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GROUNDWATER RESOURCES: A THEORETICAL REVIEW ON THE PERSPECTIVES AND DYNAMICS OF CLIMATE CHANGE IMPACT

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ABSTRACT:
This paper carries out a rational review on the current knowledge of the relationships between climate change and groundwater resources in the face of projected climate changes and the adaptation choices for policy formation. This is inevitable as climate change will bring about numerous environmental problems, including alterations to the hydrological cycle, which is already heavily influenced by anthropogenic activity. The Intergovernmental Panel on Climate Change estimates that temperature has increased 0.6 ± 0.2 °C, and predicts an increase of 2 - 4 °C over the next 100 years. Temperature increases also affect the hydrologic cycle by directly increasing evaporation of available surface water and vegetation transpiration. Consequently, these changes can influence precipitation amounts, timings, and intensity rates, and indirectly impact the storage of water groundwater reservoirs. In this regard, predicting these impacts are just as uncertain as predicting climate trends as they vary over time and space. Despite these uncertainties, there are numerous attempts to build resilient management institutions while still developing a favorable policy framework to increase the consciousness and participation that help promote and protect the optimal utilization of groundwater.

***KEYWORDS**: Climate change; Groundwater, Integrated Water resources management and Recharge.*

1.0 INTRODUCTION

Groundwater as the largest store of freshwater on earth has been developed at unprecedented rates over the past half century–for agriculture and domestic as well as industrial use. Rates of abstraction have exceeded natural replenishment rates over extended periods in many parts of the world, and environmental signs of unsustainable use and negative socio-economic impacts are increasingly evident (Eduvie *et al.,* 2020). Although groundwater related benefits are numerous, its utilization at various times has resulted in often, unintended consequences such as storage depletion, land subsidence, saltwater intrusion, reductions in streamflow, and some cases loss of wetland (Kumar, 2012). Now and into the coming century, the accumulating pressures of direct use on groundwater will likely be intensified by a rapidly changing climate (IPCC, 2007). According to IPCC (2007), the long-term fluctuations in temperature, precipitation, wind and other climate parameters will dramatically alter the hydrologic cycle, as reports estimate an increase in global average surface temperature by 0.74°C from 1906 to 2005 thus, affecting the renewable groundwater resources and their level (IPCC, 2007). This increase in the temperatures has direct impacts on the hydrological cycle with the associated changes in precipitation and evapotranspiration which can indirectly impact groundwater reservoirs as shown in Figure 1.

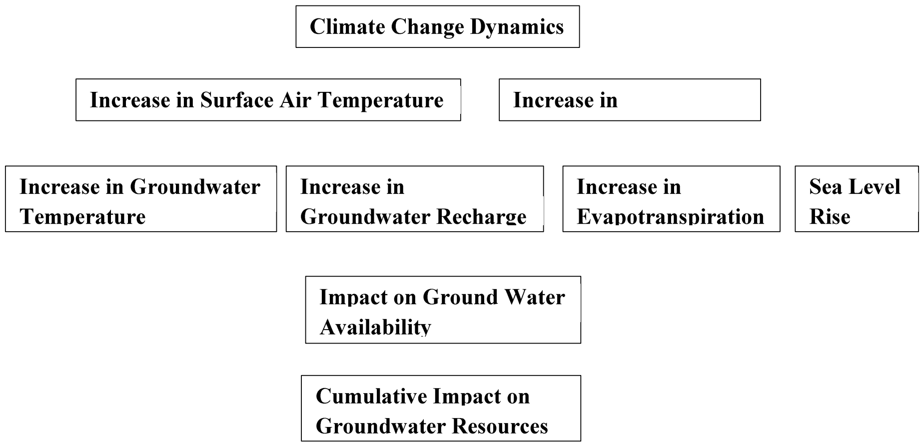

Figure 1: Conceptual diagram on impacts of climate change on groundwater (**Modified** from Karim *et al.,* 2017)

While all water resources are threatened, groundwater is particularly at risk, because of the inherent time lag between the stress and detectible system response; groundwater has been most vulnerable to man-induced stress. Despite these concerns, the impact of climate change on groundwater is less clearly understood due to a lack of sufficient scientific studies (Klove et al., 2013), as hydrological studies of climate change primarily focus on surface water, but only a few studies emphasize on groundwater. Those which focus on groundwater primarily studied the impacts of groundwater withdrawal and landuse change but the studies on impacts of climate change on groundwater availability have received less attention. It is therefore imperative to assess the potential impacts of climate change on the groundwater resources and to develop mechanics to protect the resources. In this background, this paper reviewed the current state of knowledge regarding the impact of climate change on groundwater, as well as identifying key research needs that will be critical in meeting the needs of current and future adaptive management of groundwater resources.

2.0 The Theoretical Literature

2.1 Projected Changes in the Climatic System

Global green gas emissions are driven by forces such as changes in human population, socio-economic development, and technological advancement, while Government and other stakeholders have put in place policy with a necessary action plan as interventions. In 2014, the Inter-Governmental Panel on Climate Change (IPCC, 2014) presented in its special report on emissions, six groups of scenarios or plausible futures which are based on narrative storylines and account for a wide range of driving forces. The scenarios project future emissions of greenhouse gases, carbon dioxide, methane and nitrous oxide. For gases that stay in the atmosphere for a long period, such as carbon dioxide, the atmospheric concentration responds to changes in emissions relatively slowly. This is due to the length of the half-life of carbon dioxide in the atmosphere as well as inertia in the system. Even if emissions were to halt today, the earth's surface temperature could continue to rise for a few centuries, and sea level could continue to increase for several millennia, due to thermal expansion and melting of ice. According to the IPCC, (2007) the following effects are likely to occur to surface temperatures, precipitation, and climate-related extreme events, as characterized by climate change and its dynamics:

i. Observed changes in the hydrological circle and the role of human activities
ii. Observed impacts of these changes on groundwater systems
iii. The role that adaptation can play in responding to these changes.

2.2 Global Trend on Groundwater Dynamics due to Climate Change Impacts

Although the most noticeable impacts of climate change could be fluctuations in available water quantity and quality of groundwater supplies, as it is the main available potable water supply source for human consumption and irrigation of agriculture produce worldwide. As groundwater aquifers are recharged mainly by precipitation or through interaction with surface water bodies, the direct influence of climate change on precipitation and surface water ultimately affects groundwater systems. It is increasingly recognized that groundwater cannot be considered in isolation from the landscape above, the society with which it interacts, or from the regional hydrological cycle, but needs to be managed holistically. In understanding the likely consequences of possible future changes on groundwater systems, an important component to understand is the influence that these factors exert on recharge. According to Scibek et al, (2007), recharge of an aquifer depends largely on the type of soil, vegetation, distribution, amount and timing of precipitation, surface temperature, wind speed, evapotranspiration, runoff, discharge patterns, and landuse landcover change.

The sensitivity of groundwater recharge dynamics and its relationship with temperature and precipitation were reported by Scibek et al., (2007). The increased variability in rainfall may decrease groundwater recharge in humid areas because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff. In semi-arid and arid areas, increased rainfall variability may increase groundwater recharge as only high-intensity rainfalls are able to infiltrate fast enough before evaporating. Accordingly, Earman and Dettinger, (2011), estimated aquifer water balance will become slightly negative and spring flow discharge will decrease from $17mm^3$/yr to as low as $13mm^3$/yr by 2025 in Inca-Sa Pobla, Spain. Likewise, a further projection of 17% reduction in recharge for the first quarter of the 21^{st} century in the wetlands of Majorca, Spain is reported. Accordingly evapotranspiration will increase for porous soil water zone associate aquifers that are associates vegetation and biogeochemical reactions. Similarly, groundwater in the saturated zone is also more vulnerable to climate change as this zone responds by showing changes in groundwater availability and flow of water depending on the trends of precipitation, evapotranspiration, recharge, and discharge (Schwartz and Zhang, 2003).

2.3 Groundwater Recharge and Resources

A change in the amount of effective rainfall will alter recharge, but so will a change in the duration of the recharge season. Increased rainfall, as projected under most scenarios for climate change will generally result in increased groundwater recharge, as aquifers generally are replenished by effective rainfall though due to the type of the aquifer. While an unconfined aquifer is recharged directly by local rainfall, rivers, and lakes, thereby indicating the rate of recharge to be influenced by the permeability of overlying rocks and soils. This is because macro-pore and fissure aquifer recharge is most common in porous and aggregated forest soils and less common in poorly structured soils. A confined aquifer, on the other hand, is characterized by an overlying bed that is impermeable, and local rainfall does not influence the aquifer. It is normally recharged from lakes, rivers, and rainfall that may occur at distances ranging from a few kilometers to thousands of kilometers. Aside from the influence of climate, recharge to aquifers is very much dependent on the characteristics of the aquifer media and the properties of the overlying soils (Scibek et al., 2007). Owing to this, determining the potential impact of climate change on groundwater resources, in particular, is difficult due to the complexity of the recharge process, and the variation of recharge within and between different climatic zones. However, several attempts have been made to calculate the rate of recharge including the use of carbon-14 isotopes and other modeling techniques.

2.4 Soil Moisture

The amount of water stored in the soil is fundamentally important to agriculture and has an influence on the rate of groundwater recharge. Although efforts have been made simulating soil moisture content directly by using global climate models, albeit over a very coarse spatial resolution, and research from these models shows an indication of possible directions of change. The local effects of climate change on soil moisture, however, will vary not only with the degree of climate change but also with soil characteristics. The water-holding capacity of soil will affect possible changes in soil moisture deficits; the lower the capacity, the greater the sensitivity to changes in climate. Climate change also may affect soil characteristics, perhaps through changes in waterlogging or cracking, which in turn may affect soil moisture storage properties resulting in evidences of climate change impact on groundwater resources.

3.0 The Theoretical Mechanisms of Groundwater Pollution Mitigation

3.1 Consistent Policy Frameworks Formation as Groundwater Management Approach

The need for a policy framework is critical as it helps in the effective management of groundwater resources. Accordingly, a policy framework is a set of resolutions that are adapted towards a long-term purpose with the aim of solving a particular problem (FAO, 2011). Accordingly, policy frameworks are boundaries within which groundwater management occurs. Although there are different narratives in describing policy framework however the strategic importance is the need for consistent policies, legislation and legal frameworks, strategic management planning (Foster and Loucks, 2006), and resource administration capacity regarding groundwater management (Pandey et al., 2011). These policies need to be consistent across relevant sectors and provide clear guidance for implementation such as enacting new laws and creating economic incentives (Theesfeld, 2008). A consistent policy frameworks formation as groundwater management in keeping the productive capability of aquifers is the need to steadily monitor groundwater quantity and quality as well as aquifer protection. Resulting from the notion of the importance of environmental sustainability, some forward-thinking groundwater resources managers have begun to including consistent policy frameworks formation in the management of groundwater as part of their management activities. Most prominent in the frontier is the European Union's Water Framework Directive, the Groundwater Directive with interest in the evaluation of groundwater quantitative and qualitative status assessment. This acknowledgment and inclusion of the need for consistent policy frameworks formation need to be more explicit, as it helps to avoid aquifers contamination and the impact of climate change.

3.2 Non-State Actors Participation

The involvement of non-state actors such as communities in decision-making is a common component of most successful resource management approaches (Biermann and Pattberg, 2008). Partnerships that create a management network comprised of government authorities, scientists, and water users are catalysts for effective management of resources (Ross and Martínez- Santos, 2010). Participation has shown to yield a number of benefits ranging from more informed decisions to outcomes that are better complied with, to mobilizing self-regulatory capacity, where appropriate (Hodgson, 2006). Hence, all the approaches should consider the active participation of water users and the riparian population to embrace the overall importance of resources in the management of ground water resources. This knowledge is vital in understanding and managing the impact of climate change

3.3 Estimating Groundwater Recharge

Groundwater recharge estimations are essential for the management of groundwater aquifers, providing information for sustainable use of groundwater resources. (AlRukaibi and McKinney,, 2010). Estimating groundwater is a cumulative mechanism that includes all factors inducing recharge such as soil wetness, precipitation, runoff, evapotranspiration, and land cover (Morsy, 2016). During floods and strong storm happenings, water from the flooding and strong storm events can be taken to recharge the groundwater instead of losing it as runoff. Modeling helps to estimate the amount of water and checking whether it is sufficient or not, by comparing the soil moisture levels with and without the presence of groundwater recharge. Thus, estimating groundwater recharge are useful investigation tools in the discussion of understanding and managing the impact of climate change

4.0 The Theoretical Response on Mitigation Groundwater Pollution

The response to protect the positive remunerations from impacts of climate change on groundwater resources can only be achieved through concerted efforts, smart development, and management strategies. The focus should majorly be concentrated on the implementation of achievable mitigation and adaption strategies to climate change responses. These responses include:

4.1 Smart Water Saving Technique

The need to integrate smart water saving techniques is receiving global attention, especially the use of recycled, treated water in times of water shortage as a result of climate change. In this regard, rather than relying exclusively on groundwater for all kinds of water supply, groundwater usage for irrigation purposes should be reduced and substituted with recycled, treated water municipal wastewater for irrigation in semi-urban areas. As such, the resource is used in a more sustainable way.

4.2 Groundwater Protection

Groundwater needs to be protected, and its uses adapted to climate change. Discontinuation of unsustainable abstraction of groundwater will prove more economical than trying to initiate the restoration of already mismanaged aquifers. Continued monitoring is encouraged to achieve a better understanding of groundwater, with emphasis on acquiring accurate information on the dynamics of groundwater systems. These include the protection and maintenance of groundwater systems, integrated land use, and technical installations for simple access to groundwater resources, as they are vital to the prevention of groundwater contamination, ensure sustainability and groundwater availability during the extreme conditions.

4.3 Strategies for Policy-Formation

Capacity development, good governance, and transparency as a strategy for policy making are foundations that have to be considered, as capable principles applicable for the sustainable management of groundwater resources. For policy making, the strategies concerning the management of groundwater availability due to climate change have to be comprehensive and easily accessible. This is to be done through the development of groundwater management regulatory systems which are based on monitoring, data collection, and sharing of knowledge by national water authorities. Overall, good water governance and political will to implement common agreements are the fundamental cornerstones for adaptation and mitigation measures as a response to climate change impact on groundwater.

4.4. Integrated Water Resources Management as a Response to Climate Change

Groundwater is intricate, although often overlooked not realizing that it is also vulnerable to climate change as surface water. This is because groundwater systems discharges into surface water and are recharged from surface water, therefore impacts of climate change on surface water flow regimes are expected to affect groundwater. Thus neglecting the consideration of groundwater in the process of integrated water resources management can result in the mismanagement of groundwater. Experts who have studied groundwater use around the world tend to agree that too little is known about the institutions and policies that govern the use of these resources (Mukherji and Shah, 2005). Nevertheless, innovative approaches to groundwater management have been developing in many parts of the world over the past decade. These innovative approaches feature a variety of instruments to manage groundwater (Theesfeld, 2010). Although science has long had the understanding that surface waters are natural extensions of groundwater systems, only when water became scarce, did the need to use these resources conjunctively and therefore integrated management emerged.

The increased pressures on groundwater resources require a new cohesive management method that brings clearly into account groundwater, dependent ecologies. This approach is based on new technologies for sustainable groundwater exploitation, considering their support capacity as well as the involvement of stakeholders in the management and decision making processes (Eduvie et al., 2020).

5.0 Conclusion and Recommendations

5.1 Conclusion

The changes in climate particularly variations in temperature and precipitation, have considerable impacts on groundwater resources and these impacts vary greatly in real-time. Changes in temperature and precipitation impact recharge rates and ultimately, quantity and quality of groundwater. Managing these changes will require a multidisciplinary approach at all levels of society to develop scale-specific adaptation strategies. Science will need to address the challenge of synthesizing the results of research and employing numerical models to supply managers and policy-makers with clear, science-based management scenarios. Another role of science is to support the monitoring of the response of the resource to specific management actions.

5.2 Recommendations

Going forward, researchers should focus on the effect of climate change on groundwater resources. Climate change mapping on groundwater resources will provide better outcomes and results about the vulnerability and dangers involved in real-time for an exact region. Studies should also be advanced to bring superior results from the positive effects of climate change, with the aim of reducing the negative effects. Special attention should be paid to the role of climate change on the timing of recharge and discharge through a multidisciplinary approach. This knowledge is needed to protect and manage the various services that groundwater provides to the built environment.

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