and the issue becomes even more critical due to climate change's influence.[5].

IPCC sees climate change as the main issue regarding groundwater sustainability. According to the latest reports[6] climate change is a long-term phenomenon that refers to alterations in global or regional climate components, primarily due to the accumulation of greenhouse gases, especially carbon dioxide (CO2), in the atmosphere. The amount of CO^2 in the troposphere has increased from 290.7 ppm to 407.58 ppm in 2018.[7]Since the Industrial Revolution, the global average temperature has increased by 0.08 °C (0.14 °F) per decade. [89.]

Temperature is expected to increase, especially in higher latitudes, causing ice melting and snowfall to be replaced by rainfall in the Polar Regions. This temperature increase

[1] (UNICEF n.d.)
[2] (A. Boretti 2019)
[3] (S. Earman 2011)
[4] (Priyan 2021)
[5] (Intergovernmental Panel on Climate Change, O. Edenhofer (Eds.) 2014)
[6] (United Nations - Climate Action 2023)
[7] (European Environment Agency 2019)
[8] (USGCRP 2018)
[9] (USGCRP 2018)

increases the moisture content in the atmosphere, resulting in increased precipitation in wet regions where surface water is abundant[10]. However, the evapotranspiration rate also rises, amplifying drying in arid areas, which is why it is suggested that climate change will intensify the differences between precipitation patterns in wet and dry areas. Droughts will occur more frequently in dry regions, while floods will take place more frequently in wet regions[11]. All of these effects caused by climate change, such as changes in the Earth's temperature and precipitation regimes, directly interfere with the water cycle, thereby influencing the quantity and quality of groundwater in complex ways in different regions. Groundwater is an essential component of the natural water cycle, and it serves as an enormous underground water storage reservoir. It receives water from various sources, such as surface runoff, rivers, and lakes, through infiltration and discharges through evapotranspiration, evaporation, and seepage to streams and lakes. The recharge and discharge processes directly regulate the quantity and quality of groundwater. Climate change can indirectly affect groundwater quality by altering the biological and geochemical processes that regulate microbial activities and the concentration of substances in groundwater.[12] Human activities are the primary cause of groundwater pollution, and their impacts on groundwater quality have only been studied in a few cases. Transboundary aquifers are those aquifers that cross borders of two or more nations and International treaties regulate them. These treaties are vital for collaborative water management, particularly as climate change presents new difficulties for water availability and quality. However, the extent to which these agreements facilitate adaptation to climate change has not been thoroughly examined. International law plays a critical role in shaping these agreements and can either bolster or impede adaptation efforts[13]. This paper seeks to understand the how climate change impacts the aquifiers and the available resources of transboundary groundwater under International Water Law and the challenges in its management. The paper proceeds to unveil the legal framework from the introduction of transboundary groundwater into legal framework through the Helsinki Rules to the latest Draft Article. It reads into important laws and agreements like Sustainable Development Goals, UNESCO's ISRAM, GGRETA, TWAP, followed by two of the most important case studies to understand the practical implication of these laws and principles, i.e.

[10] (S. Earman, Potential impacts of climate change on groundwater resources - a global review 2011)
[11] (S. Earman, Potential impacts of climate change on groundwater resources - a global review n.d.)
[12] (Pitz 2016) (Riedel 2019)
[13](Olmstead, S. M. 2013)

Aquifer Agreement in Guarani and the Nubian Sandstone Aquifer System. These case studies, along with other, help to understand the particle application and implementation challenges. The paper also looks into the customary international laws to understand the international law principles better and regional frameworks, Water framework Directive and Groundwater Directive in order to see practical application of IWL in order to manage transboundary aquifers and their quality by controlling pollution. It assesses the current status of transboundary groundwater agreements, analyses the influence of international law, and highlights the primary obstacles/challenges and opportunities coupled with author's recommendations in the last chapter for enhancing the rules and principles from IWL for climate change adaptation in legal frameworks directed towards these TBA and their sustainable management. By identifying these obstacles and opportunities, we can strive for a future where international legal frameworks are reinforced, collaboration is enhanced, and the sustainable management of these crucial water resources is assured, instilling hope and optimism in the reader.

1.1 Thesis Justification, Aims, Research Question and methodology

Climate change is a major global issue that is significantly affecting various environmental aspects, especially water supplies. Groundwater, an essential part of the global water supply, is particularly susceptible to the impacts of climate change. The management and conservation of many major aquifers are complicated by the fact that they cross international borders. It is crucial to promptly establish effective adaptation methods to minimize the effects of climate change on transboundary groundwater resources, necessitating strong legal and institutional frameworks. This thesis addresses the pressing need for more focused framework based on International Water Law (IWL) to cope with increasing climate change impacts on transboundary aquifers.

This thesis is primarily focused on integrating climate change adaptation measures into the legal frameworks governing transboundary groundwater resources. In response to the increasing pressure on groundwater resources due to climate change, this research seeks to address a significant gap in legal scholarship and practice. The thesis aims to play a meaningful role in the sustainable management of groundwater resources by reviewing existing agreements and proposing necessary adjustments to ensure their availability for future generations, instilling optimism about the future of water resource management.

Understanding the connection between climate change adaptation and transboundary groundwater management is crucial for maintaining sustainable water resource

management. This study contributes to the existing knowledge by highlighting the need to incorporate climate adaptation into the legal and institutional frameworks that govern transboundary groundwater resources.

The research aims presented in the following section provide clear and focused direction to the investigation. By examining various aspects of transboundary groundwater management, the thesis seeks to evaluate the effectiveness of current legal frameworks, identify challenges, and make practical recommendations. The objective of this study is to explore how international legislation and transboundary groundwater agreements can integrate adaptation strategies for climate change. The goals include:

- Assessing the status of International Water Law Frameworks including rules, conventions and TBA agreements in terms of adaptation to climate change.

- Evaluating the impact of international Water law principles on adaptation efforts, both positive and negative. Three main principles that have been emphasized upon are – equitable and reasonable utilization of resources; Obligation to cause no significant harm to the parties involved and principle of cooperation and data exchange.

- Identifying barriers to and opportunities for enhancing the response of transboundary groundwater management to climate change.

- Identifying the main challenges in managing transboundary groundwater resources in the context of climate change.

- Exploring ways to strengthen international legal frameworks and agreements to better support climate change adaptation in transboundary groundwater management.

This thesis employs a qualitative investigation of international legal frameworks and agreements pertinent to transboundary groundwater management. The chosen methodology is designed to provide a detailed legal analysis of selected cases and conventions, ensuring a comprehensive understanding of the subject matter.

The core methodological approach utilized in this study is the legal dogmatic method, also known as doctrinal research. This approach systematically examines legal norms and principles as articulated in judicial decisions and codified in legislation. It aims to clarify ambiguous legal texts, interpret current legal rules, and predict future legal developments. For an in-depth understanding of this method, "Legal Research Methods" by Michael D. Murray and Christy H. DeSanctis is recommended. This resource offers a profound

exploration of various legal research techniques, beneficial for conducting doctrinal research effectively.

Their prominence in international legal discourse influenced the selection of specific cases and conventions for this study, their relevance to the management of transboundary groundwater, and the richness of available data. The cases include the Nubian Sandstone Aquifer System Agreement and the Guarani Aquifer Agreement. These were selected to provide insights into the diverse challenges and strategies in managing transboundary groundwater across different geographical, legal, political, and environmental contexts. Indus Water Treaty is mentioned at places but only die to its significance as a successful example of cooperation among politically unsettled countries. Additionally, the study examines key rules and conventions, such as the Helsinki Rule, the United Nations Watercourses Convention, and the UNECE Water Convention, along with Customary International Law, which is instrumental in shaping international legal norms for transboundary water management of these conventions, is crucial for understanding how climate change adaptation measures are integrated into international law. These rules and conventions are not discussed chronologically, they are arranged in ordered of reference to the other. The primary analytical technique involves a meticulous review of legal documents, including international treaties, national legislation, and policy briefs. This rigorous approach facilitates the identification of significant legal principles related to transboundary groundwater management. Each selected agreement is analyzed as a case study to provide detailed insights into its implications, implementation, and legal framework. This includes an examination of the historical context, legal provisions, obligations, and outcomes of each agreement to highlight its practical and legal significance.

To contextualize the findings and provide a theoretical backdrop, the study incorporates an extensive academic literature review, including scholarly articles, books, novels, and reports from international organizations. This literature review helps identify common challenges, best practices, and potential areas for improvement in transboundary groundwater management.It is important to note that this study relies solely on secondary sources, as no interviews were conducted. This limitation is acknowledged, and the focus is placed on a specific selection of cases and conventions, which may affect the generalizability of the findings. However, the chosen examples aim to provide a representative overview of various approaches to managing transboundary groundwater.

The variability in data availability across different locations and agreements might impact the depth of analysis in certain instances.

Despite these limitations, this thesis's objective is to deliver a thorough and legally sound examination of transboundary groundwater management within the context of climate change, ensuring that the conclusions drawn are relevant and substantiated**.**

Chapter 2: Legal Perspectives on Groundwater Management Amidst Climate Variability and Transboundary Issues

2. 1 Climate Change and Its Impact on Groundwater

Ground water is an almost ubiquitous source of generally high-quality fresh water. These characteristics promote its widespread development, which can be scaled and localized to demand, obviating the need for substantial infrastructure[14]. Globally, ground water is the source of one third of all fresh-water withdrawals, supplying an estimated 36%, 42% and 27% of the water used for domestic, agricultural and industrial purposes, respectively[15]. In many environments, natural groundwater discharges sustain baseflow to rivers, lakes and wetlands during periods of low or no rainfall. Despite these vital contributions to human welfare and aquatic ecosystems, a paucity of studies on the relationship between climate and ground water severely restricted the ability of the Intergovernmental Panel on Climate Change (IPCC) to assess interactions between ground water and climate change in both its third and fourth assessment reports. [16]

Groundwater is the major source of water across much of the world, particularly in rural areas in arid and semi-arid regions, but there has been very little research on the potential effects of climate change. Effective rainfall, rivers, and lakes generally replenish aquifers. This water may reach the aquifer rapidly, through macro-pores or fissures, or more slowly by infiltrating through soils and permeable rocks overlying the aquifer. A change in the amount of effective rainfall will alter recharge, but so will a change in the duration of the recharge season. Increased winter rainfall, as projected under most scenarios for mid-latitudes, generally is likely to result in increased groundwater recharge. However, higher evaporation may mean that soil deficits persist for longer and commence earlier, offsetting

[14] (Gleeson et al. 2012)

[15] Information extracted from "Taylor, Richard G., et al. "Ground Water and Climate Change." *Nature Climate Change*, November 25, 2012. https://doi.org/10.1038/nclimate1744."

[16] (Taylor 2013)

an increase in total effective rainfall[17]. Various types of aquifers will be recharged differently. The main types are unconfined and confined aquifers. An unconfined aquifer is recharged directly by local rainfall, rivers, and lakes, and the rate of recharge will be influenced by the permeability of overlying rocks and soils. Macro-pore and fissure recharge is most common in porous and aggregated forest soils and less common in poorly structured soils. It also occurs where the underlying geology is highly fractured or is characterized by numerous sinkholes. Such recharge can be very important in some semi-arid areas. In principle, "rapid" recharge can occur whenever it rains, so where recharge is dominated by this process it will be affected more by changes in rainfall amount than by the seasonal cycle of soil moisture variability.[18]

Climate variability and change influence groundwater systems directly through replenishment by recharge and indirectly through changes in groundwater use. These impacts can be modified by human activity such as land-use change (LUC).[19]

The stress on groundwater is increasing with the growing population, while climate change is putting additional pressure[20] on water resources and raising the possibility of severe drought episodes.[21] Strategic groundwater management ensures global water and food security in a changing environment. This is another reason groundwater should be more significant in climate concerns.

Climate change affects the groundwater in many ways.[22] For the hydrological cycle, climate change affects groundwater recharge (soil infiltration and deeper percolation)[23]. With increasing temperature, the amount of water evaporating from the land surface increases, leading to the extraction of underwater storage. The impact of human activities on groundwater resources primarily results from groundwater extraction and the secondary effects of irrigation and changes in land use. By contrast, the anthropogenic effects on

[17] (Scanlon et al. 2006)

[18] (Kumar 2012)

[19] (Taylor 2013)

Natural replenishment of ground water occurs from both diffuse rain-fed recharge and focused recharge via leak-age from surface waters (that is, ephemeral streams, wetlands or lakes) and is highly dependent on prevailing climate as well as on land cover and underlying geology.

[20] (Wu 2015)

[21] (Dai 2012) (Trenberth 2013) (Marvel 2019)

[22] (Taylor 2013)(Cuthbert 2019)

[23] (Berg 2016)

groundwater resources are mainly due to groundwater pumping and the indirect effects of irrigation and land use changes."[24]

Climate change impacts both the amount and quality of groundwater. Understanding these systems will enable more effective management actions in the face of climate change.[25],[26]. The relationship between climate change and groundwater is complex, necessitating more research to establish effective adaptation techniques for sustainable groundwater management.

Resources for Transboundary Groundwater

Groundwater, a crucial resource for water supply, is increasing significance as surface water quality deteriorates. Water is anticipated to become more valuable than oil in the twenty-first century particularly in dry places with acute clean water scarcity.[27] This emphasizes the strategic relevance of groundwater, particularly in transboundary scenarios, when aquifers cross numerous nations, demanding collaborative management through regulatory legal frameworks.

The management of transboundary groundwater resources is crucial to maintaining water security and necessitates strong legal frameworks and international collaboration. These aquifers are subterranean water reserves those cross international borders and are shared by two or more countries. The paper focuses on transboundary aquifers.

2.2 Adapting to climate change in transboundary aquifer management

In general, TBA management is more complicated than national and subnational water management because of the water management regime (The guiding concepts, regulations, and practices for water management) often vary more among nations than within them[28] as we discussed above. Thus, cooperation across various institutional, legal, and political frameworks, as well as across various information management strategies and budgetary arrangements, is necessary for TBA management. In order to achieve this kind of synchronization, joint bodies are often essential. In addition, riparian nations must to

[24] (Wen-Ying Wu 2020)

[25] Sea-level rise may cause saltwater intrusion into coastal aquifers, altering groundwater quality and compromising drinking water supplies. Once salt water has entered the fresh water system, it is difficult to reverse the process. Low-lying coastal zones and tiny island developing states are already susceptible. On the other hand, saline/brackish groundwater basins provide opportunities for economic activity and ecosystems.

[26] (Andrea Castaño-Sánchez 2020)

[27] (Golovina and Grebneva 2021).

[28] (Wolf and Newton 2008)

search for legal solutions that would benefit both parties involved in their water management issues.

The UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes, sometimes known as the "Water Convention", provides a common legal foundation for international cooperation[29]. The foundation of the Water Convention is international equality and reciprocity. Its provisions provide the framework around which nations might develop their initiatives. In addition to providing a range of guidance for practical implementation and best practices, the Water Convention's implementation program reinforces those provisions. Groundwater, believed to be a source of fresh water, is used for direct human consumption across borders. But due to surface water scarcity, groundwater is exploited unmonitored; this extraction leads to scarcity and pollution. The Protocol on Water and Health was created under the Water Convention with the intention of safeguarding human health and welfare via better water management and the prevention, control, and reduction of diseases associated with water. An essential instrument for addressing the effects of climate change, particularly those on human health, is the Protocol on Water and Health[30],[31].

A guideline on water and climate adaptation was finalized in 2009[32]. The Guidance aims to facilitate collaboration and decision-making in transboundary basins concerning many pertinent or developing climate change-related challenges.

For this reason, the Guidance covers adaptation to potential climate change effects on the frequency of floods and droughts, aspects pertaining to water quality and health, and workable strategies to deal with the transboundary effects, such as integrated surface and groundwater management for flood and drought mitigation and response. The Guidance places significant emphasis on acknowledging the possible advantages of floods, including enhanced water accessibility and enhanced biological conditions in floodplains. The Guidelines outline the procedures and adaption strategies that must be implemented, beginning with the transboundary context, in order to create a water strategy that is climate proof. It focuses on the extra difficulties that climate change has brought about for water

[29] (UNECE 1992)
[30] (Tanzi et al. 2015)
[31] (UNECE and WHO Regional Office for Europe 1999)
[32] (UNECE 2009)

management, such as how climate change affects planning for water management and how such planning should be adjusted to account for the changing climate[33].

2.3 Principles of International Water Law

International water law provides the foundation for managing transboundary water resources, including groundwater. Key principles include equitable and reasonable utilization, the obligation not to cause significant harm, and the duty to cooperate. These principles are encapsulated in various international agreements and conventions[34].
Equitable and reasonable utilization ensures that all riparian states have fair access to water resources, promoting sustainability and preventing conflicts. The obligation not to cause significant harm mandates that states must avoid activities that could negatively impact other states' water resources. The duty to cooperate emphasizes the importance of collaboration and information sharing among states[35].
The management of transboundary groundwater resources poses distinct issues. Many aquifers straddle national borders, necessitating extraction regulation harmonization and transboundary collaboration built on mutual trust and openness[36]. The possibility of conflict over water scarcity, as well as the requirement for sustainable management techniques, highlights the importance of international collaboration[37].

Case Study: Russia and Estonia

An example of transboundary groundwater management can be seen in the Lomonosov aquifer, shared by Russia and Estonia. This aquifer is crucial for drinking water supply and has been the subject of extensive hydrogeological studies and cooperative management efforts[38]. Fine-grained sands and significant water-bearing capacities characterize the Lomonosov aquifer, primarily located in the East European artesian basin. Joint exploitation and monitoring have shown that the hydrodynamic situation remains relatively stable, despite considerable water withdrawal activities on both sides of the border.

[33] (Schmeier 2013)
[34] (Caponera 2019)
[35] (McCaffrey 2011)
[36] (Eckstein and Eckstein 2005)
[37] (Wolf 2007)
[38] (Solanko and Ollila 2011)

Effective management of transboundary groundwater necessitates strong legal and institutional structures. In Russia, the Water Code governs water resource management, which is complemented by international treaties[39]. However, there is a need for more consistent laws that integrate surface and groundwater management. The existing fragmented legal approach frequently results in regulatory gaps and disputes.
Water resource management, particularly within international borders, has become increasingly important as a result of rising water demand, climate change, and geopolitical issues[40]. The intricacy of managing shared water resources needs detailed international laws and treaties.

International water law has evolved significantly over the last century, with various principles guiding the management and utilization of transboundary water resources[41]. This study outlines the fundamental principles that underpin international water law, such as equitable and reasonable use, the obligation not to cause significant harm, and the principles of cooperation and information exchange[42]. These concepts have been integrated into several treaties and accords, promoting collaboration between riparian governments.[43]
Equitable and reasonable use is a cornerstone principle that ensures equitable and sustainable access to water resources for all riparian governments. This concept is supplemented by the commitment not to cause significant harm, which compels governments to avoid actions inside their territory from negatively impacting neighboring states' water supplies.

Challenges in Managing Transboundary Groundwater

Since transboundary groundwater resources are shared by several countries, managing them presents special difficulties that are made worse by the effects of climate change. These common resources, also known as transboundary aquifers, are not limited by country borders and necessitate coordinated management strategies that take into consideration a range of national interests, legal systems, and socioeconomic circumstances. The management of transboundary groundwater becomes more difficult as climate change continues to affect hydrological cycles. In order to improve our knowledge of and ability to manage these essential resources, this chapter explores the difficulties

[39] (Bogdanovic 2006)
[40] (Caponera and Nanni 1992)
[41] (Dellapenna and Gupta 2009)
[42] (Wouters 2013)
[43] (Caponera 2019)

involved in managing transboundary groundwater in the context of climate change and points out significant gaps in the existing research. We will study these challenegs in detail in the coming chapters.

Managing transboundary groundwater involves working with nations that have different institutional, legal, and regulatory frameworks, there are a number of complex problems involved. The unpredictability of climate change's effects on water availability, quality, and groundwater resource sustainability exacerbates these problems.

Legal Frameworks

A legal framework is an organized set of rules and regulations that oversee legal procedures and actions. It encompasses laws, rules, recommendations, and fundamental concepts set by authorities to prescribe, in this case, usage of groundwater resources shared by more than one nation.[44] This section will study the relevant articles of the relevant frameworks and highlight the gaps, which makes their presence weak.

Two important pieces of legislation that control the usage of international watercourses are the UN Watercourses Convention and the Helsinki Rules, which were developed by the International Law Association and ratified by the United Nations. We also look into Souel Rules and Berlin Rules which provide us with important provisions required for an effective agreement and revisions on the former rules.

These instruments set forth concepts including the duty to cooperate, the obligation to not cause major harm, and the equitable and reasonable utilization. They offer a structure for settling conflicts and negotiating water-sharing agreements. These guidelines and agreements form the cornerstones of transboundary water management, impacting international treaties and accords.

2.3.1The Helsinki Rules (1966)

One of the first attempts to create regulations for the use of international watercourses, covering both surface water and linked groundwater, was the Helsinki Rules on the Uses of the Waters of International Rivers, which were ratified by the International Law Association (ILA) in 1966. The ideas presented in the Helsinki Rules, while mainly

[44] Extracted from "Smith, M., K. Cross, M. Paden, and P. Laban, eds. 2016. *Spring – Managing Groundwater Sustainably*. Gland, Switzerland: IUCN."

addressing surface waters, are also applicable to transboundary aquifers, particularly those that are hydraulically linked to surface waters.[45]

- Article II defines an international drainage basin as "surface and underground waters forming a system of natural or artificial watercourses, lakes, or other bodies of water." According to this definition, transboundary aquifers that are linked to surface waters are covered by the Helsinki Rules.
- The idea of a "reasonable and equitable share" in the use of an international drainage basin's waters is emphasized in Article IV. This idea supports a fair and equitable use of transboundary aquifers that takes into account the requirements of all basin governments. It can be applied to that situation as well.
- Article V addresses the duty to prevent actions that impact transboundary aquifers, such as excessive groundwater extraction or contamination, from causing other basin states considerable harm.
- In order to effectively utilize and maintain the basin, Articles VI and VII urge cooperation among basin governments. This cooperation includes data sharing and cooperative management efforts, both of which are essential for the long-term sustainable management of transboundary aquifers.

The groundbreaking Helsinki Rules introduced the ideals of equitable utilization and collaboration among governments sharing water resources. However, their significant concentration on surface waters makes their applicability to transboundary aquifers relatively limited. The regulations offer a fundamental structure for managing concerns about shared aquifers, particularly when other explicit accords still need to be improved.

2.3.2 The Seoul Rules on International Groundwaters 1986 (Adopted by the International Law Association at the Sixty-Second Conference Held at Seoul in 1986)[46]- The Seoul Groundwater Rules, approved in 1986, made clear by the International Law Association that the Helsinki Rules applied to groundwater. The Seoul Groundwater Rules acknowledge that groundwater can have worldwide consequences and should thus be managed globally, even if it has little or no relation to surface watercourses.

[45] Rules can be read at https://www.internationalwaterlaw.org/documents/intldocs/ILA/Helsinki_Rules-original_with_comments.pdf
[46] Pdf can be accessed at "http://www.cawater-info.net/library/eng/l/seoul.pdf"

- Article 1 - If an aquifer and its waters together form an international basin, in whole or in part, then the waters of the aquifer intersected by the boundary between two or more States are considered international groundwaters. Regardless of whether the aquifer and its waters constitute surface waters that are a component of a hydraulic system flowing into a common endpoint, those states are basin states in the sense of the Helsinki Rules.
- Article 2 - The interdependence of groundwater and other waterways, including aquifer connections and leaching brought on by activities and jurisdiction is something that basin governments have to take into account.
- Artcile 3 - According to international law, basin states must avoid or mitigate pollution of international groundwaters, with an emphasis on long-term impacts. To maintain groundwater, safeguard geologic structures, and take into account cooperative quality requirements and environmental protection measures, they must confer and share pertinent information and data. In response to requests, they also work together to gather and examine more information about global groundwaters and their aquifers.
- Article 4 - At the request of any one of the basin states, the integrated management of their international groundwaters should be taken into consideration, along with cooperative use with surface waters.

It provides based for international recognition of the TBA as an independent body, which require separate set of rules and regulations.

2.3.3 UN Watercourse Convention 1997

The United Nations Convention on the Law of Non-Navigational Uses of International Watercourses (UN Watercourses Convention) was enacted by the UN General Assembly in 1997 and went into effect in 2014. While the agreement focuses on Transboundary Rivers and lakes, it also includes rules that apply to transboundary groundwater inasmuch as they are related to surface water.

- According to Article 1, a "watercourse" is a system of surface and groundwater that form a single entity due to their physical interdependence. This fundamental term broadens the scope of the Convention to include the portion of groundwater linked to surface water within the system.

- Article 2 expands on the concept of "international watercourse," which encompasses sections of a watercourse located in different states, addressing issues of interrelated transboundary groundwater.
- Article 5 underlines the notion of "equitable and reasonable utilization and participation," a cornerstone of international water law, and applies to using linked groundwater resources.
- Article 7 establishes the commitment not to cause significant harm and requires nations to take all necessary precautions to prevent considerable harm to other watercourse states.
- Article 8 promotes collaboration among watercourse nations based on sovereign equality, territorial integrity, mutual benefit, and good faith, all of which are important considerations for managing transboundary groundwater resources.
- Article 9 requires river nations to create joint commissions or other instruments for collaboration. Such collaboration is required to manage shared groundwater resources, which may include cooperative monitoring, data exchange, and the development of sustainable usage policies.
- Article 12 and subsequent articles on "Protection and Preservation of Ecosystems" and "Prevention, Reduction, and Control of Pollution" expand protective measures to the aquatic environment, including groundwater.

The agreement establishes a core framework for collaboration over shared waterways, vital to ensuring sustainable and equitable usage, especially in light of rising demand and hazards aggravated by climate change. While the UN Watercourses Convention specifies these terminologies and concepts that might be applied to connected transboundary groundwater systems, it does not explicitly address [1]stand-alone groundwater or the effect of climate change on it specifically.

2.3.4 Berlin Rules (2004)[47]

"These Rules incorporate the experience of the nearly four decades since the Helsinki Rules were adopted, taking into account the development of important bodies of international environmental law, international human rights law, and the humanitarian law

[47] Can be accessed at "Inter International Law Association. "Water Resources Law." In *Report of the Berlin Conference*, 37-45. 2004. Members of the Committee: Dr. Gerhard Loibl (Chair, Austria), Professor Joseph W. Dellapenna (Rapporteur, USA), Professor Malgosia Fitzmaurice (Secretary, UK).

relating to the war and armed conflict, as well as the adoption by the General Assembly of the United Nations of the UN Convention. This revision does not address the substantive rights and duties of international organizations, the accountability of such organizations, or the dispute settlement procedures applicable to such organizations."[48]

- Article 39 - The following article is based on the responsibilities of monitoring groundwater as outlined in Seoul Rules, article 3. These responsibilities apply to all aquifers, not just those considered part of international drainage. Even in cases where it is concluded that the obligation to gather information is restricted to transboundary contexts, a State may not be aware if an aquifer is transboundary and, therefore, may not know if the more limited duty applies unless the State takes comprehensive steps to develop information on all aquifers within its jurisdiction, regardless of proof of international connections.
- Article 42 - Transboundary AquifersParagraph 2 acknowledges that if political boundaries determine management practices, each state is less likely to achieve its managerial goals compared to when the states involved with the aquifer work together. This concept was acknowledged in Seoul Rules, article 2, albeit with different wording. There are very few instances of the type of basin wide aquifer management called for in this Article in current state practices, mainly because international agreements focusing on groundwater are still uncommon. The more assertive approach in paragraph 1 is starting to appear in regional agreements concerning aquifer management.[49] Under the principle of fair utilization, states may not utilize more than their fair share of groundwater, whether from a renewable or non-renewable aquifer. Several international agreements now aim to limit groundwater drawdown to ensure that states limit their usage to an equitable and reasonable share. When setting drawdown rates for transboundary aquifers, basin states must consider the duty not to cause significant harm to another state (Article 16) and the obligation to protect aquifers (Article 41). Paragraph 5 indicates that states must cooperate in safeguarding the recharge of aquifers. Similarly, paragraph

[48] Full report can be accessed at "International Law Association. "Water Resources Law." In *Report of the Berlin Conference*, 1-10. 2004. Members of the Committee: Dr. Gerhard Loibl (Chair, Austria), Professor Joseph W. Dellapenna (Rapporteur, USA), Professor Malgosia Fitzmaurice (Secretary, UK)."

[49] Refer to the UNECE Charter, article VI (2).

6 asserts that the principle of preventing significant harm applies to transboundary aquifers, considering the principle of equitable utilization.

The focus on collaboration and fair use is a reflection of the rising acceptance in international law of the necessity of cooperative strategies for the sustainable management of shared water resources. The Berlin Rules set a progressive tone for future agreements, notwithstanding the obstacles presented by the limited current practices and the dearth of international accords particularly targeting groundwater. These regulations open the door to more efficient and sustainable management of transboundary aquifers, guaranteeing the preservation of water resources for future generations while promoting global cooperation and legal compliance. They achieve this by harmonizing the principles of preventing significant harm with equitable utilization.

2.3.5 The Bellagio Draft Treaty on Transboundary Groundwater

The Bellagio Draft Treaty, also known as the "Bellagio Draft Treaty on Transboundary Groundwater," is a scholarly proposal developed in 1989 during a workshop at the Rockefeller Foundation's Bellagio Conference and Study Centre in Bellagio, Italy. The draft was never accepted as a formal international treaty. However, it is frequently cited for its groundbreaking notions in transboundary groundwater law, which influenced international legal developments and discussions.[50]

Here is how the Bellagio Draft Treaty handles transboundary groundwater[51]:

- Scope of Application: The treaty recognizes the need to explicitly address transboundary aquifers or aquifer systems located on the territory of two or more states.
- General obligations: The draft treaty sets forth broad duties to maintain and use transboundary groundwaters equitably and fairly. It advocates for the coordinated management of shared aquifers and avoiding severe harm to other aquifer states.
- Provisions for collaboration: The proposal highlights the need for collaboration. This includes exchanging information and data, performing cooperative monitoring, and consulting on actions that may affect common groundwater resources.

[50] Refer to "Hayton, Robert D., and Albert E. Utton. "Transboundary Groundwaters: The Bellagio Draft Treaty." Revised and Augmented."

[51] Refer to "Maria Elena Giner, "Municipal Water Supply on the Border," United States-Mexico Law Journal 11 (2003): 53-56"

- Equitable Utilization: It proposes the principle of equitable and reasonable use of transboundary groundwater, encouraging states to consider factors such as each country's contribution to groundwater formation, the population reliant on the water, and the availability of alternative sources.
- Pollution Prevention: The proposed legislation seeks to prevent, mitigate, and control pollution to transboundary aquifers, emphasizing precautionary measures given the lack of scientific clarity regarding the deleterious impacts of specific activities.
- Dispute Settlement establishes means for peaceful conflict resolution, such as discussions, mediation, and arbitration that are consistent with customary international law processes.
- Data Exchange and Scientific Collaboration: The proposed treaty promotes regular information exchange and scientific collaboration in research, technical aid, and capacity building.

Despite never being legally ratified, fundamental themes in the Bellagio Draft Treaty foreshadowed many of the principles that would later appear in the UN International Law Commission's (ILC) Draft Articles on Transboundary Aquifers, which we discuss next. These Draft Articles, finished in 2008, advance many of the Bellagio themes and is now the most authoritative instrument giving guidance on the management, use, and conservation of transboundary aquifers, although they do not have the binding character of a convention or treaty.

2.3.6 Draft articles

The 'Draft Articles on the Law of Transboundary Aquifers' adopted by the International Law Commission (ILC) in 2008 provide a more directly applicable legal framework for transboundary aquifers that are hydraulically disconnected from surface watercourses. However, these articles still need to be adopted as conventions.

The "Draft Articles on the Law of Transboundary Aquifers" are a set of articles produced by the International Law Commission (ILC), a United Nations expert organization, to establish a systematic legal framework for the proper management and usage of transboundary aquifers[52].

[52] The refered articles can be read at International Law Commission. "Draft Articles on the Law of Transboundary Aquifers." 2008. Accessed [28th-04-2024]. https://legal.un.org/ilc/texts/instruments/english/draft_articles/8_5_2008.pdf.

The ILC accepted the Draft Articles in August 2008, followed by the United Nations General Assembly in December 2008 with Resolution A/RES/63/124. Although not legally enforceable, they guide governments in developing agreements and policies for the fair and sustainable use of shared groundwater resources.

The key topics in the Draft Articles include the following:

- Sovereignty: States have control over a section of a transboundary aquifer or aquifer system located on their territory. (Article 3)
- Equitable and fair utilization: States that share an aquifer should use it equitably and reasonably, considering the aquifer's and other states' demands. (Article 4 & 5)
- States are obligated not to cause serious harm to other states that share the same aquifer. (Article 6)
- General responsibility to cooperate: States are legally required to collaborate through agreements and regularly share data and information. (Article 7)
- Regular interchange of data and information: States should provide and share information on the aquifer's status and use. (Article 8)
- Ecosystem protection and preservation: Measures should be taken to safeguard and sustain aquifer-dependent ecosystems. (Article 10)
- Contamination prevention, reduction, and control: States should take all necessary steps to avoid, minimize, and control aquifer contamination. (Article 12)
- Emergencies: In an emergency that may impact the aquifer, states must communicate and assist one another in mitigating the consequences. (Article 17)

The Draft Articles seek to foster collaboration, avoid conflicts, and ensure the protection and optimal use of transboundary aquifers for current and future generations. While they are not legally enforceable like a convention, they are an essential foundation for international law governing transboundary water resources and climate change. Some areas and nations have used the Draft Articles as a template to create legal instruments and agreements for managing shared aquifers.[53]

2.3.7 UNECE Water Convention (1992)

The United Nations Economic Commission for Europe (UNECE) developed the Convention on the Protection and Use of Transboundary Watercourses and International

[53] Extracted from "Allan, A., Loures, F., and Tignino, M. "The Role and Relevance of the Draft Articles on the Law of Transboundary Aquifers in the European Context." *Journal of Environmental Law and Policy* 8, no. 8 (2011): 231-251. https://brill.nl/jeep."

Lakes (1992), also known as the Water Convention, UNECE. Its original goal was to ensure the sustainable use and protection of transboundary watercourses and international lakes within the European region.[54] However, changes were agreed in 2003 that allowed nations outside the UNECE region to become parties to the Convention, and these revisions went into effect in 2016, making the Convention available for states to join worldwide.

The Convention's provisions about transboundary groundwater management are as follows:

- Definition: The term "transboundary waters" encompasses not only transboundary rivers and lakes but also their related groundwaters (which are part of the same aquatic system). (Article 1)
- General Provisions: Countries must take all necessary steps to avoid, regulate, and mitigate transboundary impacts, safeguard the environment, and guarantee sound and rational management of transboundary waterways, which include groundwater.(Article 2)
- Prevention, Control, and Reduction: The parties must guarantee that transboundary waters are used ecologically sound and sensible, with the goal of conserving water resources and protecting the environment. This includes both surface and groundwater resources. (Article 3)
- Monitoring: The Convention asks for establishing and implementing collaborative programs to monitor the state of transboundary waterways, including groundwater. (Article 5)
- Research and Development: The parties are encouraged to conduct research and development on the state of transboundary waters, which would inevitably include studies on groundwater where it is linked to surface water systems. (Article 6)
- Bilateral and Multilateral Cooperation: The parties are urged to develop bilateral or multilateral agreements or arrangements governing their shared seas. When these accords apply to basins with transboundary aquifers, groundwater should be incorporated into management plans. (Article 9)

We can see that the UNECE Water Convention makes no distinction between linked and separated groundwater, implying an integrated approach to water management incorporating groundwater as a whole basin ecosystem component[1]. This broad breadth is

[54] International legal water cooperation. http://cawater-info.net/bk/9-2-2_e.htm

critical for tackling groundwater issues as part of the integrated management of transboundary water resources.

Above conventions find their roots in IWL principles which emphasis on collaboration, coordination, responsibility and equality along with other principles.

Following case studies demonstrates the importance of these terms in existing agreements

- **The Gabcikovo-Nagymaros Project Case (Hungary/Slovakia, 1997):**

The construction of several dams on the Danube River was the source of contention in this case between Slovakia and Hungary. Due to environmental concerns, Hungary unilaterally stopped development on the project, allowing Slovakia to continue on its own.

The ICJ found that both nations had failed to uphold their end of the bargain, but it also recommended that talks and collaboration be maintained in order to find a solution.

The decision underscored how crucial environmental factors are to transboundary water management and how both sides must honor their agreements while working toward a compromise. It states that the activities would result in deletion of groundwater level and supply and also the quality of groundwater in the entire region.[55]

This case emphasizes the necessity of striking a balance between development and environmental protection, as well as the role that international courts play in mediating transboundary water issues.

Comparative Analysis

Aquifers that are shared across borders must be sustainably used, and this requires transboundary groundwater management. Because each region has a different set of political, legal, environmental, and socioeconomic circumstances, they have also developed different management strategies for these common resources as we can see in *The Colorado River Compact (1922) (United States and Mexico)*[56] where Colorado River crosses into Mexican territory and the seven U.S. states have agreed to the Colorado River Compact, which has an effect on Mexico as well. In addition to meeting Mexico's water needs, the compact distributes water across the states.

The compact establishes a standard for the distribution of water between states and internationally, highlighting the necessity of explicit agreements and the significance of

[55] This can be read on pages 32, 40 and 72 from the official judgment," International Court of Justice. "Case Concerning the Gabcikovo-Nagymaros Project (Hungary v. Slovakia)." Judgment of 25 September 1997. *Reports of Judgments, Advisory Opinions and Orders*."

[56] Pitt, Jennifer. "The Colorado River Compact at 100: Can It Survive Another Century?" *Audubon*, November 22, 2022. https://www.audubon.org/news/the-colorado-river-compact-100.

upholding commitments made to countries downstream.

The Colorado River Compact illustrates the difficulties in striking a balance between conflicting water demands in dry areas and is a pioneering example of transboundary water management.

The Nile Basin Initiative provides a model for Cooperative Water Resource[57]. It is a cross-border cooperation initiative aimed at managing and utilizing the shared water resources of the Nile River among its riparian states. Established in 1999, the NBI comprises eleven nations, including Burundi, the Democratic Republic of the Congo, Egypt, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda. Eritrea is an observer at this event. The main goal of the NBI is to advance sustainable socioeconomic development by ensuring equitable utilization of the common Nile Basin water resources and everyone benefiting from them.[58]

The NBI operates through two primary programs: the Subsidiary Action Program (SAP) and the Shared Vision Program (SVP). The SVP promotes trust and collaboration among member states through regional programs such as agricultural development, energy production, and water resource planning. These initiatives aim to create the groundwork for peaceful coexistence, political stability, and strengthening economic integration in the region.

The SAP focuses on the Eastern Nile and Equatorial Lakes, addressing larger regional problems like flood management, agricultural irrigation, and hydropower development. Facilitating communication among the nations of the Nile Basin has been essential in reducing tensions, especially between Ethiopia and Egypt around the Grand Ethiopian Renaissance Dam. The NBI has also played a significant role in strengthening the Nile Basin countries' ability to better manage their water resources, offering capacity-building initiatives and technical support.[59]

However, the NBI still faces challenges such as climate change effects, economic differences, and political unrest in some member nations. To ensure sustained success,

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[57] International Waters Governance. 'Nile River Basin Initiative.' Accessed March 27, 2024. http://www.internationalwatersgovernance.com/nile-river-basin-initiative.html."

[58] Referred from Shabbana, Ghazzala. "Disputes Over Sharing of Transborder Rivers in West Asia." (2010). https://core.ac.uk/download/144526575.pdf.

[59] Full report can be read at "Transboundary Water Cooperation in the Nile Basin." MENA Report , no. (2019):

member states must remain flexible and committed to adapting their strategies and solutions to changing situations.

2.4 Implementation Challenges:

In managing transboundary groundwater resources, coordination across national borders, legal frameworks, and environmental circumstances can be highly complicated and challenging. While researching for the data above there were a number of obstacles that surfaced and must be overcome for transboundary groundwater management agreements to be implemented successfully, including legal, technical, political, and socio-economic challenges.

Political Challenges:

Divergent National Interests: Conflicting interests arise when countries that share an aquifer prioritize different uses of water, such as agriculture, industry, or domestic supply. These differences may give rise to disputes about the distribution of water, which would make it challenging to come to or carry out agreements.

Sovereignty Concerns: Because they believe that cooperative management may violate their sovereignty, countries may be hesitant to give up authority over their share of a shared aquifer. This may make it more difficult to work together and create efficient management plans.

Political Instability: The ability to carry out and enforce transboundary groundwater agreements is seriously jeopardized in areas impacted by political instability, conflict, or inadequate governance. Effective management attempts have been impeded by political upheaval in the North Western Sahara Aquifer System (NWSAS) region and also as discussed above in IWT.

Socio-Economic Challenges:

Economic Disparities: The execution of management agreements may be impacted by the economic disparities between the nations that share an aquifer. Richer nations might be able to devote more resources to sustainable management techniques, whereas poorer nations might find it difficult to fulfill their commitments or might put short-term profits ahead of sustainability over the long run.

Pressures on Water Demand: As a result of urbanization, industrialization, and population growth, there is an increased demand for water, which strains available

groundwater supplies. Over-extraction may result from this, which would make it challenging to apply sustainable management techniques.

Stakeholder Involvement: The active participation of several stakeholders, including governments, local communities, non-governmental organizations (NGOs), academic institutions, and the commercial sector, is essential to the effective transboundary groundwater management process. These parties are essential to the process of making decisions, carrying them out, keeping an eye on things, and making sure that pooled groundwater resources are sustainable. Their engagement is critical to promoting collaboration, increasing openness, and establishing confidence between nations that share an aquifer.

Therefore, it can be concluded that political, technological, and environmental issues complicate management of transboundary groundwater. Cooperative management agreements may be complicated by disagreements between national interests and sovereignty concerns. These problems are made worse by political instability, especially in areas like the North Western Sahara Aquifer System. Other difficulties include pressures from urbanization and socioeconomic inequality. In order to build collaboration and trust that are essential for successful management, stakeholders such as local communities, NGOs, and governmental agencies are important. Their participation guarantees the longevity of shared water resources and adjusts management techniques to the shifting geopolitical environment.

Chapter 3: Transboundary Groundwater Agreements

Transboundary groundwater agreements have been in place since the early 20th century, as the necessity of cooperative management has come to be understood more and more. As the significance of groundwater became increasingly apparent, separate agreements for transboundary aquifers emerged, while the majority of the early accords concentrated on surface water resources[60]. The way these agreements have developed is a reflection of our increasing understanding of the interdependence of water resources and the need for coordinated management strategies.

Groundwater was frequently left out of early transboundary water accords, which instead concentrated on the distribution and control of surface water[61]. But the necessity for particular agreements addressing transboundary aquifers increased as groundwater emerged as a vital resource for industry, agriculture, and drinking water. With the introduction of the Helsinki Rules in 1966, which expanded the principles of fair and reasonable use to both surface and groundwater resources, the incorporation of groundwater in international water law gained pace.[62]

3.1 Key Laws and Agreements

For the purpose of properly addressing the issues posed by climate change, transboundary groundwater resources that are shared by two or more nations must be managed cooperatively[63]. We studies the legal frameworks governing these agreements in the last section now we will look into few of these agreements which are formed to support sustainable management and address the effects of climate change. All the same, the degree of cooperation among riparian governments, the strength of their legal systems, and their ability to manage resources adaptively all have an impact on how effective these accords are. This section looks at a few of the most important laws and agreements, emphasizing their salient characteristics and practicality.

3.1.1: International Water Law

The world is facing a growing concern regarding transboundary aquifers and rivers, especially in countries that share these crucial natural resources. The stress on available water resources is increasing with growing population densities and intensification of

[60] (Salman 2007)
[61] (Dellapenna and Gupta 2009)
[62] (Benvenisti 1996)
[63] (Eckstein 2002)

economic development[64]. This has led to significant competition for water resources between industry sectors, irrigation, hydropower generation, and countries sharing the same aquifer system. [65]However, aquifers are much more challenging to regulate because wells on private land require more significant effort for monitoring and regulatory supervision, which we discussed in the last section.

There are no dedicated laws that directly tackle the consequences of climate change at the moment. Nevertheless, regulations and policies in place pertain to transboundary waters, encompassing both surface and subsurface water bodies. This segment will comprehensively examine all pertinent regulations and policies to evaluate their efficacy in sustainably managing transboundary aquifers.

As we discussed in the last chapter The UN International Law Commission recognized the significance of transboundary water and started working on drafting a related convention.[66] The UN General Assembly adopted the 1997 Convention, officially known as the Convention on the Law of Non-Navigational Uses of International Watercourse, after 27 years of work. In 1966, the International Law Association (ILA), a non-governmental organization, included groundwater explicitly in their Helsinki Rules, which dealt with surface and groundwater flowing to a common endpoint. In 1986, the ILA created the Seoul Rules, as the Helsinki Rules needed to address other groundwater flows entirely. The Seoul Rules are mainly concerned with transboundary groundwater and provide specific articles on "hydraulic interdependence," "protection of groundwater," and "groundwater management and surface waters," with the latter addressing the issue of conjunctive use.

Challenges

In addition to the challenges discussed in the last chapter one of the challenges of legislating on aquifers is their diverse nature and heterogeneity, making inflexible legislative classifications undesirable to hydrogeologists[67]. Therefore, hydrogeologists must be better versed in international law or politics and have been unwilling to engage in this debate. As a result, many important matters related to the sound management of transboundary aquifers needed to receive the attention they deserved[68] as a solution, the ISARM initiative is now addressing many of these urgent issues by assisting the UN International Law Commission's Special Rapporteur in addressing transboundary aquifers.

[64] (Benvenisti 1996)
[65] (Barasa 2020)
[66] (S.Puri, 2009)
[67] (S. Puri 2003)
[68] (Mechlem 2003)

The Special Rapporteur in the UN International Law Commission plays a crucial role in shaping international norms concerning the management and use of transboundary aquifers. Their responsibilities include drafting international legal principles, facilitating negotiations and consensus, conducting research and analysis, recommending dispute resolution mechanisms, raising awareness and advocacy, collaborating with scientific and expert bodies, and focusing on the utilization and protection of transboundary aquifers. The impact of their work is evident in the contributions of special Rapporteur Chusei Yamada, who delivered draft articles on the law of transboundary aquifers in the early 2000s, which we discussed in the last section. These articles were adopted by the ILC in 2008 and taken to the UN General Assembly, demonstrating the tangible results of their efforts. The ongoing work of successive Special Rapporteurs is vital for fostering international cooperation and ensuring the sustainable management of this crucial natural resource[69].

Global water agreements and relevant principles of IWL

Global water agreements and International Water Law (IWL) principles are crucial for managing and protecting water resources. This section discusses the relevant International and two regional pieces of legislation and their contribution to the sustainable management of transboundary water basins. Sustainable management plays a vital role here because this paper has interpreted it as a mitigation step towards climate change's effects[70].

3.2.Sustainable Development Goals

Sustainable Development Goal indicator 6.5.2 and the Water Convention report on monitoring progress in transboundary groundwater management[71] - SDG indicator 6.5.2, adopted by the General Assembly in July 2017 as part of the global indicator framework for the SDGs, measures the 'proportion of transboundary basin area within a country covered by an operational arrangement for water cooperation,' which includes river and lake basins as well as aquifers. Thus, the indicator encompasses transboundary cooperation in both surface and groundwater environments.[72] Limited experiences have been recorded in setting up and operationalizing a fully empowered and functional institution responsible for the governance of a transboundary aquifer system. Despite this, progress has been made in establishing consultation mechanisms within existing institutions, such as the

[69] (Eckstein 2002)
[70] (Gleeson et al. 2012)
[71] (UNESCO 2012)
[72] (UNECE 2021)

Stamp Riet Aquifer shared by Botswana, Namibia, and South Africa. [73] Formal institutional arrangements favorable for transboundary cooperation can be achieved through joint identification of needs and interests and multidisciplinary assessments of the shared aquifer. The inclusion of Sustainable Development Goal (SDG) Target 6.5 in the 2030 Agenda for Sustainable Development has raised awareness about implementing integrated water resources management (IWRM) at all levels, including through transboundary cooperation, where appropriate. SDG Indicator 6.5.2 monitors Progress towards SDG Target 6.5 by evaluating the proportion of transboundary basin area (rivers, lakes, and aquifers) covered by an operational arrangement for water cooperation.[74] This indicator assesses whether transboundary aquifers are covered by their specific arrangements, within river and lake basin arrangements, or broader bilateral arrangements. The Water Convention's regular reporting system, established in 2015, intends to examine and improve the Convention's implementation while also identifying requirements and gaps in transboundary cooperation. The reporting template, in the form of a questionnaire, monitors the level of national Convention implementation, considering all transboundary basins, rivers, lakes, and aquifers.

The results of the 2017 reporting cycle demonstrate that cooperation on transboundary aquifers [75]is falling behind, as emphasized in the reports Progress on Transboundary Water Cooperation: Global baseline for SDG indicator 6.5.2 and Progress on Transboundary Water Cooperation under the Water Convention. [76]

The Water Convention Secretariat's activities support initiatives in transboundary basins that help to build or revise transboundary water cooperation agreements and arrangements for surface and groundwater management. For example, in February 2019, a roundtable on transboundary collaboration on the Senegalo-Mauritanian Aquifer System brought together the four aquifer states, The Gambia, Guinea Bissau, Mauritania, and Senegal, as well as the region's two leading transboundary basin organizations, the Senegal River Basin Development Organization and the Gambia River Development Organization. It permitted a discussion on common aquifer management concerns and the development of potential possibilities for cooperation to support the sustainable management and use of the aquifer

[73] (UNECE 2023)
[74] (UNESCO, International Association of Hydrogeologists 2022)
[70] (UNECE 2018)

as a first step towards deepening cooperation[77]. Moreover, sustainable management of river basins is the only plausible solution to mitigate climate change's impact on the aquifers.

3.3 UNESCO

Despite the critical role of transboundary aquifers in environmental and human development, policymakers have not given this vital resource the required attention.[78] Unfortunately, unlike transboundary river basins, there are no global policies or legal instruments to directly govern transboundary aquifers and mitigate the effects of climate change on the quality and quantity of water[79]. To bridge this gap, the International Association of Hydrogeologists (IAH) established a Commission on Transboundary Aquifer Resources Management (TARM) following its 1997 Congress in Nottingham, UK, to promote their study and joint international cooperation. The IAH initiative coincided with adopting the UN Convention on International Watercourses and the UNESCO International Hydrological Programme (IHP), which had the theme "Water Interactions: Systems at Risk and Social Challenges." The 14th Session of the Inter-Governmental Council of UNESCO 2000 approved joint TARM activities of IAH and UNESCO in cooperation with the Food and Agriculture Organization (FAO) and the United Nations Economic Commission for Europe (UNECE).[80]

Key Contributions of UNESCO in Transboundary Aquifers Management

UNESCO's International Hydrological Programme (IHP) has been actively involved in the research and management of transboundary aquifers.[81] This engagement is part of the organization's wider mission to encourage worldwide collaboration in water resource

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[77] (UNECE 2021)

[78] Bittinger, M.W. 1972. A survey of interstate and international aquifer problems. Ground Water 10, no. 2: 44–54 Hayton, R., and A.E. Utton. 1989. Transboundary groundwaters: The Bellagio draft treaty. Natural ResourcesJournal 29, 663–722

[79] (Bourne 1992)

[80] Information extracted from "Aureli, Alice – UNESCO Land Subsidence International Initiative. https://www.landsubsidence-unesco.org/members/aureli/"
and "Aureli, Alice. "Transboundary Aquifers: A Global Program to Assess, Evaluate, and Develop Policy." *Ground Water* (2005)."

[81] Extractd from "United Nations Educational, Scientific and Cultural Organization (UNESCO). *International Hydrological Programme (IHP) Eighth Phase: "Water Security: Responses to Local, Regional, and Global Challenges" Strategic Plan IHP-VIII (2014-2021)*, 23-27."

management.[82] UNESCO plays an important role in the initiation, coordination, and support of major worldwide efforts. UNESCO provides scientific and technical expertise for monitoring and managing transboundary water resources. Through its International Hydrological Programme (IHP), it also guarantees that projects such as ISARM, TWAP, and GGRETA are based on strong scientific foundations[83], which we will discuss in the following section.

3.3.1 International Shared Aquifer Resource Management (ISRAM)

The scope of interagency joint action was defined in a Framework Document with the acronym ISARM (Internationally Shared Transboundary[84]Aquifer Resource Management). ISARM collaboration draws on the synergy of international agencies that support and promote the sound use of transboundary aquifers. Several regional initiatives are underway, such as the ISARM-Americas Programme (coordinated by the Organization of American States [OAS]), the ISARM-Europe Programme (coordinated by the UNECE), and the ISARM-Balkans (coordinated by UNESCO-INWEB). Studies financed through the Global Environment Facility (GEF) have commenced in Africa and the Caribbean. The global ISARM (Internationally Shared Aquifer Resources Management) Initiative is a multi-agency initiative headed by UNESCO and the IAH to improve knowledge of scientific, socioeconomic, legal, institutional, and environmental concerns connected to transboundary aquifer management. It has facilitated the development of legal frameworks and treaties, promoted UNESCO guidelines, and influenced national policies. ISRAM has also set international benchmarks, raised awareness and capacity, and strengthen governance. These collective efforts mark significant progress toward global water security and sustainable resource management[85].

The issue of shared international seas is as ancient as the national borders that define those waters as international. During the previous century, great progress was achieved in regulating cooperative management of surface watercourses; several international river, lake, and basin commissions were established, and legal treaties were signed. Although some of these operations target "a groundwater component," significant similar efforts connected to invisible groundwater began only a few years ago with the ISARM Programme.

[82] Refer to “"International Hydrological Programme (IHP)." UNESCO. Accessed [23-06-2024]. https://www.unesco.org/en/ihp.”
[83] Information extracted from UNESCO webpage “https://ihp-wins.unesco.org/”
[84] (Puri 2001)
[85] (Burchi 2018)

3.3.2 GGRETA

Several initiatives linked to ISARM have commenced, and the Government of Libya has proposed a significant project. The government has suggested that the African Centre for the Management of Shared Groundwater Resources in Tripoli manage this valuable resource. UNESCO and the World Meteorological Organization (WMO) will be involved in establishing the center.[86]

The Groundwater Resources Governance in Transboundary Aquifers (GGRETA) Project tackles issues of transboundary aquifers and responds to the urgent need to increase understanding of their physical and socioeconomic features. It is a key component of UNESCO's International Shared Aquifer Resource Management

The project is split into three phases:

- GGRETA 1(2013-2015)[87]
- GGRETA 2 (2016-2018)[88]
- GGRETA 3 (2019-2022)[89]

It uses methods based on water diplomacy and science[90]. GGRETA strives to improve the governance of transboundary aquifers by creating and supporting governance frameworks. These frameworks comprise legal, institutional, and regulatory mechanisms that countries may implement to better manage shared groundwater resources.

[86] Puri, Shammy, ed. *Internationally Shared (Transboundary) Aquifer Resources Management: Their Significance and Sustainable Management. A Framework Document*. IHP-VI, IHP Non Serial Publications in Hydrology. Paris: UNESCO, November 2001. Contributors: Bo Appelgren, Geo Arnold, Alice Aureli, Stefano Burchi, Jacob Burke, Jean Margat, Philippe Pallas, UNECE.

[87] This phase's goal was to better understand groundwater dynamics and each prototype transboundary aquifer through scientific analysis.

[88] This phase's goal was to increase cross-border conversation through common management tools while also encouraging governance changes and providing the groundwork for consultation and cooperation procedures.

[89] The goal of this phase is to improve regional stability, collaboration, and peace by establishing collaborative frameworks for transboundary groundwater governance.

[90] "The project has been implemented since 2013 in three pilot aquifers and regions in cooperation with partners and stakeholders: Stampriet Transboundary Aquifer System and Africa; Pretashkent Transboundary; Aquifer System in Central Asia; Ocotepeque-Citala Transboundary Aquifer System, in Central America The overall project objective is to achieve better governance of shared groundwater resources in the three pilot regions through an approach based on transboundary cooperation and science-based multidisciplinary assessments." (IGRAC n.d.)

3.3.3 TWAP

The Transboundary Waters Assessment Programme (TWAP) is a global initiative that evaluates transboundary water systems, including aquifers. It provides essential data and assessments for creating international agreements and legal frameworks related to transboundary aquifers. TWAP establishes consistent methodologies for evaluating aquifers' status and potential risks, ensuring a standardized approach to water resource management. It strengthens international legal instruments by providing health and risk statuses to promote specific legal provisions, and amendments focused on sustainability. TWAP assessments guide national and international governance frameworks for transboundary aquifers, assisting in developing scientifically grounded laws and policies. It fosters cross-border collaboration by promoting dialogues and collaborative agreements among countries sharing transboundary aquifers. TWAP's capacity building and technical assistance empower countries to effectively manage their shared water resources and adhere to international legal standards, ensuring sustainable water management. TWAP's findings and methodologies significantly influence global water policy debates, establishing a model for science-based international cooperation and advocating for a more comprehensive, coordinated approach to global and regional water security[91].

It is a worldwide Environment Facility (GEF)-funded initiative that aims to perform the first worldwide baseline evaluation of transboundary water systems. The evaluation was conducted in five components: transboundary river basins, lake basins, large marine ecosystems, open ocean and transboundary aquifers, and SIDS groundwater systems. The latter is the component in which IGRAC has participated as a project partner by organizing regional meetings and constructing a TWAP Information Management System that contains all obtained groundwater data[92].

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[91] (UNEP 2016)

[92] IGRAC, in collaboration with UNESCO-IHP, has been in charge of carrying out the project's groundwater component, including the assessment of 199 transboundary aquifers and 43 small island developing states. IGRAC has also managed the data and information for the groundwater component. Other services supplied are:

There are designs and development of software requirements for the TWAP Groundwater Information Management System (IMS).

Co-organized and presented workshops in regional South America, Africa (2), Europe, and Asia.

Participation in cross-cutting working groups on governance, data, and information management.

Objective

- To undertake a global assessment of transboundary aquifers and SIDS groundwater systems through a formalized consortium of partners.

IGRAC has been active in GRAPHIC, a project that promotes and develops sustainable groundwater management while considering expected climate change and its associated human implications. IGRAC has expertise in MAR research at both the local and regional levels. The Global Groundwater Monitoring Programme (GGMP) addresses climate change. Due to their geophysical characteristics, the so-called SIDS (Small Island Developing States) is more sensitive to climate change than other countries. The Global Overview of Salty Groundwater Occurrence and Genesis describes salty/brackish groundwater bodies and analyses their influence on change to help with saline groundwater management[93].

UNESCO's involvement with ISARM, TWAP, and GGRETA demonstrates its dedication to promote sustainable and collaborative management of transboundary water resources. UNESCO's International Hydrological Programme (IHP) offers the scientific, technological, and policy assistance required for these programs to succeed. This partnership improves global water security by encouraging international cooperation in the management of common water systems[94].

All three initiatives have a significant influence on policy by offering scientific evaluations, supporting international norms, encouraging collaboration, and improving governance frameworks for transboundary water management. These efforts assist nations in developing and implementing effective policies that promote the sustainable and fair use of shared water resources, ultimately contributing to global water security and peace[95].

Comparing surface water and groundwater management in the context of climate change might yield valuable strategies and insights. For example, integrated management systems that consider both surface and groundwater can improve overall water resource management. Shared approaches, such as integrated water resource management (IWRM) methodologies, may be used since surface and groundwater resources face comparable issues. Analyzing efficient surface water management techniques can produce models for improving groundwater management, particularly in light of climate unpredictability. By addressing these problems, we are contributing to a comprehensive framework that

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- To support informed investments by the GEF and other international organizations.
- To be sustained through a periodic process in partnership with critical institutions to incorporate transboundary considerations into a regular assessment program.' (igrac n.d.)

[93] (igrac n.d.)
[94] (UNESCO n.d.). International Hydrological Programme
[95] (UNESCO n.d.). Transboundary Water Management

improves management strategies and increases understanding of how climate change affects transboundary aquifers.

3.4 Case Studies

These case studies provide light on the problems and accomplishments of managing shared groundwater resources.

3.3.1 Aquifer Agreement in Guarani

The Guarani Aquifer is one of the world's largest transboundary groundwater reserves, spanning around 1.2 million square kilometers beneath the surface of Argentina, Brazil, Paraguay, and Uruguay. This massive aquifer holds an estimated 40,000 cubic kilometers of freshwater, making it an important resource for the South American area. The aquifer's significance stems not only from its vastness, but also from its ability to offer a continuous supply of water to millions of people, support agricultural operations, and preserve ecological equilibrium.[9697]

Historically, the Guarani Aquifer has been managed independently by the nations in which it exists. This fragmented management method raised worries about over-extraction, pollution, and the aquifer's long-term viability. Recognizing the need of a cooperative management framework, the nations concerned wanted to establish a formal agreement to assure the long-term use and conservation of this crucial resource.

The Guarani Aquifer Agreement, signed on August 2, 2010, establishes a groundbreaking legislative framework for cooperative aquifer management and sustainability[98]. The agreement is founded on many major legal principles:

1. Principle of Sovereignty: The agreement recognizes each country's sovereignty over the portion of the aquifer beneath its borders. This approach is consistent with international law and protects the territorial integrity of the countries concerned.
2. Equitable and Reasonable Utilization: The agreement underlines the need of using aquifer resources in an equal and reasonable manner. This idea is crucial for ensuring that everyone benefits from the aquifer without inflicting major harm to others. It is consistent with the concepts established in the 1997 UN Convention on

[96] (Amore and Tundisi 2017)
[97] (Sindico et al. 2018)
[98] (UNESCO 2021). *Progress on transboundary water cooperation*

the Law of Non-Navigational Uses of International Watercourses and the 2008 Draft Articles on the Law of Transboundary Aquifers.

3. Cooperation and Information sharing: The agreement requires a frequent sharing of data and information between the nations. This provision is critical for good management since it allows for coordinated monitoring, evaluation, and decision-making on the aquifer's usage and conservation.
4. Sustainable Management: According to the agreement, the aquifer should be managed in a way that balances developmental demands and environmental preservation. This includes procedures for monitoring, scientific study, and the execution of safeguards against over-extraction and contamination.

The path to the Guarani Aquifer Agreement was fraught with challenges and cooperation. The importance of the aquifer, along with increasing demands from urbanization, agricultural, and industrial activity, pushed the countries to seek a collaborative approach. In the late 1990s and early 2000s, the World Bank's Groundwater Management Program and UNESCO's International Hydrological Programme (IHP) were beneficial in facilitating country-level discussions[99]. These organizations offered technical assistance, supported research, and contributed to the development of a scientific foundation for informed decision-making. The World Bank supported the Guarani Aquifer System Project, which sought to better understanding of the aquifer's properties, promote sustainable management techniques, and create international collaboration.to its management[100].

The Guarani Aquifer Agreement has significantly impacted the aquifer's management and conservation. Several major achievements demonstrate its success:

1. Institutional Framework: The agreement created a joint committee to supervise its implementation. This commission acts as a forum for ongoing debate and cooperation among the nations. It guarantees that decisions on the aquifer are made cooperatively and openly.
2. Sustainable Management Practices: The agreement has resulted in the implementation of sustainable management practices throughout the area. Regular monitoring and scientific studies are carried out to assess the aquifer's health and influence management choices. These initiatives assist to strike a balance between the demand for water extraction and the requirement to preserve the aquifer for future generations.

[99] (UNESCO 2020). *Governance of groundwater resources in transboundary aquifers*
[100] (UNESCO 2015)

3. Conflict Prevention: By establishing explicit legal provisions and dispute resolution systems, the agreement reduces the likelihood of water-related conflicts. The emphasis on collaboration and equitable use helps to avoid disagreements and develops a collaborative atmosphere among the countries.
4. Enhanced Knowledge and capabilities: The agreement has helped the nations better understand the aquifer's dynamics and enhance technical capabilities. Training programs, conferences, and collaborative research activities have improved the countries' ability to manage the aquifer efficiently.
5. Legal precedent: The Guarani Aquifer Agreement serves as an example for other regions experiencing comparable issues. Its concepts and regulations are consistent with international water law and provide a framework that may be used to address additional transboundary aquifers across the world.

The Guarani Aquifer Agreement is of great legal relevance both regionally and worldwide. Its adherence to international legal norms strengthens its validity and offers a solid foundation for collaborative water management. The agreement demonstrates how international law may help with the sustainable and equitable utilization of common natural resources.[101] The agreement's principles mirror the wider aims of international water law, such as those established in the 1997 UN Convention on the Law of the Non-Navigational Uses of International Watercourses and the 2008 Draft Articles on the Law of Transboundary Aquifers. By embracing these concepts, the Guarani Aquifer Agreement underscores the significance of collaboration, sustainability, and equitable use of shared water resources.[102]

The Guarani Aquifer Agreement provides a comprehensive and legally binding framework for the long-term management of a major transboundary water resource. It emphasizes the significance of international cooperation, legal clarity, and institutional assistance in tackling complicated environmental issues. The deal not only protects the aquifer for future generations, but also acts as an example for other places experiencing similar challenges. The success of the Guarani Aquifer Agreement demonstrates the ability of legal frameworks to allow cooperative management of shared natural resources. It highlights how countries may collaborate to promote sustainable and equitable use of essential resources, assuring their protection and availability for future generations. The accord

[101] (World Bank 2009). *Groundwater Management Advisory Team*
[102] (UNESCO. 2015)

demonstrates the ability of international law to promote peace, collaboration, and sustainable development.

3.4.2 Agreement for the Nubian Sandstone Aquifer System

The Nubian Sandstone Aquifer System (NSAS) is one of the world's biggest transboundary groundwater deposits, extending under the nations of Chad, Egypt, Libya, and Sudan. This aquifer system is vital to these nations' water resources in an arid and semi-arid region[103][104]. The administration and control of the NSAS is critical to maintaining sustainable water usage and avoiding possible disputes among riparian governments.

The importance of the NSAS extends back to ancient civilizations, when it functioned as a significant water supply in the region. However, systematic attempts to research and manage this large aquifer did not begin until the late twentieth century. Initial exploratory research indicated the aquifer's vast extent and potential for meeting the water demands of the countries it serves. Recognizing the strategic significance of the NSAS, riparian governments began to collaborate on scientific research and data exchange to better understand the aquifer's properties and potential[105].

In 1992, the riparian nations launched a collaborative effort with UNESCO and the International Atomic Energy Agency (IAEA) to improve the NSAS's long-term management. This collaboration resulted in the formation of the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System (JASAD-NSAS) in 1999, formalizing cooperation among Chad, Egypt, Libya, and Sudan[106]. The JASAD-NSAS's legal framework is founded on the concepts of equitable and reasonable use, no major harm, and collaboration, which are central to international water law[107]. The JASAD-NSAS agreement requires the exchange of data and information on the aquifer, collaborative monitoring of water extraction activities, and coordinated efforts in planning and executing water resource management plans. This legislative framework emphasizes the need of openness and mutual trust among riparian nations, encouraging a collaborative approach to manage the shared water resource.

The JASAD-NSAS is the key institutional mechanism for carrying out the legal framework that governs the NSAS. It is made up of delegates from each riparian state and is organized

[103] (Abdel-Mogheeth et al., 2010)
[104] (Shibasaki et al., 2007)
[105] (Salman & Uprety 2002)
[106] (McCaffrey 2001)
[107] (Shibasaki et al., 2007)

into committees and working groups that focus on certain areas of aquifer management. It's institutional framework promotes frequent communication, data sharing, and cooperative decision-making, ensuring that all member nations have a role in aquifer management[108].
The institutional framework is intended to address specific challenges associated with transboundary groundwater management. It includes methods for conflict settlement, technical collaboration, and capacity building, all with the goal of improving riparian governments' combined ability to manage the NSAS sustainably. It fosters a collaborative atmosphere, which helps to avoid possible disputes and promotes equitable sharing of aquifer benefits.
The NSAS's governance relies on effective conflict resolution mechanisms. The JASAD-NSAS agreement includes many levels of conflict resolution, starting with negotiation and consultation within the Joint Authority. If issues cannot be addressed at this level, they may be directed to mediation or arbitration, as specified in the agreement[109]. This multi-tiered strategy guarantees that disagreements are resolved in an organized and methodical way, lowering the risk of escalation.
A significant example of the dispute settlement mechanism in action happened in the early 2000s, when arguments emerged over the allocation of extraction quotas from the NSAS. The riparian governments were able to achieve an agreement on equitable extraction restrictions due to JASAD-NSAS mediation, avoiding possible conflict and safeguarding the aquifer's long-term usage. This example demonstrates the usefulness of established conflict settlement systems in promoting peace and collaboration among member.
Despite its strong legal and institutional structure, the NSAS confronts various current challenges. Climate change and variability pose serious concerns to the aquifer's stability, potentially affecting recharge rates and water supply. The existing allocation agreements' static character may not sufficiently address these dynamic changes, necessitating adaptive management solutions to preserve aquifer sustainability.
Furthermore, socioeconomic growth in riparian nations is increasing demand for water, placing further strain on the NSAS. Urbanization, industrialization, and agricultural development all contribute to increased water withdrawal, which, if not managed appropriately, may result in aquifer overexploitation[110]. These trends highlight the importance of ongoing monitoring, data exchange, and collaborative management to

[108] (Abdel-Mogheeth et al., 2010)
[109] (Salman and Uprety 2002)
[110] (McCaffrey 2001)

balance the aquifer's competing demands[111]. Technological improvements also bring possibilities and challenges for the NSAS management team. While enhanced monitoring and extraction technologies can increase water efficiency, they also raise questions about potential environmental consequences and the fair distribution of technical advantages. Ensuring that all riparian governments have access to and benefit from technology improvements is critical for sustaining justice and collaboration in aquifer management. The Nubian Sandstone Aquifer System is an important case study in transboundary water management, demonstrating the significance of legal and institutional frameworks in managing shared water resources. The concepts of reasonable and equitable usage, no major harm, and collaboration underpin the NSAS's successful management, which is aided by the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System (JASAD-NSAS)[112].

In order to guarantee the sustainable equitable management of this essential water resource, the riparian nations of the NSAS must uphold a strong legislative framework, promote institutional collaboration, and utilize efficient dispute resolution methods. Other transboundary aquifer systems across the world may learn a lot from the NSAS's experience, which emphasizes the need of international collaboration in tackling shared water concerns.

3.5 Regional Framework

This paper will examine the Water Framework Directive and Groundwater Directive, two pieces of legislation from the European Commission. Both provide a framework for water-related policies. They are important to read along with the above international convention to understand the relevance of regional agreements and their required standards to ensure effective management and preservation of quality and quantity of water.

3.5.1 Water Framework Directive (2000/60/EC)

The Water Framework Directive (WFD), officially known as Directive 2000/60/EC, is a fundamental piece of European Union law establishing a framework for water policy and management in EU member states. It seeks to safeguard and restore pure water throughout Europe and assure its long-term sustainability. "The key objectives of the WFD are set out in Article 4 of the Directive. It requires Member States to use their River Basin Management Plans (RBMPs) and Programmes of Measures (PoMs) to protect and, where

[111] (Shibasaki et al., 2007)
[112] (Salman and Uprety 2002)

necessary, restore water bodies in order to reach good status and to prevent deterioration."[113]

The WFD targets transboundary waters, including surface and groundwater, and attempts to improve all water bodies' ecological and chemical state.

Relevant areas of the WFD dealing with transboundary groundwater are:

- Preamble and Article 1 (Purpose): The preamble emphasizes the necessity of managing water at the river basin district level, including transboundary groundwater. Article 1 establishes the goal of safeguarding and improving the condition of all waterways, including groundwater, and avoiding future degradation.
- River Basin Districts, Management Plans, and Competent Authorities: This article introduces the idea of river basin districts (RBDs) and mandates EU member states to define RBDs on their national territory, which may include portions of transboundary rivers. Each RBD requires a river basin management plan (RBMP), which must include provisions for managing transboundary groundwater sources shared with other nations. (Article 3)
- Environmental Objectives: Specific environmental objectives for groundwater bodies are specified, such as avoiding or restricting pollution inflow and preventing degradation of their condition. (Article 4)
- Characterization of River Basin Districts: Each member state must examine the features of its RBDs, assess the effect of human activities, and perform an economic study of water usage. This includes transboundary groundwater bodies, which must be completed in collaboration with other governments that share the bodies of water. (Article 5)
- Registers of Protected Places: This article mandates member states to keep a record of all protected places within each RBD, which may include groundwater bodies that provide drinking water. (Article 6)
- Protected Areas: It expressly demands the conservation of groundwater sources utilized for human use to ensure sufficient clean drinking water. (Article 7)
- River Basin Management Plans: RBMPs shall be developed and publicized, including particular measures for protecting transboundary groundwater bodies and

[113] (European Commission n.d.)

coordinating with neighbouring nations in the shared river basin region. (Article 13)

The Directive promotes collaboration between member states and non-EU nations in transboundary waterways. To fully execute these rules, member states must work together to monitor, review, and establish cooperative water management strategies and plans for shared river basin districts, including transboundary groundwater and their changing nature due to climate change. The goal is to integrate these shared resources sustainably and consistently with the WFD's overarching objectives.

3.5.2 The Groundwater Directive (2006/118/EC)

The Groundwater Directive, also known as "Directive 2006/118/EC on the protection of groundwater against pollution and deterioration," expands on the Water Framework Directive (WFD) by establishing precise procedures for assessing and protecting groundwater quality. It seeks to prevent and manage groundwater contamination and degradation throughout the European Union.

Here are significant parts of the Groundwater Directive that concern transboundary groundwater:

- Objective: The Groundwater Directive aims to establish a framework that outlines precise methods for preventing and controlling groundwater contamination, including pollution in transboundary groundwater bodies. (Article 1)
- Identifying and reversing significant and sustained upward trends: This article addresses the need to detect significant and prolonged rising trends in pollutant concentrations and specify starting points for trend reversals. This method would apply to transboundary groundwater bodies, and collaboration among member nations is required to implement uniform and coordinated actions. (Article 4)
- Measures to prevent or limit pollutant inputs into groundwater: Member States must establish measures to prevent or limit pollutant inputs into groundwater, which naturally extend to transboundary groundwater bodies, necessitating coordination among states that share such resources. (Article 5)
- Compliance and trends assessment, threshold values: This article outlines how member states would examine compliance with excellent groundwater chemical status and establish threshold contaminant levels. To guarantee uniform protection

measures for transboundary groundwater, nations must coordinate their efforts. (Article 6)

- Measures to prevent or restrict indirect discharges: Member States must ban the release of certain hazardous chemicals, including indirect discharges that may harm transboundary groundwater bodies. (Article 7)

The Groundwater Directive should be studied with the WFD, especially when dealing with transboundary concerns. The Groundwater Directive expands on several aspects of the WFD about groundwater, supplementing its sister directive by establishing more comprehensive criteria for groundwater protection against pollution and degradation. Cross-border cooperation on implementation is required in circumstances where transboundary groundwater bodies are in danger, which includes ensuring uniform execution of the directives' requirements and harmonizing pollution thresholds.

As seen above, both conventional international water agreements and the established principles in International Water Law (IWL) have laid the groundwork for managing and utilizing transboundary water resources. However, they have a significant blind spot. They must be equipped to tackle the specific and emerging challenges posed by climate change, particularly about transboundary aquifers.

These legal frameworks, developed initially when climate variability was not a primary concern, heavily emphasize managing surface water. They tend to take a static approach to water resource management, assuming stable hydrological conditions. This oversight becomes especially evident with transboundary aquifers, which are vulnerable to changes in recharge patterns, deterioration in water quality and other impacts brought about by climate change. The current regulations under IWL, guided by principles such as equitable and reasonable utilization and the prevention of significant harm, need to be equipped to adapt dynamically to the changed behaviors of aquifers under evolving climatic conditions. International water law must urgently progress and incorporate specific provisions that address the complexities of managing aquifers in the context of climate change. These provisions, far from being a burden, can bring significant benefits. They should cover collaborative monitoring and sharing of data on aquifer systems, adaptive management strategies informed by scientific insights, and mechanisms for resolving disputes that consider the impacts of climate change.

These advancements are crucial. With them, international frameworks will be equipped to protect transboundary aquifers from climate change's unpredictable and potentially

devastating impacts. This gap underscores a pressing call to action for policymakers, legal experts, and international organizations to integrate climate change adaptation into the fabric of international water law, ensuring its continued relevance and effectiveness in a rapidly changing global environmental landscape.

3.6 Customary International Law

Customary international law refers to practices and concepts that have evolved and are recognized as legal duties by governments in their actions, regardless of whether they are codified in treaty law.[114] Certain customary international law standards are relevant and applicable to groundwater management, even if they were not designed with these specific problems in mind but we saw the role played by them while learning the articled in various legal frameworks.

Customary international law refers to international duties that arise from established state practice rather than formal written conventions and treaties. It is recognized as binding, even if not codified in a specific treaty[115]. While no complete codified treaty specifically addresses transboundary groundwater, many customary international law concepts are widely regarded as applicable to transboundary aquifer management and a few of them we already saw in the above discussed rules, agreements and conventions.

Here are the critical elements of customary international law that apply to the management of transboundary groundwater:

- Sovereign Equality and Territorial Sovereignty: Each state has sovereignty over natural resources within its borders. However, this right is limited by the obligation to ensure that activities under its jurisdiction or control do not harm the environment in other states or areas beyond national jurisdiction.
- Equitable and Reasonable Utilization: This principle, which is also found in the UN Convention on the Law of Non-Navigational Uses of International Watercourses (1997) and the work of the International Law Commission (ILC), governs the use of shared watercourses, including both surface and groundwater. It requires nations to use transboundary water resources fairly and reasonably for all parties involved, considering all relevant aspects and circumstances.

[115] (Barrett 2020)

- Obligation. Not to cause significant harm: This guideline supplements equitable and fair usage. This concept requires governments to take all reasonable precautions to avoid inflicting significant harm to other states that share the water supply. If harm occurs, states must remove or alleviate it and, where needed, arrange compensation with the impacted states.
- Cooperation: States that share transboundary groundwater resources must collaborate. This includes exchanging information, technical data and technology, informing potentially impacted states about initiatives that might have a negative impact, and discussing with co-riparian states how to use and manage the shared resource.
- Environmental Protection: States must ensure that activities within their authority do not harm the environment, the ICJ in the Gabcikovo Nagymaro Project case established particularly transboundary water resources and ecosystems as.
- Duty to Notify and Negotiate: Per the cooperative mandate, states have a customary international law obligation to notify, consult, and, if necessary, negotiate with potentially affected states before engaging in activities that may significantly adversely impact transboundary groundwater resources.
- Sustainable Development: While not universally accepted as a principle of customary international law on the same level as the others, sustainable development is becoming increasingly recognized as an essential goal for environmental governance and international law, combining developmental needs with environmental preservation.

While widely acknowledged, the principles above might be challenging to implement in the absence of particular bilateral or multilateral treaties since their application is sometimes dependent on governments' individual circumstances and desire to abide by these standards. Many jurisdictions choose special agreements managing shared transboundary aquifers to improve transparency and enforceability. As we already discussed in last chapter's 2.4.3 section where The ILC's Draft Articles on the Law of Transboundary Aquifers (2008) expanded on these principles with articles intended to guide state practice. However, these Draft Articles have yet to be ratified as a binding convention.

Climate change, a relatively new area of international law, whether customary or treaty-based, is underpinned by critical norms. These norms are essential, including

environmental protection, cooperation and information sharing, common but differentiated responsibilities (CBDR), and the precautionary principle. However, their application is not solely a matter of law but also states' willingness to follow and enforce them. As international law evolves, new treaties and conventions may provide more precise and enforceable laws on critical issues such as climate change and groundwater management.

Chapter 4: Analysis of Relevant International Laws and Frameworks

4.1 Analysis of Key Agreements and Frameworks

The management of transboundary water resources, including rivers, lakes, and aquifers that cross or define political borders, presents both significant challenges and opportunities in international law and relations. Effective management of these resources is crucial for guaranteeing water security, promoting sustainable development, and avoiding conflict and adaption to climate change. Over time, different international agreements, rules, and frameworks have been formed to control the use and conservation of these common resources. This chapter examines the efficacy of these tools, which we discussed in chapter 2 and 3, taking into account their legal principles, implementation issues, and implications for international cooperation, and specifically to climate change in relations to TBA.

The Helsinki Rules on the Uses of the Waters of International Rivers, created by the International Law Association (ILA) in 1966, are among the first comprehensive initiatives to give rules for the use of international watercourses. These regulations provide principles like as equitable and reasonable usage, the need not to cause significant harm, and the necessity for cooperation among riparian nations. Despite its [116]substantial effect on succeeding legal instruments, the Helsinki Rules are non-binding, limiting their enforcement and practical application[117]. They were followed by Seoul Rule (1986), which brought groundwater under international jurisdiction.

The United Nations Convention on the Law of Non-Navigational Uses of International Watercourses, often known as the UN Watercourses Convention, was approved in 1997 and expands on the ideas of the Helsinki Rules. The Convention establishes a more thorough framework for the fair and reasonable use of shared watercourses, emphasizing the need to prevent serious harm and to adapt management practices to changing hydrological condition due to climate change[118]. It also establishes procedures for collaboration and conflict settlement. As of 2021, the Convention has 39 parties, showing modest acceptability. However, the lack of important watercourse nations like China,

[116] (ILA 1966)
[117] (Boisson 2013)
[118] (UN 1997)

India, Egypt, Israel and Turkey among the signatories reduces its worldwide applicability and influence[119] [120].

The Berlin Rules on Water Resources, established by the ILA in 2004, are an update to the Helsinki Rules that incorporate current environmental principles and human rights issues under Article 42[121]. It stressed on collaboration and corporation with Article 39 emphasizing on exchange of information. These guidelines include a wider range of issues, such as environmental preservation, sustainable development, and public engagement in decision-making processes. While the Berlin Rules are extensive and forward-looking, they are non-binding, like the Helsinki Rules, which restricts their direct enforcement and practical influence[122].

The Internationally Shared Aquifer Resources Management (ISARM) program, initiated by UNESCO and other organizations, intends to improve long-term management of shared aquifers by developing cooperative frameworks.[123] The program aims to increase awareness, promote scientific research, and enable collaboration among nations that share aquifer resources. While ISARM has been successful in emphasizing the importance of transboundary aquifer management and encouraging collaborative efforts, the practical application of its guidelines varies greatly across regions, reflecting differences in political will, economic capacity, and institutional frameworks[124].

Bilateral and multilateral agreements play an important role in transboundary water management. Notable instances are the Indus Waters Treaty (1960) between US and Canada and the Nile Basin Initiative, which involves numerous African countries.

A. Rivera covers the intricacies involved in managing transboundary aquifers situated along the US-Canada border in a paper[125]. Rivera examines the difficulties in managing these shared water resources from a scientific, policy, and social standpoint. The report highlights the necessity of cooperative research and policy development in order to properly manage and safeguard these aquifers. It discusses the social ramifications of water resource management and emphasizes the significance of incorporating scientific evidence

[119] Tanzi & Arcari 2001
[120] (Salman & Uprety 2002)
[121] (ILA, 2004)
[122] (McIntyre, 2010)
[123] (Salman & Uprety, 2002)
[124] (Eckstein 2017)
[125] Read for reference “Rivera, A. "Transboundary Aquifers along the Canada–USA Border: Science, Policy and Social Issues." *Journal of Hydrology: Regional Studies* 4 (2015): 623-643.”

into the formulation of policy. In order to address the problems of water scarcity, pollution, and the effects of climate change on these vital resources, the document asks for further cooperation between the two nations.

In contrast, the Nile Basin Initiative seeks to promote collaboration and long-term development among Nile Basin countries. Despite its accomplishments in fostering communication and cooperative initiatives, the initiative continues to encounter challenges from political tensions, upstream-downstream dynamics, and arguments over water rights and development projects[126].

4.2 Effectiveness of Existing Agreements for TBA in light of Climate change

The usefulness of transboundary groundwater agreements in mitigating climate change effects varies greatly. The strength of legislative frameworks, the amount of collaboration among riparian governments, and the ability for adaptive management are all-important elements in determining efficiency. Strong legal frameworks are required for the efficient management of transboundary groundwater resources. Agreements with explicit legal provisions for data exchange, collaborative monitoring, and conflict resolution are more successful. For example, the Guarani Aquifer Agreement has explicit provisions for these characteristics, which contributes to its efficacy in mitigating climate change consequences.[127]

Transboundary groundwater agreements require high levels of cooperation and confidence among riparian governments to be successful. Despite persistent political difficulties between India and Pakistan, the Indus Waters Treaty has remained successful because to strong institutional procedures and mutual confidence built over decades.[128] Agreements that include adaptive management concepts, such as regular monitoring, flexibility in water allocations, and the capacity to amend management techniques in response to new data, is better prepared to deal with climate change consequences. The Nubian Sandstone Aquifer System Agreement exhibits this strategy, which promotes continuous data gathering and adaptive methods.[129]

Legal frameworks lay the groundwork for collaboration and dispute resolution. The Helsinki Rules, UN Watercourses Convention, and Berlin Rules all define clear legal principles, such as equitable usage, the need not to cause major harm, and the necessity for

[126] (Teshome 2008)
[127] (Sindico et al. 2018)
[128] (Benvenisti 1996)
[129] (Ahmed et al. 2017)

collaboration. These principles are critical for directing riparian governments' behavior and establishing a foundation for negotiation and dispute settlement. The Helsinki and Berlin Rules, however, are non-binding, limiting their enforcement and practical significance[130]. The UN Watercourses Convention, while binding on its parties, has limited acceptance, with important watercourse governments not signing, limiting its worldwide application and impact[131].

Legal frameworks are critical for implementing and enforcing transboundary water agreements. Many agreements provide for shared management bodies, data exchange, and conflict resolution processes[132]. For example, the Nile Basin[133] Initiative comprises the Nile Basin Council of Ministers and the Nile Basin Secretariat, which monitor cooperation efforts and assure adherence to agreed-upon standards. These institutional processes are critical for establishing confidence, promoting discourse, and ensuring that agreements are effectively implemented. However, their usefulness may be hampered by political and economic differences among member nations, a lack of capacity, and insufficient budget.

Inclusivity is another important aspect in the efficiency of transboundary water management regimes. Modern agreements increasingly recognize the value of incorporating all stakeholders, especially local communities, non-state actors, and marginalized groups, in decision-making processes. The Berlin Rules, for example, place an emphasis on public engagement and human rights protection in water management[134]. Inclusive decision-making methods may increase the validity of agreements, create cooperation, and guarantee that all stakeholders' demands and interests are met. However, attaining inclusion in reality can be difficult owing to power imbalances, a lack of understanding, and insufficient resources for stakeholder participation. The practical implementation of transboundary water agreements often faces significant problems. Differences in political will, economic capabilities, and institutional frameworks across nations might impede successful collaboration and execution[135]. Effective implementation necessitates ongoing efforts to increase trust, strengthen capacity, and adapt to emerging concerns such as climate change and technology advances.

[130] (McCaffrey 2001)
[131] (Dellapenna 2007)
[132] (Dellapenna 2007)
[133] (Salman & Uprety, 2002)
[134] (ILA, 2004)
[135] (Swain 2011)

The NBI, established in 1999, intends to foster collaboration and sustainable development among Nile Basin nations such as Burundi, DR Congo, Egypt, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda[136]. The approach has been successful in promoting communication, establishing trust, and implementing collaborative initiatives. However, political tensions, upstream-downstream dynamics, and arguments over water rights and development projects continue to pose issues for the NBI[137]. Effective fulfillment of the NBI's objectives necessitates ongoing efforts to foster confidence, strengthen capability, and address the concerns of all member nations.

4.3 Challenges

Existing agreements, laws, and frameworks for transboundary water management have achieved significant accomplishments in encouraging collaboration, averting disputes, and boosting sustainable development. Legal frameworks such as the Helsinki Rules, UN Watercourses Convention, and Berlin Rules define fundamental principles for the equitable and reasonable use of shared water resources, as well as the need to avoid major harm[138] as we discussed in the last section. Institutional frameworks such as joint management bodies and mechanisms for conflict resolution play a vital role in encouraging collaboration and guaranteeing the efficient execution of agreements. Inclusivity in decision-making processes increases the validity of agreements and guarantees that all stakeholders' demands and interests are met. However, challenges remain in the practical implementation of these frameworks[139]. Many agreements are non-binding, which limits their enforceability, but the absence of universal approval of binding treaties, such as the UN Watercourses Convention, limits their global application[140]. Differences in political will, economic capabilities, and institutional frameworks across nations might impede successful collaboration and execution[141]. Addressing these concerns necessitates ongoing efforts to foster trust, increase capacity, and respond to emerging issues like climate change and technology improvements.

Moving forward, stronger enforcement mechanisms, increased inclusion, and improved data sharing are required to ensure long-term and equitable management of transboundary water resources. To improve the effectiveness of existing frameworks and promote

[136] (Teshome, 2008)
[137] (Swain 2011)
[138] (McCaffrey 2001)
[139] (McIntyre 2010)
[140] (Eckstein, 2017)
[141] (Puri & Aureli 2009)

sustainable and equitable management, it is critical to develop binding international treaties with robust enforcement mechanisms, build the capacity of institutions responsible for transboundary water management, establish transparent and consistent mechanisms for data collection and sharing, ensure inclusive decision-making processes, and regularly update agreements to address emerging issues.

One of the challenges of legislating on aquifers is their diverse nature and heterogeneity, making inflexible legislative classifications undesirable to hydrogeologists[1]. Therefore, hydrogeologists must be better versed in international law or politics and have been unwilling to engage in this debate. As a result, many important matters related to the sound management of transboundary aquifers needed to receive the attention they deserved[1] as a solution, the ISARM initiative is now addressing many of these urgent issues by assisting the UN International Law Commission's Special Rapporteur in addressing transboundary aquifers. The Special Rapporteur in the UN International Law Commission plays a crucial role in shaping international norms concerning the management and use of transboundary aquifers. Their responsibilities include drafting international legal principles, facilitating negotiations and consensus, conducting research and analysis, recommending dispute resolution mechanisms, raising awareness and advocacy, collaborating with scientific and expert bodies, and focusing on the utilization and protection of transboundary aquifers. The impact of their work is evident as we saw. The ongoing work of successive Special Rapporteurs is vital for fostering international cooperation and ensuring the sustainable management of this crucial natural resource.

Chapter 5: Recommendations

The study results on transboundary groundwater agreements' climate change adaption strategies highlight the advantages and disadvantages of the present frameworks. Strong legislative frameworks, collaboration between riparian nations, and the incorporation of data exchange and scientific research are necessary for effective adaptation. While several accords have advanced significantly, others continue to confront major obstacles that reduce their efficacy. The findings suggest that transboundary groundwater agreements, like the Guarani Aquifer Agreement, that incorporate adaptive management measures work better to mitigate the effects of climate change. These agreements encourage resilience and sustainable management practices by placing a strong focus on cooperative monitoring, data sharing, and emergency preparation[142]. Based on these findings, policymakers should give the incorporation of adaptive management concepts into transboundary groundwater agreements a priority in order to improve their efficacy in the context of climate change[143]. The Nubian Sandstone Aquifer System Agreement exemplifies the development of joint authority, which is vital in coordinating research, monitoring, and management efforts. These authorities guarantee the efficient implementation of adaptive measures and promote the sharing of data. This emphasizes how crucial it is to establish joint management bodies with the authority to supervise the execution. This emphasizes how crucial it is to establish joint management organizations and provide them the authority to supervise the execution of transboundary groundwater agreements.

The study also emphasizes how critical it is for riparian governments to establish mutual trust and collaborate internationally. Strong institutional procedures and mutual confidence may sustain collaboration even in politically hostile situations, as evidenced by agreements such as the Indus Waters Treaty[144]. The primary focus of policymakers needs to be on supporting regional projects and diplomatic endeavors that establish confidence and encourage cooperative management of shared water resources.

The findings also highlight important obstacles, such as institutional and legal constraints, political unrest, and technological problems. International accords are frequently hampered in their execution by conflicting national laws, a lack of enforcement mechanisms, and insufficient institutional capacity. Coordination and coordinated management initiatives

[142] (UNESCO, 2009)
[143] (Puri & Aureli, 2009)
[144] (McCaffrey, 2007)

may be further hampered by political disputes between riparian governments. Technical challenges, such as data scarcity and inadequate monitoring systems, also pose significant obstacles to effective adaptation.

The effectiveness of various transboundary groundwater agreements and international regulations in addressing climate change adaptation varies. Notable for their complete approach to adaptive management and cooperative monitoring are the Guarani Aquifer Agreement and the Nubian Sandstone Aquifer System Agreement. In order to comprehend and manage the effects of climate change, these agreements place a strong emphasis on collaboration and data exchange. Although the pact has undergone recent changes that incorporate ideas of adaptive management, there are still obstacles to its success due to the continued political tensions between nations[145].

International legal frameworks that are crucial for the management of transboundary water resources include the UN Watercourses Convention and the Draft Articles on the Law of Transboundary Aquifers. But the absence of universal ratification and legally obligatory enforcement mechanisms sometimes limits their efficacy. Transboundary groundwater resource management in the context of climate change requires adherence to the values expressed in these treaties, including the prevention of major harm and fair and appropriate exploitation. However, the desire and collaboration of nations is crucial to their execution[146].

Additionally essential to fostering cooperative management and climate change adaptation are regional frameworks like the EU Water Framework Directive and the SADC Revised Protocol on Shared Watercourses. These frameworks encourage data exchange, public participation, monitoring, and the incorporation of climate change issues into the management of water resources. Distinct national agendas and varying degrees of conformity across member states pose hurdles to their implementation.

[145] (Wolf, 1998)

[146] (Jarvis et al., 2005)

Recommendation

The study reveals significant shortcomings in current transboundary groundwater agreements and international regulations.

Based on the study findings, the following recommendations are made:

- **Strengthening Legal Frameworks:** Create binding international treaties that clearly address climate change adaptation in transboundary groundwater management. There is a lack of enforceable enforcement tools and explicit dispute resolution measures. Many agreements are based on voluntary collaboration, which might restrict their efficacy in mitigating climate change consequences. Future policy development should concentrate on enhancing legal frameworks by include binding clauses and developing explicit methods for enforcement and dispute settlement.
    - *Enhancing Institutional capacities***:** Improve the technical and administrative capacities of institutions in charge of transboundary groundwater management. Establish collaborative management organizations to monitor the execution of transboundary groundwater agreements, as well as training programs and capacity-building efforts. Many agreements lack the technical and administrative resources required to execute adaptive management solutions. Capacity-building programs and the formation of joint management bodies are critical for closing this gap. Future policy development should prioritize institutional capacity building through training programs, technical support, and the creation of regional and international collaborative platforms.
    - *Mechanism for legal enforcement* **-** fines for non-compliance, rewards for compliance, and global oversight organizations to keep an eye on how agreements are being carried out. Establish penalties for illicit extraction of groundwater and offer tax breaks or subsidies to those who follow sustainable water use guidelines. This technique is similar to the regulatory strategy employed in Western Australia, where major groundwater withdrawals require a license and noncompliance is penalized.
- **Promoting Scientific Research and Data Sharing:** There is a lack of integration of scientific research and data exchange into transboundary groundwater management. In order to adapt effectively, reliable and complete data on

groundwater supply, quality, and utilization are required. However, differences in data gathering procedures and an unwillingness to share information sometimes inhibit joint efforts. Future research should focus on developing standardized data gathering and sharing techniques concerning water levels and effects of climate change on the water cycle, both actual and predicted, as well as promoting worldwide research collaborations.

- *Research Funding* **-** Provisions for funding research and development aimed at comprehending how climate change affects aquifers and creating creative management strategies ought to be included. This is an absolute must, not just a recommendation. We can make sure we are constantly one step ahead in the management of our water resources by supporting research through grants and collaborations with academic institutions and research groups.
- *Standardised Data collection and sharing platform* - Establish worldwide research networks and data-sharing platforms to help with informed decision-making and adaptive management. Create standardized data collecting and sharing processes to guarantee accurate and complete data on groundwater resources and utilizing recent advances in technology depicting the possible effect of climate change on the water related activities in the region. This might involve the use of blockchain for safe and transparent data sharing, artificial intelligence for water management, and cutting-edge remote sensing technology. Use AI algorithms to forecast future trends in water availability and deploy Internet of Things (IoT)-based sensors for real-time groundwater monitoring. This strategy can be compared to Singapore's Smart Water Management System, which optimizes water resources using technology.

- **Fostering International Cooperation:** Political disputes between riparian governments provide a substantial barrier to successful transboundary groundwater management. Building mutual confidence and promoting diplomatic efforts are critical to resolving these problems. Policymakers should use diplomatic efforts, regional initiatives, and joint management organizations to encourage dialogue and collaboration among riparian governments. Emphasize mutual trust and collaborative management of shared water resources.
  - *Incorporating Adaptive Management concepts***:** Make sure that transboundary groundwater agreements include adaptive management

concepts. Encourage cooperative monitoring, data exchange, and contingency planning to increase groundwater resource resilience to climate change impacts. For example, development of policies and techniques for handling the increased unpredictability of water availability, dealing with possible dangers of pollution from extreme weather, and putting resilience-enhancing infrastructure changes into practice. Install regulated aquifer recharge systems in drought-prone areas, utilizing excess water from the rainy seasons to raise groundwater levels during the dry seasons. The Orange County Water District in California, USA, has effectively used this strategy, resulting in a notable increase in water availability.

- *Addressing Political Tensions*: Develop ways for reducing political tensions among riparian governments. Encourage the engagement of impartial international organizations to facilitate discussions and conflict settlement. Encourage regional integration and collaboration through international agreements and efforts as we see in IWT.

- **Increasing Public Awareness and Participation:** Bring local communities and stakeholders into the decision-making process. Implement public awareness campaigns and education initiatives to highlight the significance of sustainable groundwater management and climate change adaptation. Integrate traditional knowledge and traditions with managerial techniques.
  - *Strategies for Stakeholder Engagement and Capacity Building*: methods for involving stakeholders and enhancing capacity at every level. This includes community awareness campaigns, policymakers' workshops on the most recent climate research and adaptive management strategies, and training programs for regional water managers. Create community engagement programs that include local stakeholders in groundwater monitoring initiatives. For example, in Gujarat, India, community-based groundwater management involves local farmers in controlling irrigation techniques and measuring water levels.
  - *Cultural and Social Considerations*: Groundwater agreements should contain clauses that uphold indigenous peoples' rights to their water and incorporate conventional wisdom on water management. Indigenous Water Reserves in Australia serve as an illustration of this, providing water access

for indigenous communities and integrating their traditional ecological knowledge into water management practices.

- **Funds and Resource Allocation:** Obtain funds and resources for the execution of transboundary groundwater agreements. Create financing tools to enable collaborative monitoring, capacity-building efforts, and adaption projects. Encourage the participation of international organizations and funders in funding efforts. Generating special funds for water management that are adapted to climate change, requesting funding from international organizations, and forming public-private partnerships to finance significant infrastructure projects. Create a Transboundary Water Management Fund to finance collaborative initiatives for sustainable groundwater management. The fund will be financed by contributions from participating nations and foreign donors. The Green Climate Fund, which funds international initiatives to mitigate the effects of climate change, is an analogous idea. It is especially important in cased where one or both of the riparian states are low income countries
- **Climate Change Projections and Scenario Planning**: Integrating climate change estimates and scenario planning is not mentioned in the transboundary aquifer management plans. This is necessary to predict future circumstances and get ready with the right answers. The guidelines ought to mandate that the River Basin Management Plans (RBMPs) incorporate scenario analysis and climate models. ***Quantitative Targets and Benchmarks****:* Establishing precise, quantifiable objectives for variables like water quality, usage effectiveness, and a decline in conflict occurrences can aid in assessing how well executed agreements and regulations are working. Aim to cut the amount of groundwater extracted by 20% over the next ten years by encouraging communities to adopt water conservation and implementing water-efficient agricultural methods.
    - *Integration with Broader Climate Policies*: coordinating with international climate financing systems, contributing to international climate agreements like the Paris Agreement, and tying groundwater management plans to national adaption strategies. Make sure that groundwater sustainability is incorporated into the national plan for mitigating and adapting to climate change by coordinating groundwater management strategies with the Nationally Determined Contributions (NDCs) under the Paris Agreement.

- *Regular Review and Update Procedures:* To guarantee that management plans and agreements stay applicable and efficient in the face of changing climate science and socioeconomic circumstances, the agreements and legal frameworks should include clauses requiring the regular review and updating of management plans and agreements. All transboundary groundwater agreements should be subject to a five-year review cycle that takes into account current scientific research and socioeconomic developments. The adaptive management approach employed in the U.S.-Canada Great Lakes Water Quality Agreement can serve as a model for this practice.

- **Specific Measures for Climate Resilience**: The instructions in the framework often emphasize pollution and degradation, but they don't include strategies to make aquifer systems more resilient to the effects of climate change, like changed rates of recharge and more fluctuations in water availability. It is important to include specific resilience-building strategies like establishing recharge zones (like artificial recharge through infiltration basins) and using sustainable groundwater extraction methods (such encouraging water-saving irrigation techniques).

By addressing these missing points in the legal frameworks, the agreements can be strengthened to provide a more robust and comprehensive framework for managing transboundary groundwater resources effectively in the context of climate change. These changes will help adapt to current and future challenges and promote sustainable and equitable water management practices across borders. These points will enhance their effectiveness and relevance in protecting these vital water resources in a rapidly changing global environmental landscape.

Conclusion

This comprehensive research study on the complex dynamics of managing transboundary groundwater resources in light of the challenges presented by climate change. This study emphasizes the significant role of international legal frameworks in facilitating adaptive strategies. By analyzing various international agreements and specific cases, the study underscore the essential need for robust legal and cooperative mechanisms to safeguard groundwater resources that traverse multiple countries.

An exploration of fundamental legal instruments such as the Helsinki Rules, the Seoul Rules, the UN Watercourses Convention, and the Berlin Rules, establishes pivotal principles for equitable and reasonable use, prevention of significant harm, and cooperation among nations sharing water resources. These principles found in IWL are further discussed as vital for sustainable management of the TBA along with sustainable development goals and UNESCO framworks. Nonetheless, it became apparent that these frameworks often inadequately address the evolving challenges brought about by climate change, especially concerning groundwater.

Through in-depth case studies of the Nubian Sandstone Aquifer System and the Guarani Aquifer, illustrates how well crafted agreements can foster cooperation among neighboring countries and enable sustainable management practices. These examples have underscored the value of adaptive management strategies capable of addressing the intricate geopolitical issues associated with shared water resources and adapting to changing hydrological conditions.

However, there are significant deficiencies in existing international legal frameworks, particularly their limited focus on addressing the impacts of climate change on groundwater resources. These deficiencies have serious implications for the sustainability of our water resources and the potential for international conflict. Consequently, the findings advocate for the development of more specific regulations for climate change adaptation within international water law, as well as the enhancement of mechanisms for

data sharing, monitoring, and joint management to bolster the resilience of groundwater resources.

In conclusion, the sustainable management of transboundary groundwater in the face of climate change necessitates collaborative efforts from various stakeholders, including local communities, non-governmental organizations, the scientific community, and national and international bodies. Strengthening legal and institutional frameworks, enhancing cooperative mechanisms, and embracing adaptive management strategies are crucial. However, these changes also present an opportunity for positive transformation, ensuring the sustainability and resilience of these vital water resources and inspiring hope for the future.

My study effectively addresses the initial research question by providing a comprehensive understanding of how international law and transboundary groundwater agreements can integrate climate change adaptation measures. The conclusions and recommendations of this thesis seek to advance the ongoing discourse on IWL and support the development of more effective policies that protect transboundary groundwater for future generations. In particular, the study advocates for the urgent development of more specific regulations for climate change adaptation within international water law, fostering international peace, cooperation, and sustainable development.

Groundwater often overlooked yet a crucial component of our global water supply, underscores the urgency of sustainable water management and aquifer protection. This research aligns with findings that trans boundary frameworks, agreements and conventions based on international law, particularly International Water Law and EU Law must be potent in addressing aquifers and climate change. The necessity for binding treaties, enhanced data sharing, capacity building, and institutional frameworks is paramount, especially in low-income countries, to facilitate sustainable groundwater usage. By emphasizing the impact of climate change on groundwater and its critical role in sustainable development, this research underscores the need for immediate and concerted efforts to ensure this precious resource remains clean, accessible, and abundant for future generations.

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