Bulletin of Nepal Geological Society, 2025, Vol. 42, pp. 109–114 *ISSN 2676-1386 (Print); ISSN 2676-1394 (Online)*

Challenging Aspects of Groundwater Depletion Due to Seasonal and Temporal Variation in the Terai Region of Parsa, Bara, Rautahat and Sarlahi

Jaya Laxmi Singh*, Ajay Raj Adhikari and Binod Pant

Mechanized Irrigation Innovation Project, Department of Water Resources and Irrigation, Jawalakhel, Lalitpur
**Corresponding author's email: jaya.sin16@gmail.com*

ABSTRACT

Groundwater plays a vital role in sustaining agriculture in Nepal's Terai region, where seasonal rainfall and increasing irrigation demands place significant stress on aquifer systems. This study investigates the seasonal and temporal fluctuations in groundwater levels in four key districts-Parsa, Bara, Rautahat and Sarlahi-highlighting critical challenges posed by intensive irrigation, climate variability, and geological constraints. Field data and hydrogeological assessments reveal that sandy sub-surfaces, shallow water tables, and irrigation pressures contribute to similar patterns of local depletion across these districts. The study recommends the establishment of recharge zones, crop pattern adjustments, infrastructure rehabilitation to promote sustainable groundwater management, research in ground water zones and intake of water of plant habitats, and improvement of intergovernmental co-ordination considering the emergency water management in critical situation.

Keywords: *Groundwater depletion; climate water balance; Terai region*

INTRODUCTION

Nepal, being an agriculture-based nation, relies heavily on agricultural productivity for its economic sustainability and food security. However, with rapid population growth, urban expansion, and rising demand for food and resources, the current level of agricultural output is increasingly insufficien to sustain livelihoods and meet the needs of its people (Pathak 2017). This shortfall poses significant challenges to rural communities, exacerbates poverty, and heightens the occasional risk of food insecurity across the country. This challenge is further compounded by the encroachment of farmland due to urban development and industrial expansion, which reduces cultivable land. Thus, enhancing agricultural productivity has become imperative, making irrigation the most critical input. Without reliable irrigation, other agricultural advancements remain ineffective (Kaini et al. 2020)

Recently, in 2025, the Terai region particularly districts of Madhesh Pradesh have been experiencing an unusual dry spell. The monsoon has arrived late, with rainfall 70% below average during the first two months of the season. The increase in evaporation deepening the negative Climate water balance (CWB) is intensifying the drought process; this, in turn, will pose new threats to agriculture, especially to crop production (Łabędzki et al. 2014). Further, global warming is inevitable (Lee et al. 2023), so adaptation to changing climatic conditions will be needed. Hence, Climate change is becoming the key factor that leads to the increase of evaporation rates disrupted by traditional rainfall patterns due to the increase in temperature. Along with the delayed monsoon onset due to global warming effects. Other factors though include local groundwater depletion, encroachment, over extraction rather than recharge may be another factor that indirectly impacts the yield of ground water.

STUDY AREA

The districts of Bara, Parsa, Rautahat, and Sarlahi are located in the south-central part of Nepal's Terai region, along the border with the Indian state of Bihar. This lowland area is characterized by fertile alluvial plains, a subtropical climate, and intensive agricultural activity.The East-West Highway passes through the study area. The study area is about 148 km west from Chitwan Bazar of the Chitwan district. The nearest airstrip from the project area is Simara airport, Bara from where daily flights link with Kathmandu

Madhesh Province in Nepal has a humid subtropical climate characterized by hot summers and mild winters. Temperatures can reach above 45°C in the summer, especially in the Terai region, which is the southernmost part of the province. Winters are generally mild, though nights can be cool. The province also experiences monsoon seasons with varying rainfall, contributing to its agricultural landscape. The flat topography, with fertile alluvial soil, supports intensive farming, but it also presents challenges in managing seasonal water availability. In Madhesh Pradesh including all; eight districts (Parsa, Bara, Rautahat, Sarlahi, Mahottri, Dhanusa, Siraha, Saptari) around 5, 80,000-hectare of cultivable land is available and around 3,93,580-hectare land has developed irrigation infrastructure (MoWRI 2024).

Agriculture is the primary economic activity, with over 80% of the population of project area engaged in farming. The main crops include rice, wheat, maize, sugarcane, Banana and pulses. Bara, Parsa, Rautahat and Sarlahi are one of Nepal's most industrialized districts, with numerous factories, including sugar mills, cement factories, crushers and agro-based industries and significant in livestock farming, particularly cattle, buffalo, goats, and poultry. The people can just live on their products for the year if the monsoon goes favorable. Minor health facilities are available in the

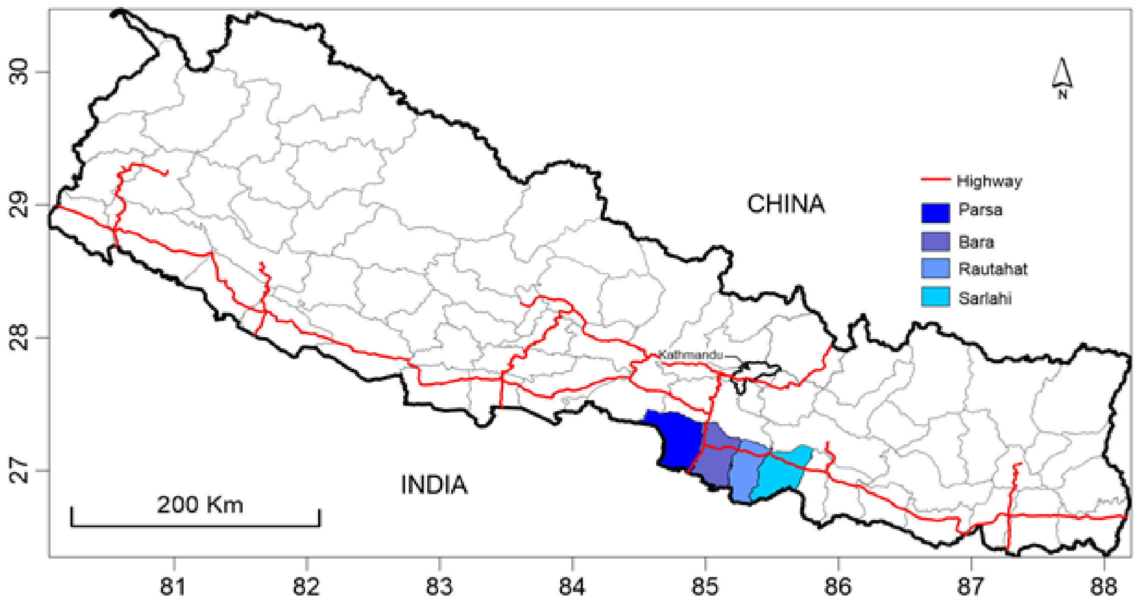

Fig. 1: Location map of project area.

area; the major facilities are only available at Birgunj. The project area has a rather good marketing network. The nearest major marketplace is Birgunj, Because of the transportation facilities, agricultural products can easily be transported and sold in and around whenever necessary. Similarly, necessary household commodities for household consumption can also be transported from outside. The area's proximity to the Indian border facilities cross-border trade, an important economic activity in Bara.

The project area forms part of the northern stretch of the vast Indo-Gangetic alluvial plain. Beneath it lies the Siwalik Formation, a sequence of rocks dating from the Middle Miocene to the Pleistocene (Nakayama and Ulak 1999).

Over time, rivers flowing from the Siwalik hills have deposited layers of Quaternary sediments across this landscape. These deposits, ranging from coarse gravels to fine clays, have created a complex hydrogeological environment where groundwater recharge, storage, and flow vary significantly from north to south.

Geologically, the region can be divided into three distinct zones (Sharma 1990). The Bhabar Zone, along the northern Terai, is made up of coarse materials such as boulders, cobbles, and gravel. Because of its high permeability, this zone serves as the primary recharge area, where rainfall and river water readily seep underground. Just south of it lies the Inner Terai Zone, a transitional belt where the coarse deposits of the Bhabar begin to give way to finer materials. Moving further south, the Southern Terai or Gangetic Plain is dominated by fine sediments-sand, silt, and clay-that act more as a storage zone for groundwater than as a recharge area. Within these zones, different types of aquifers support the region's water supply. Unconfined aquifers are shallow and respond quickly to rainfall and river seepage, making them vital for local use but also vulnerable to seasonal variation. Confined aquifers lie deeper, recharged more slowly through vertical percolation or lateral inflo , and provide a more stable but harder-to-replenish source of water. Phreatic aquifers, present in both the Bhabar and Gangetic formations, represent the water table aquifers most commonly tapped for domestic and agricultural needs. The composition of these aquifers varies with the sediments. Hard formations, made of gravel, cobbles, and pebbles, allow rapid infiltration and groundwater flo . Medium formations, such as coarse sand, fine gravel, and siltstone, offer a balance between storage and permeability. Soft formations, including silt, clay, and fine sand, hold water effectively but release it slowly, limiting recharge and flo . One of the most critical aspects of this system is the difference in hydraulic behavior across the zones. In the Bhabar, conductivity and transmissivity are exceptionally high, allowing large amounts of water to percolate underground. This recharged groundwater then migrates southward, gradually feeding the finer aquifers of the Gangetic plains. In this way, the Bhabar functions as a natural recharge engine, sustaining groundwater reserves that support both ecosystems and human activities across the Terai.

RECENT STATUS OF PROJECT AREA

The farmers of the project area were observed to be hardworking and quite aware of the benefits of modern farming. Their efforts to get more production from their fields have been hampered mainly due to the non-availability of a reliable source of irrigation yet. The main crop of the area is rice, wheat, maize etc., which are completely rain fed in nature as well as shallow and Deep Tubewell.

On 2082/03/26 BS, the Government of Madhesh Pradesh officiall declared the province a "Dry Area" for the next three months. This decision comes in response to a significant decline in rainfall, which has been recorded at only 46% of the average level for the season. As a result, although approximately 375,000 hectares of land are usually cultivated with rice in the region (MoWRI 2024), these areas are now unsuitable for rice cultivation due to insufficien water availability. Fig. 2 shows the current Ropai Percentage (Plantation of rice) in Madhesh Pradesh. Comparatively, the districts: Saptari, Mahottari, Dhanusha, Siraha, Sarlahi and Rautahat have less percentage of cultivation of rice.

The declaration aims to address the emerging agricultural crisis and take proactive measures to mitigate the effects of the drought on farmers and food security in the province. The current agricultural crisis and the declaration of Madhesh Pradesh as a dry area are the result of several interrelated factors:

i. Climate change and variability

According to the Department of Hydrology and Meteorology (DHM), the monsoon in 2025 became active from 29th May. Historical data indicate that by 28th July, the region typically receives an average precipitation of 654.6 mm. However, the current data shows only 302.9 mm of rainfall recorded during the same period in 2025. This accounts for just 46.3% of the expected rainfall, clearly reflecting a significant shortfall. Such drastic deviations in rainfall not only jeopardize seasonal farming activities, particularly rice cultivation, but also strain the broader water supply system, affecting both agriculture and daily livelihoods in the province.

ii. Decrease in Availability of water

The main sources of water in this Province includes rivers, streams, groundwater and water creeks. However, in recent years, these sources have shown alarming signs of depletion. Notably, small rivers that once flowed consistently throughout the year are now drying up during critical months. Major rivers such as the Kamala River and Bagmati River, which are vital for irrigation and local water supply in Madhesh Pradesh, have experienced significantly reduced flow volumes compared to previous years. A comparative analysis of the monthly discharge data for the Bagmati River over the past 25 years is illustrated in Fig. 3. This data clearly shows a downward trend in river flo , reflecting the increasing impact of changing climate conditions, reduced rainfall, and over-extraction of water resources.

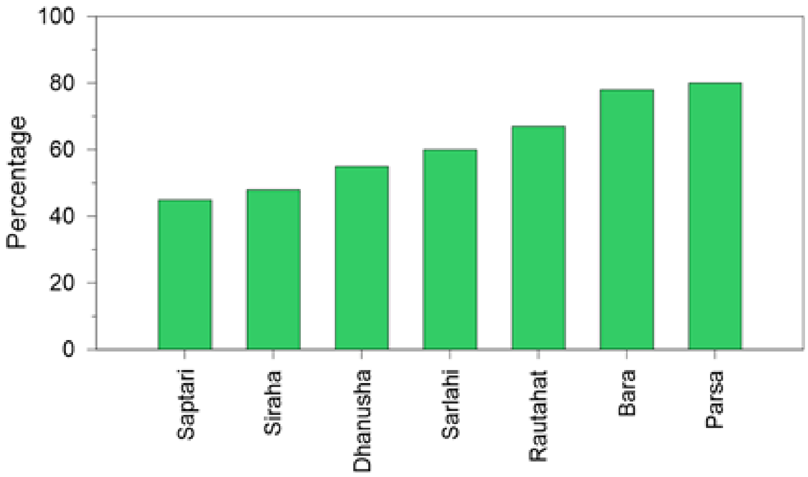

Fig. 2: Cultivated area in Madhesh Pradesh-2, Nepal (MoWRI 2024).

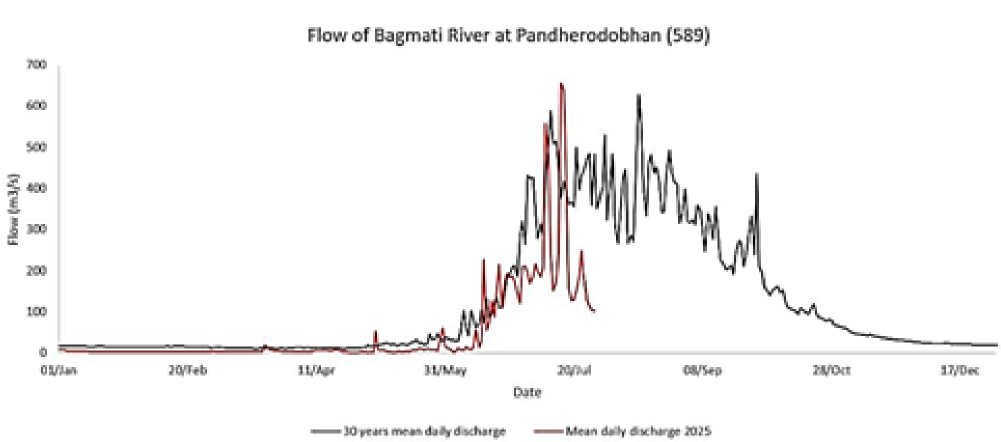

Fig. 3: Comparative Flow of Bagmati at station number 589 (MoWRI 2024).

iii. Seasonal Fluctuations and Groundwater Status

Table 1 gives a clear picture of how groundwater behaves differ ntly across the Terai districts, especially when looking at static water level (SWL) and dynamic water level (DWL). In some places like Bara (Kalaiya and Jitpur Simara), wells even show artesian conditions, where water naturally rises to the surface as "free flo ," meaning no pumping is needed at times. In contrast, other wells such as those in Sarlahi (Lalbandi) record much deeper SWL values over 80 m, pointing to confined aquifers that are harder to tap. The DWL data, which shows how far the water drops during pumping, also varies widely. For example, relatively shallow pumping depths of 14 to 21 m are seen in some Bara wells, while in Sarlahi (Lalbandi) the DWL goes beyond 115 m, reflecting high demand or deeper aquifer systems. Some wells also include a "present" DWL reading, showing current conditions, which helps in understanding how groundwater levels are changing over time. Taken together, the data highlights the diversity of groundwater conditions from shallow, easily accessible, and even naturally flowing wells to much deeper and more challenging aquifers underscoring the complexity of managing water resources in the Terai. Field data below illustrates the seasonal decline in static water level (SWL) and dynamic water level (DWL) across several monitored sites:

Table 1. Field data showing the seasonal decline of static water level (Measurement Year: 2081, Falgun to 2081, Ashadh BS)

S.N.	District	Municipality	Ward	Date	Depth (m)	Screen (m)	SWL (bgl)	SWL	DWL (bgl)	DWL Present
1	Bara	Kalaiya	15	28/11/2078	125	18	1	8.23	21	39.2
2	Bara	Jitpur Simara	14	30/09/2078	102	18	Free Flow	Occasionally free flo	15	39.2
3	Bara	Nijgadh	6	28/01/2079	110	18	38	40	43	50.5
4	Bara	Kalaiya	15	16/09/2078	124	18	Free Flow	3	14	—
5	Bara	Kalaiya	27	21/07/2078	121	15	2	3	16	13.3
6	Bara	Mahagadimai	9	17/01/2079	114	18	10	5	17	—
7	Parsa	Thori	3	23/11/2078	105	18	—	35.7	—	36.11
8	Parsa	Thori	3	28/10/2078	105	18	33	37	36	42.3
9	Rautahat	Katahariya	7	06/10/2078	102	18	1	3	19	26.7
10	Rautahat	Baudhimai	6	09/03/2080	129	18	5	7	15	—
11	Sarlahi	Hariwan	11	04/03/2079	165	18	—	12.5	—	63.8
12	Sarlahi	Lalbandi	16	21/06/2079	177	21	81.5	88	115	—
13	Sarlahi	Kabilasi	8	—	—	—	5.15	—	—	13.96

iv. Aging and non-functional infrastructure

A significant proportion of deep tubewells in the project area are either damaged or non-operational, largely due to pump failures and theft of transformers. Table 2 highlights the condition of tubewells across the districts. Of the 220 functional units serving a command area of 6,600 hectares, many require frequent maintenance. Specificall , 46 tubewells in Sarlahi, 63 in Bara, 25 in Parsa, and 52 in Rautahat are in need of repair. These high maintenance requirements reflect an aging infrastructure that is increasingly difficul to sustain. In addition to mechanical wear, theft has emerged as a critical challenge: 112 transformers have been stolen, leaving hundreds of tubewells inoperative. This has directly crippled irrigation in key agricultural areas, further compounding the stress already evident in groundwater resources. With fewer functional systems, farmers are forced to rely more heavily on the remaining operational tubewells, deepening the drawdown of aquifers and accelerating depletion trends.

Table 2. Field data observation showing the Condition of Deeptubewell

District	Completed in this fiscal year		System need to be developed (including this fiscal year)	Need to maintenance				Fuctional tubewell	Command area
	Tubewell	System		Routine	Recurrent	Periodic	Emergency		
Sarlahi	28	7	63	0	4	5	38	53	1590
Rautahat	21	9	50	0	1	29	22	69	2070
Bara	17	10	27	5	3	4	51	71	2130
Parsa	18	3	21	10	0	2	13	27	810
	84	**29**	**161**	**15**	**8**	**40**	**124**	**220**	**6600**

RECOMMENDATIONS

i. Establish recharge zones

Promote rainwater harvesting, recharge wells, and percolation ponds, particularly in the Bhabar zone or favorable places after feasibility, to restore aquifer health. Groundwater recharge mappings to identify and protect critical recharge areas are also essential for designing the project.

ii. Crop Diversification and Rotation

Encourage the cultivation of less water-intensive crops (e.g., millet, legumes, mustard) during dry seasons.

iii. Rehabilitation of Irrigation Infrastructure

Replace and upgrade damaged tubewells and associated hardware to increase water efficien . Prioritize repair and electrification of the 100+ non-functional tubewells to optimize water availability during critical cropping periods.

iv. Electrification and Pump Installation

Ensure timely electrification and pump installation for functional tubewells to avoid blockages and promote timely irrigation.

v. Prevent theft and vandalism

As indicated in the above, a total of 112 transformers have been stolen across the four districts. This large-scale theft has severely disrupted the power supply required for operating irrigation systems, resulting in the inability to irrigate significant portions of agricultural land during this season

To prevent further incidents and ensure uninterrupted irrigation services, it is strongly recommended to install anti-theft sensors or surveillance systems on all transformers, with priority given to those located near border areas, which are more vulnerable to such criminal activities. This preventive measure will help:

- Ensure continuous power supply for irrigation,
- Deter future theft attempts,
- Enhance overall infrastructure security in high-risk zones.

vi. Aquifer Mapping

A comprehensive approach to groundwater management involves conducting detailed hydrogeological mapping to identify stress zones, aquifer characteristics, and areas with high recharge potential, coupled with elevation mapping to assess surface undulations and pinpoint depressed areas suitable for artificial recharge. Isotope studies can trace the origin of recharge water, providing critical insights for the protection and management of key recharge zones. Additionally, the installation of monitoring systems, including groundwater level sensors, rainfall gauges, and evapotranspiration measurement tools, enables real-time tracking of aquifer health and overall water balance.

vii. Land planning, control of land encroachment

The gradual expansion of residential settlements into the Middle Terai and Bhabar zones is becoming increasingly evident. These ecologically sensitive areas are vital for the natural recharge of groundwater aquifers. If urban encroachment continues unchecked, it could disrupt the hydrological balance, leading to long-term water scarcity and environmental degradation. To safeguard groundwater resources for the future, comprehensive land-use planning is essential. This should include:

- Zoning regulations that restrict development in high-recharge zones.
- Sustainable urban design that incorporates green infrastructure and permeable surfaces.
- Community awareness programs about the importance of these regions for water security.

viii. Study of eucalyptus grandis

There is a widely held perception that Eucalyptus grandis consumes a significant amount of groundwater, potentially affecting the availability of water in surrounding areas. However, no definitive or location-specific scientific documentation has been found to support this claim.

Given the importance of sustainable groundwater management, especially in water-sensitive regions, it is essential to conduct comprehensive, site-specific research to assess

- The actual water uptake rate of Eucalyptus grandis under local soil and climatic conditions,
- Its impact on surrounding water tables and nearby vegetation,
- Long-term implications for agricultural water availability.

Such research is critical for making informed decisions about land-use planning, afforestation programs, and water resource conservation. Until conclusive data is available, caution should be exercised in large-scale planting of this species, particularly in groundwater-dependent areas.

ix. Enhance Intergovernmental Co-ordination

Due to a lack of interdepartmental coordination, the construction of tubewells has not maintained the necessary distance between wells. Ideally, the construction of each well should consider its area of influence to avoid overlapping. However, in this case, both the drinking water well and the irrigation well have been constructed within the same influence zone

For optimal performance, a minimum distance of at least 1 kilometer should be maintained between tubewells to prevent interference and ensure sustainable water extraction.

CONCLUSIONS

Given the current scenario of water shortages affecting crop production, it is crucial that all stakeholders, including farmers, water user committees, and government agencies actively engage in addressing both direct and indirect factors that hinder the availability of irrigation water.

Efforts should not be limited to times of scarcity or drought; proactive and long-term planning is essential to build resilience against future climate change impacts. Early collaboration and preparedness are key to ensuring sustainable water resources and agricultural productivity.

REFERENCES

Kaini, S., Gardner, T. and Sharma, A.K., 2020, Assessment of socio-economic factors impacting on the cropping intensity of an irrigation scheme in developing countries. Irrig Drain 69:363-375. https://doi.org/10.1002/ird.2427. https://doi.org/https://doi.org/10.1002/ird.2427

Łabędzki, L., Bąk, B. and Smarzyńska, K., 2014, Spatio-temporal variability and trends of Penman-Monteith reference evapotranspiration (FAO-56) in 1971-2010 under climatic conditions of Poland. Polish J Environ Stud 23:2083–2091

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., ... and Park, Y., 2023, IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPC

MoWRI, 2024, Identification and solution of Drinking Water, Irrigation due to drought in Madhesh Pradesh, Ministry of Energy Water Resources and Irrigation

Nakayama, K. and Ulak, P.D., 1999, Evolution of fluvial style in the Siwalik Group in the foothills of the Nepal Himalaya. Sediment Geol 125:205–224

Pathak, D., 2017, Delineation of groundwater potential zone in the indo-gangetic plain through GIS analysis. J Inst Sci Technol. https://doi.org/10.3126/jist.v22i1.17760

Sharma, C.K., 1990, Geology of Nepal Himalaya and Adjacent Countries