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GROUNDWATER MANAGEMENT: INTEGRATING GEOLOGICAL AND HYDROLOGICAL DATA FOR EFFECTIVE DECISION MAKING

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SUMMARY

The most valuable natural resource for all of humanity, not just for a state or nation, is water. A country's ability to prosper largely rests on how wisely it uses this resource. Thus, water, which flows in rivers and streams, can be said to be a nation's primary asset. This proves rivers are important, and further justification is needed to emphasise how important they are. The global acceptance of river basins as planning and management domains stems from the fact that water transcends national boundaries. India's rivers are one of its most defining characteristics; the people of India place great religious significance on them. Since groundwater is the most abundant freshwater resource, it is essential to pinpoint the groundwater potential zones for the ongoing and sustainable growth of socioeconomic and agricultural advances. Hard, fractured rock aquifers underlie most of south India's densely inhabited areas. The meagre amount of freshwater that these aquifers provide is the only source that people may use for cultivation and drinking. Because of the diverse nature of the aquifer owing to varied composition, degree of weathering, and density of fracturing, groundwater conditions in hard rock terrain are multivariate. Therefore, a thorough understanding of the distribution and features of the aquifer under the various hydrogeologic circumstances of the research region is necessary for the long-term utilisation of groundwater resources. This study's primary goal is to evaluate the possibility for groundwater management utilising hydrological and geological investigations.

Key words: *water, ground water management, geological, hydrological.*

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INTRODUCTION

The distribution of groundwater in India is somewhat unequal because of the country's diverse geological formations, which exhibit significant lithological and temporal variations, a complicated tectonic framework, and varying climates. In India, precipitation primarily replenishes groundwater supplies during the monsoon season. Recharging the ground water is aided by canal irrigation as well as other types of irrigation systems [1]. India has an annual capacity of 342.43 km for natural groundwater recharge from rainfall, or 8.56% of the nation's total annual rainfall [7]. The canal irrigation system has the ability to improve groundwater recharge by approximately 89.46 kilometres per year. The world's largest user of groundwater is India [2]. It consumes more than 25% of the world's groundwater reserves annually, or 230 cubic kilometres. For their household and drinking water needs, around 30% of people in cities and more than 90% of people in rural areas rely on groundwater. The percentage of tube wells used for irrigation climbed from 1% in 1960–1961 to 40% in 2006–2007, marking the most significant shift in India's groundwater situation. This shows that the country's reliance on groundwater has grown over time (CGWB 2011). Because municipal water supplies are poor and inconsistent, urban dwellers are increasingly depending on groundwater [16]. Since groundwater is an essential component of the ecosystem, it cannot be studied in a vacuum. Water conservation, water efficiency, water reuse, groundwater recharge, and ecosystem sustainability have not received enough attention. Because of the unchecked use of bore well technology, groundwater is being extracted at such a high pace that recharging is frequently insufficient [14]. Reduced forest cover and soil degradation are also major contributors to reduced water availability in many areas. [4].

In this case, the introduction is examined in section 1 of the article while the pertinent literature is examined in section 2. Section 3 and 4 explains the goal of the work, Section 5 shows the discussion of the work, and Sectio n 6 concludes the project.

GROUNDWATER: HYDRO-GEOLOGY

Saturated rocks and/or sediment from a range of geological formations make up groundwater systems. An aquifer is generally defined as a formation that can yield amounts of water that are suitable for human consumption. Because aquifers differ geologically, their physical properties also differ. For example, different aquifers may be considered renewable or exhaustible resources depending on how much surface water or precipitation replenishes or recharges them. Furthermore, the geological structure affects how groundwater stocks react to abstractions. Therefore, it's critical to ascertain the characteristics of the specific hydrological and geological environment in order to comprehend the dynamics of a given aquifer. The salient features and key differences amongst aquifers are briefly described below [5].

Unconfined and Confined Aquifers

In general, precipitation and/or surface water that percolates vertically downward through the underlying earth structure can replenish unconfined aquifers. The water table is the upper limit of an unconfined aquifer, and the water that is found there is regarded as renewable. An impermeable ledge in an otherwise permeable ground upon which water infiltrating from above is held for a duration dictated by the permeability of the surrounding ground constitutes a perched aquifer, which is a specific case of an unconfined aquifer. Conversely, confined aquifers are located beneath less porous rock strata known as aquitards, which either completely prohibit recharge or restrict it to lateral subsurface flows from recharge zones where the aquitard is not present. Water found in confined aquifers that are not replenished may have been deposited millions or even thousands of years ago; this type of water is known as fossil water and is regarded as an exhaustible resource. [6].

Conjoined Surface and Groundwater

An additional differentiation that is crucial, especially in the context of managing water resources, is the degree to which aquifers are connected to other bodies of surface water like rivers or lakes [3]. Aquifers that are beneath and next to rivers and other similar watercourses are known as tributary aquifers. There is a direct correlation between the watercourse's behaviour and that of these unconfined aquifers. In the United States, an example of surface water connected to an alluvial aquifer is the South Platte River in Colorado. The river is the main source of recharging the aquifer, and surface water flow is impacted by aquifer extraction. Additionally, aquifer water may serve as the source of springs; hence, any ecological process or economic usage associated with these springs will also be associated with the groundwater stock rather than the flow [17].

Composition and Physical Characteristics

Aquifers differ in their physical characteristics and geological makeup; the most significant ones are their ability to store water and the underground groundwater flows that occur, for example, in reaction to pumping. The following are some crucial attributes:

- Porosity is a measurement of a rock's percentage of voids or holes (interstices) that allow water to be stored. These voids may result from secondary processes like weathering or rock movements, or they may reflect the characteristics of the aquifer medium, such as pores in limestone or intergranular spaces in sandy aquifers.
- Sterativity, sometimes referred to as the coefficient of storage, is the amount of water that may be drawn out of an aquifer's surface area for every unit change in depth (or head).
- Transmissivity: quantifies how much of a groundwater level drop brought on by pumping at one location is transferred to the remaining portion of the aquifer. i.e., the degree to which the aquifer's water level drops either locally or consistently throughout its whole surface. When transmissivity is low, the water level only falls locally, sometimes even creating depression cones. Local pumping impacts the aquifer's total water level when transmissivity is strong.

The degree to which abstractions might cause irreversible alterations in aquifers is another difference between them. For instance, saltwater intrusion usually affects coastal aquifers. Examples of this are the Hermosillo aquifer in Mexico and the Kiti aquifer in Cyprus. Once this intrusion has happened, it cannot be stopped or is only partially stopped at great expense by injecting recycled or semi-purified water—a process known as artificial injection. In a similar vein, abstraction-related aquifer collapse and the resulting loss of storage are frequent and permanent events. For instance, due to abstraction, land surfaces in central Arizona have lowered by up to 9 meters in the last 20 years. [8].

INTEGRATED GROUNDWATER MANAGEMENT

In order to achieve balanced economic, social welfare, and ecosystem outcomes over time and space, integrated groundwater management, or IGM, is here defined as an organised process that encourages the coordinated management of groundwater and related resources (including conjunctive management with surface water), taking into account non-groundwater policy interactions. Despite being widespread, the governance aspect of integration frequently poses the biggest obstacle to efficient IGM. Encouraging responsible group behaviour is a key component of groundwater governance, since it guarantees the management, preservation, and environmentally sound use of groundwater resources and aquifer systems. The legal and regulatory framework, common understanding and awareness of sustainability concerns, efficient institutions, and plans, strategies, budgets, and incentive structures that are in line with societal objectives all help to support this [9]. A variety of viewpoints, such as institutional design, participation, and accountability, can be used to analyse governance. A variety of policy methods, such as the five categories of instruments, are discussed in these talks.

- Command and control tools: licenses, management zones, and regulatory standards are examples of tools that the state uses to try and influence a target group's behaviour.
- Economic tools that affect microeconomic decisions in the direction of a desired state by affecting the costs and advantages of potential courses of action, such as taxes, subsidies, or water markets.
- Collaborative agreements that seek to improve non-economic incentives (altruism, reciprocity, trust, and concern for future generations) in order to encourage cooperative behaviours amongst groundwater users.
- Instruments of diffusion and communication, which disseminate information intended to affect people's knowledge, attitudes, and/or motivations and their decision-making (e.g. connected to individual water use)
- Infrastructure tools and investments, which denote public sector expenditures meant to enhance groundwater management, like those that are employed to start managed aquifer recharge

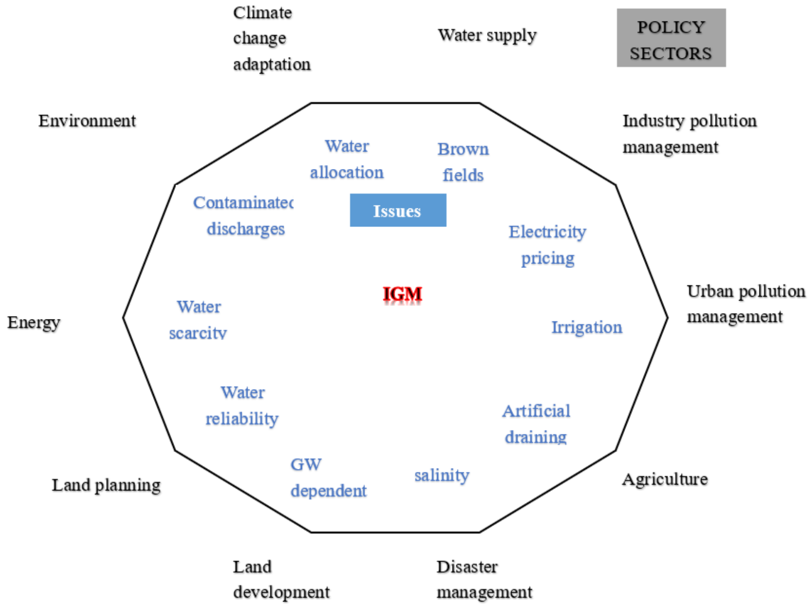

Figure 1. Groundwater: hydro-geology (source: Web)

To achieve acceptable environmental and socioeconomic outcomes, policymakers should ideally create institutions and strategies that not only integrate these tools well but also remain resilient to future changes in both the natural and human environments (e.g., population growth, climate change). Making sure the interventions are consistent is one of the key concerns. It is crucial to take into account potential synergies because the implementation of one tool may enhance or decrease the efficacy of other instruments. A method for determining intervention alternatives and tools and evaluating their efficacy in various contexts should be provided by IGM. The complexity of groundwater governance is reflected in the difficulties in formulating and carrying out groundwater distribution rules and in coordinating duties across sectoral, jurisdictional, and geographic borders in figure 1.

IGM functions in the human environment, taking into account the stakeholders' social, political, cultural, and economic traits. The capacity to balance the needs for groundwater sustainability and water consumption is a critical skill for groundwater managers. Economic policies and market conditions that are in place, together with social values that include associated resource values, policies, and market conditions, all influence demand for usage [10]. Concerns for future generations and ecosystems are among the social factors that drive the demand for groundwater sustainability and conservation. The current political environment can therefore have an impact on these drivers. The evolution of the institutional framework, which was previously discussed in the section on governance, is also shaped by social factors. Understanding the direct and indirect relationships between the groundwater system and the human environment is essential for managing groundwater systems. This covers the socioeconomic effects of restricted groundwater access or decreased groundwater quality, as well as human reactions to management initiatives and other variables such as climate. The behavioural and economical elements that affect the adoption of new technology or improved practices that IGM has found are also rooted in the human setting. [18].

DATA REQUIREMENT FOR GROUNDWATER STUDIES

Locating groundwater resources is getting harder and harder, just like finding any other type of underground natural resource on Earth [12]. As a result, any novel method that can help locate the site for a borehole and prevent the widespread insertion of ineffective wells is quite valuable. Therefore, multidisciplinary studies are essential for comprehending the existence of groundwater and are crucial for effective planning and management of groundwater in hard rock locations [13]. Given the numerous issues surrounding the search for groundwater in hard rock regions, contemporary technology, such as remote sensing and geophysical investigation methods, is better suited to locate water-bearing formations. A multitude of scholars worldwide are studying groundwater availability in hard rock locations. These methods are effectively applied in various environments to identify possible groundwater zones at the national and international levels.

Gathering all of the available hydrological and geological information about the groundwater basin under investigation is the initial step in every groundwater study. Information on soils, land use, vegetation, irrigation, aquifer characteristics and borders, precipitation, evapotranspiration, pumped abstractions, stream flows, surface and subsurface geology, water tables, and groundwater quality will all be covered. A program of field study must be started if such data are either nonexistent or extremely sparse, as no model whatsoever makes hydrological sense if it is not founded on a coherent hydrogeological understanding of basin. After then, a conceptual model of the basin with all of its numerous inflow and outflow components is created using all of the previously discovered and outdated data [11]. A conceptual model rests on certain presumptions that need to be checked in a subsequent research stage. However, at the outset, it ought to address the crucial query: is the groundwater basin made up of a single aquifer (or any lateral mix of aquifers) enclosed by an impermeable base below? The next step, which is creating the numerical model, can be done if the response is in the affirmative. The various data are first synthesised using this model, and then the assumptions in the conceptual model are tested [19]. Developing and testing the numerical model requires a set of quantitative hydrogeological data.

EXPERIMENTAL ANALYSIS

In many regions of the world, the quantity and quality of groundwater resources have dropped to critical levels over the past 40 years due to a variety of factors working together. Using more groundwater than is naturally supplied is known as groundwater overdraft, and it has happened in a number of nations. The frequency of these overdrafts is especially significant in desert nations like Yemen, Namibia, and Jordan where groundwater is the main supply of water. Expensive investments in long-distance surface water transfers or desalination are commonly considered the answer when groundwater supplies run out. It is obvious that these expenditures need to be evaluated in the context of alternative groundwater management techniques. Similarly, concerns over the quality of groundwater are particularly important in many nations. One of the most commonly given instances is Bangladesh, where naturally occurring arsenic pollution of the groundwater causes serious health issues for impoverished rural areas.

Furthermore, industrial or agricultural pollutants and residues have contaminated groundwater supplies in numerous places. Due to this situation, the causes of groundwater depletion are being examined again, and the fundamentals of groundwater management are being closely examined. A network of observation wells and/or piezometers must be created in order to gather information on the location of recharge and discharge areas, the depth and shape of the water table 1, and the direction of groundwater movement. To provide inferential statistical analysis between the many VFs (Variable factors) and their individual effects on the frequency with which the water management was implemented, Karl Pearson's Correlation method was utilised. Conducting a Pearson's correlation requires consideration of five underlying assumptions. While the first two are related to the chosen research methods and measures, the first three are concerned with how well the data matches the Pearson correlation model.

Table 1. Principles of groundwater management

Item	Strongly agree	Agree	Disagree	Strongly disagree
Positive	4	3	2	1
Negative	1	2	3	4

The water table 2 is always fluctuating because it responds to the different components of recharge and outflow that make up a groundwater system. The (mean) highest and (mean) lowest water table positions, as well as the mean water table of a hydrological year, are significant in any drainage study. This is why it is necessary to measure the water level frequently for a minimum of a year. A fortnight may be a better interval between readings, but one month should not be exceeded. As much as practicable, all measurements ought to be taken on the same day in order to provide a comprehensive view of the water table 2.

Table 2. Regression Analysis of Integrating groundwater management

Source of Variation	Sum of Squares	df	Mean Square	F
Regression	20144.243	2	10072.122	33.008**
Residual	123887.698	406	305.142	
Total	144031.941	408		

A groundwater-quality monitoring program's sampling frequency is determined by the water's physio-chemical characteristics and the anticipated rate of change in chemical constituent concentrations. Because groundwater travels slowly—possibly just a few centimetres to a few decimetres per day—day-to-day variations in the constituent and property concentrations at a site (or well) are typically too modest to be noticed. Twice yearly sample should be sufficient to monitor key ion and nutrient concentrations as well as groundwater physical property values. By changing the sampling season, conditions could be recorded over a two-year cycle. Trace inorganic and organic compounds, which make up the second group of constituents, could be sufficiently monitored by taking samples from background areas (those unaffected by human activity) wells once every two years. However, more frequent sampling should be taken into consideration if the kinds and conditions of any upgradient sources of these compounds are changing in figure 2.

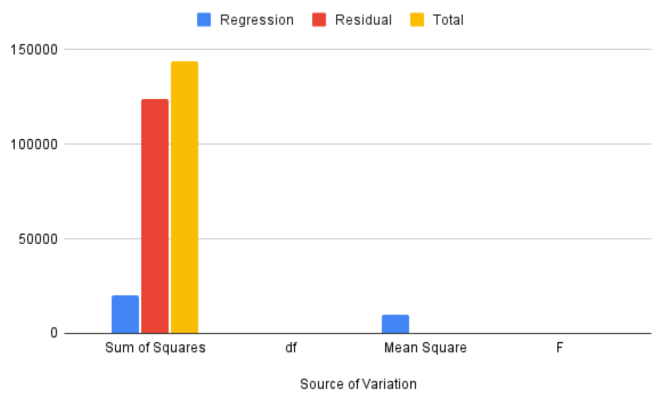

Figure 2. Regression Analysis plot

A number of considerations point to the need for long-term groundwater quality monitoring. Long-term monitoring is required not just by the program's structure as outlined below, but also by the large range of time scales over which fluctuations in groundwater quality are expected [15]. Surface water bodies that serve as groundwater discharge regions may take a while to reflect changes in variables affecting the water quality in recharge areas due to the sluggish velocity of groundwater movement. The length of a groundwater-quality monitoring program is also influenced by the rate at which the chemical constituents of interest are changing in the source area.

Table 3 shows that the relationship between groundwater management and Pearson's correlation was assessed. The value of the Pearson correlation coefficient, sometimes known as "r," is -0.061. Furthermore, the two variables have a statistical significance (p-value) of 0.208. Given that p>0.05, the correlation coefficient is statistically not significantly different from zero. Groundwater management is more common when each percentage point that a water drops, but only slightly.

Table 3. Correlation between groundwater: hydro-geology

Karl Pearson's Correlation		
Variable Factor of groundwater: hydro-geology		
	Variable Factor	**Frequency**
Pearson Correlation	1	-.061
Sig. (2-tailed)		.208
N	423	423
Pearson Correlation	-.061	1
Sig. (2-tailed)	.208	
N	423	423

According to Table 4, Pearson's correlation was employed to assess the relationship between the frequency of online shoppers' purchases and the products' quality. According to the test, there was a negative correlation between the frequency of groundwater management among respondents from the sample population. The value of the Pearson correlation coefficient, sometimes known as "r," is -0.087. Furthermore, the two variables have a statistically significant (p-value) relationship of 0.074. Given that p>0.05, the correlation coefficient is shown to be statistically not substantially different from zero.

Table 4. Correlation between Water Table-Contour Lines

Karl Pearson's Correlation		
Variable Factor		
	Variable Factor - Quality	Frequency of quantity
Pearson Correlation	1	-.087
Sig. (2-tailed)		.074
N	423	423
Pearson Correlation	-.087	1
Sig. (2-tailed)	.074	
N	423	423

To determine whether there is a statistically significant interaction effect, the researcher advises examining the Tests of Between-Subjects Effects table. The product of the two independent variables is how the interaction effect is displayed in a two-way ANOVA.

Table 5. Two-way ANOVA

Tests of Between-Subjects Effects				
Dependent Variable: Frequency of online purchase				
Source	**df**	**Mean Square**	**F**	**Sig.**
Governance	2	1.817	2.0020	0.1360
Human Setting	1	0.16	0.1760	0.6750
Natural Setting	2	0.823	0.9070	0.4050

The "Sig." column of Table 5 displays the p-value, or significance value, for the interaction effect. Based on the observation, the p-value for the interaction effect is.405 (p =.405). This indicates that the interaction effect is statistically insignificant because it is bigger than.05 and does not satisfy p <.05.

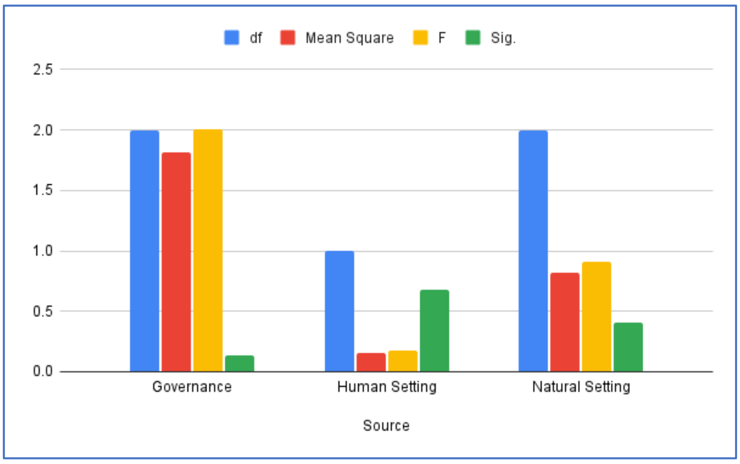

Figure 3. Two-way ANOVA plot

In figure 3, implies that the frequency of activity in the Natural Setting and the Human Setting are not directly correlated. Consequently, it can be concluded that there is a statistically negligible interaction between them.

CONCLUSION

One of the most vital natural resources for development, life, and the creation of diverse ecosystems and landscapes is water. Thus, the three pillars of sustainable development—social, environmental, and economic—cannot be achieved without the effective and efficient management of this resource. Groundwater has historically been a significant source of water for human survival. Groundwater has long been regarded as a steady and dependable resource since it is protected from short-term variations in weather patterns. Because of the interdependencies between humans, ecosystems, surface water, and groundwater, an integrated strategy to management is required. Understanding the linkages between the problem's component parts is necessary for this kind of management. For planners and decision-makers, accurate and trustworthy information about groundwater resources—including their quality—is essential. To meet the need for groundwater for irrigation and drinking, significant state and federal funding has been made in the fields of groundwater exploration, development, and management. This work produces a vast amount of data. Our priorities must be increased data management, accurate analysis, and efficient data distribution. Large and complex groundwater problems that vary greatly in size, nature, and real-life scenarios can be solved by numerical models. Anisotropy, uncertainty, and spatial heterogeneities may all be easily handled with the development of high-speed computers. However, the availability and correctness of the measured/recorded data needed for any modelling study is a major factor in determining the study's effectiveness. Thus, determining the data requirements for a specific modelling research and gathering and keeping track of the necessary data are essential components of any groundwater modelling endeavour.

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