

## Current Status and Future Prospect of Ground Water of Palwal District Haryana, India

<sup>1</sup>Nepal Singh, <sup>1</sup>Aparna Sinha, <sup>2</sup>Mohd Mazhar, <sup>2</sup>Khusboo, <sup>1</sup>Saqib Shakeel, and <sup>1</sup>Ajhar Hussain\*

### Author's Affiliations:

<sup>1</sup>Department of Geology, Aligarh Muslim University, Aligarh, India- 202002

<sup>2</sup>Department of Pharmacology, School of medical and Allied Sciences, K. R. Mangalam University Gurgaon India

\*Corresponding Author: Ajhar Hussain, Department of Geology, Aligarh Muslim University, Aligarh India- 202002

E-mail: [glyazhar@gmail.com](mailto:glyazhar@gmail.com)

Received on 21.08.2025, Revised on 25.10.2025, Accepted on 29.11.2025

**How to cite this article:** Singh N., Sinha A., Mazhar M., Khusboo, Shakeel S., and Hussain A. (2025). Current Status and Future Prospect of Ground Water of Palwal District Haryana, India. *Bulletin of Pure and Applied Sciences- Geology*, 44F (2), 154-174.

### Abstract:

The Palwal district of Haryana, located in a semi-arid region of northwestern India, is currently facing growing pressure on its groundwater resources due to a combination of climatic variability, industrial expansion, and unsustainable agricultural practices. This study presents a comprehensive geo-hydro-environmental assessment of the groundwater status in the region. Drawing upon hydrogeological surveys, borehole lithology, water table data, and soil and aquifer characteristics, the research reveals significant groundwater depletion and increasing water quality issues, particularly salinity and nitrate contamination in blocks adjacent to the Yamuna River. Seasonal fluctuation in water levels (ranging from 2 to 20 m bgl) is evident, with over-extraction linked to rapid urbanization and agricultural demand. The subsurface strata are composed mainly of older and newer alluvium with limited aquifer capacity in fractured quartzite zones. Hydrogeochemical models and aquifer characteristics suggest that the recharge capacity is constrained, and future yield is threatened. The region also suffers from frequent natural hazards such as floods, droughts, and heatwaves, further stressing water availability and health infrastructure. Land use data indicates a predominance of agricultural land, with forest cover at just 1.54%, exacerbating water stress. The study concludes that effective groundwater management in Palwal requires integrated strategies – such as managed aquifer recharge (MAR), GIS-based monitoring, conjunctive water use, and regulatory mechanisms – to restore balance between abstraction and recharge. This research contributes a critical baseline for planning sustainable groundwater policies in Palwal and offers replicable insights for similar regions facing aquifer degradation.

**Keywords:** Groundwater, Yamuna River, Lithology, Aquifer, Environment, Palwal, India

## 1. INTRODUCTION

Groundwater sustainability has emerged as a pressing challenge in the semi-arid landscape of Palwal District, Haryana, where accelerated groundwater extraction and climate variability have triggered alarming depletion trends. This

study examines the present hydrogeological conditions and evaluates the future prospects of groundwater resources using multiple empirical datasets, including historical fluctuations in the water table, borewell discharge rates, and physico-chemical water quality indicators. The findings show a consistent and rapid decline in

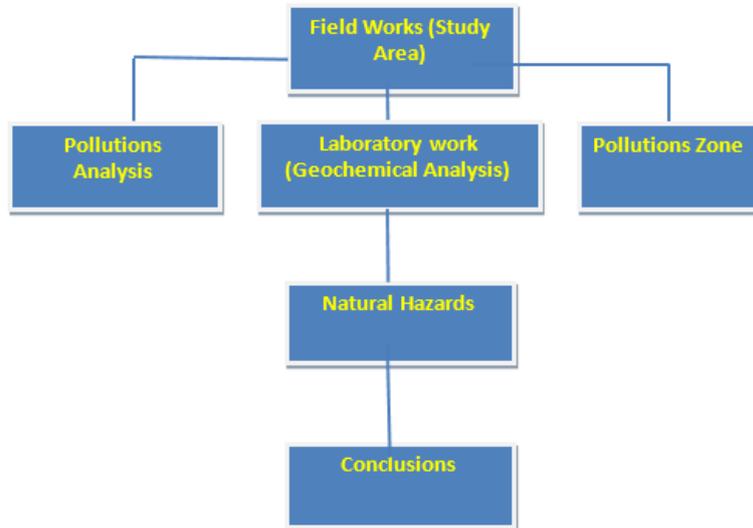
groundwater levels, with several administrative blocks registering annual depletion rates that surpass the safety limits prescribed by the Central Ground Water Board (CGWB). In parallel, water quality has deteriorated, reflected by rising levels of total dissolved solids (TDS), nitrates, and fluoride—raising significant concerns for public health and agricultural productivity. To anticipate long-term outcomes, the study employs hydrogeochemical modelling and assesses the effectiveness of adaptive strategies such as managed aquifer recharges (MAR), integrated surface-groundwater use, and decentralized community-led water governance. The overall assessment highlights that groundwater systems in Palwal are approaching a critical threshold and, if current extraction patterns persist, risk irreversible aquifer degradation. The research emphasizes the need for a shift toward holistic and integrated groundwater management that combines regulatory mechanisms, stakeholder participation, and technology-enabled monitoring. The study not only enhances understanding of groundwater stress in the region but also provides a practical management framework that can be applied to similar hydrogeological environments across North India.

Groundwater sustainability in semi-arid regions has been extensively examined in hydrological and environmental research due to its critical role in supporting agriculture, domestic supply, and ecological stability. Studies across northern India have consistently reported a continuous decline in groundwater levels resulting from over-extraction, unregulated borewell development, and erratic monsoonal recharge (CGWB, 2020; Kumar et al., 2019). Research by Singh and Sharma (2018) highlights that districts within Haryana, including Palwal, experience severe anthropogenic pressure on aquifers, leading to declining yields and deteriorating water quality. Increasing concentrations of total dissolved solids, nitrates, and fluoride have been observed, correlating with agricultural

intensification and inadequate wastewater management (Yadav et al., 2021). Hydrogeochemical modelling studies emphasize that climatic variability exacerbates depletion by altering recharge dynamics and evaporation rates (Gupta & Rao, 2020). Adaptive approaches such as managed aquifer recharge (MAR) and conjunctive use of surface and groundwater resources are recognized as essential for restoring aquifer balance (Kumar & Singh, 2022). Furthermore, decentralized governance frameworks involving community participation and real-time monitoring technologies have proven effective in enhancing groundwater resilience (Patel et al., 2023).

Overall, the literature underscores the urgent need for integrated groundwater management in semi-arid landscapes. The present study aligns with these findings, focusing on Palwal District to evaluate hydrogeological status, water quality deterioration, and sustainable management interventions. Groundwater is a vital resource for agriculture, domestic use, and industrial activities, particularly in semi-arid regions like Haryana. In Palwal district, groundwater plays a crucial role in sustaining livelihoods due to the seasonal nature of rainfall and the lack of perennial surface water sources. However, increasing population, unregulated borewell extraction, and changing land-use patterns have significantly stressed the region's groundwater reserves (Central Ground Water Board [CGWB], 2021). Studies indicate a steady decline in groundwater levels, with some blocks falling into the "overexploited" category (Haryana Water Resources Authority [HWRA], 2022). Despite ongoing government interventions, the gap between extraction and recharge remains critical. Understanding the current status of groundwater and identifying sustainable management practices is essential to ensuring long-term water security. This study aims to assess the present condition and future prospects of groundwater in Palwal through hydrogeological data, usage patterns, and policy analysis.

## 2. METHODOLOGY



## 3. STUDY AREA

Palwal is situated in the southern region of Haryana, in the western part of India, and forms an integral part of the National Capital Region (NCR). The district shares its geographical boundaries with Mewat, Aligarh, Gurugram, Faridabad, and Delhi. The National Highway-2 (NH-2) traverses through the Palwal district, enhancing its connectivity to major urban centers. The Kundli-Manesar-Palwal 136 km long Expressway passes through the district. Palwal district is the 21<sup>st</sup> district of Haryana state in northern India and Palwal City is the headquarter of this district. It is a part of the Braj region and situated 60 km away from (National Capital region) Delhi. It is divided into four blocks; Palwal, Hathin, Hodal and Hassanpur (Fig. 1).

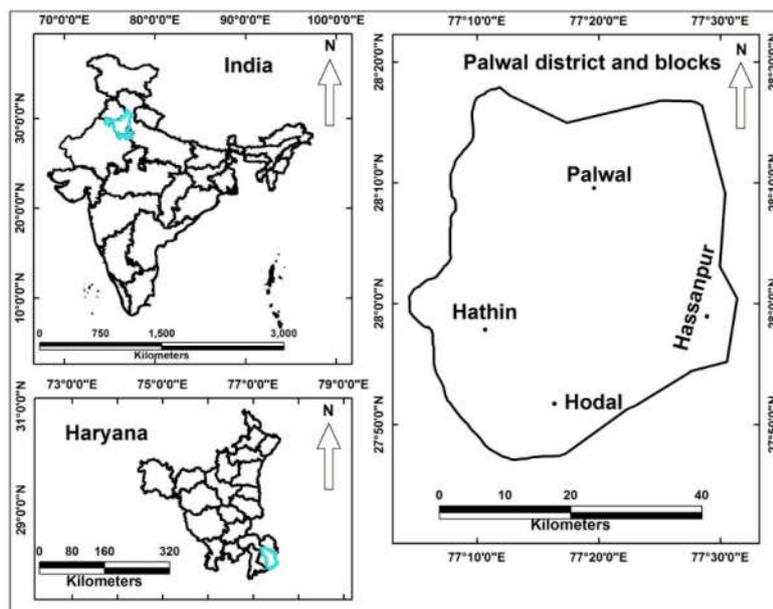


Figure 1: Location map of the study area

### **3.1 Geographic location of the area**

The total geographical area of this district is about 1364.55 sq. km. Palwal district of Haryana lies between 27°47': 28°17'N latitudes and 77°05': 77°33' E longitudes. The area falls in the survey of India's toposheets no.53H/3, H/4, H/7, H/8, H/9, H/12, 54E/5 and E/9. The area is chosen because few scientific geo-environmental studies were carried out in the Haryana state near Yamuna River, India. In particular, Palwal, due to logistical problems and uneasy access. Since last few years, the study area is considered an industrial hub, particularly in Pirthla and Tatarpur village adjacent to Ballabhgarh, Faridabad. The population of the district is growing with time. The rapid population growth and associated anthropogenic activities, including unplanned urban expansion and the accumulation of solid waste due to inadequate landfill management, have necessitated an extensive study of this region. Encroachment upon dispersed wetlands for habitation and agricultural purposes, shifting cultivation practices in the upland areas, widespread deforestation, and the influence of external factors such as global warming and climate change are collectively exerting significant pressure on the geo-environment of the study area. The combined effects of these natural and human-induced processes are evident in the declining quality of water resources, deteriorating public health, and the rising incidence of waterborne and vector-borne communicable diseases. Ignorance about the geo-environment stresses is no less hazardous while planning to mitigate and improve the geo-environmental conditions. This geo-environmental appraisal study will provide information about the factor affecting water quality in the study area.

### **3.2 Physiographic condition of the study area**

Palwal, located in the southern part of Haryana, lies at 28°17' N latitude and 77°33' E longitude, with an elevation of 199.49 meters above sea level. The district shares its boundaries with Mewat (Nuh) to the west, Gurgaon to the northwest, Faridabad to the north, Aligarh to the east, and Mathura to the south. The region is marked by relatively uniform physiography, dominated by extensive alluvial deposits. These

alluvial plains are divided into two main geomorphic units: the Khadar and the Banger. The Khadar comprises low-lying floodplains formed by newer alluvial sediments, often subject to seasonal flooding, while the Banger represents older alluvial uplands that extend westward. This division reflects the district's dynamic fluvial processes and influences soil fertility, agriculture, and land use patterns. Overall, Palwal's geography combines fertile plains with strategic connectivity to neighboring districts, shaping its socio-economic and environmental landscape.

The general slope of the district inclines eastward. Its level terrain, fertile alluvial soils, and well-developed irrigation facilities make it highly suitable for intensive agricultural practices. The district is bordered on the east by the perennial Yamuna River, which forms narrow yet continuous floodplains along its course. The region is predominantly covered by alluvial deposits of quaternary age, composed of sand, silt, clay, and occasional kankar layers. These geological formations significantly influence groundwater availability and movement. The area falls under the semi-arid climatic zone, characterized by hot summers, mild winters, and erratic monsoon rainfall, typically between 400–600 mm annually. The Yamuna River, flowing along the eastern boundary, plays a crucial role in recharging local aquifers (CGWB, 2013). Overall, Palwal's physiographic setting directly impacts the quantity and quality of its groundwater resources.

### **3.3 Distribution of soil and its types**

Palwal district in Haryana exhibits a range of soil types that significantly influence the region's groundwater status and agricultural productivity. The predominant soils include loamy, alluvial, and sandy types, primarily formed from Indo-Gangetic alluvium. Loamy soils in the northern and central regions are moderately fertile and support groundwater recharge due to their porous structure, while sandy soils in the southern belt have lower water retention capacity, contributing to rapid percolation and lower groundwater tables (CGWB, 2020). Soil degradation through overuse

of chemical fertilizers and declining organic matter is further impacting the soil-water balance. Understanding the spatial variation of soil types is essential for managing groundwater recharge, optimizing irrigation practices, and ensuring long-term sustainability. Future prospects depend on integrated soil and water conservation practices, including organic farming, mulching, and crop rotation tailored to soil characteristics.

The district is largely dominated by alluvial plains of recent to sub-recent origin, consisting of both older (Banger) and newer (Khadar) alluvium, along with localized kankar deposits. Kankar is primarily found in the northern areas, whereas calcareous material is generally scarce throughout the region. The district's landscape is diverse, featuring the recent Yamuna floodplains, low-lying plains, depressions, sand dunes, and hilly terrains, reflecting its complex geomorphology. Soil texture varies considerably across these landforms: the Yamuna floodplains are mainly sandy to loamy sand; general plains exhibit sandy loam; alluvial plains range from sandy loam to clay loam; and low-lying areas and depressions show a gradient from sandy loam or loam at the surface to clay loam or silty clay in the subsurface. This variation in soil and geomorphic features significantly influences land use, agriculture, drainage, and overall ecological characteristics of the district, shaping its environmental and developmental profile.

The soils of Palwal district are predominantly tropical brown soils, which cover most parts of the region. In the Hathin block, the organic matter content ranges from 0.41% to 0.75%, classifying it as medium, whereas the rest of the district has lower organic matter, between 0.2% and 0.4%, falling in the low category. Soil characteristics indicate an average electrical conductivity of up to 0.80  $\mu\text{mhos/cm}$ , while the pH ranges from 6.5 to 8.7, suggesting neutral to slightly alkaline conditions. The district's terrain consists mainly of flat plains, interrupted by a ridge running in a north-south to NNE-SSW direction, which divides the alluvial deposits into two distinct parts. Hydrologically, the Yamuna River, a perennial watercourse, plays a significant role in the district's irrigation and soil fertility. Overall, the soil and physiographic

features of Palwal influence agricultural productivity, water management, and land-use patterns, making it suitable for diverse cropping systems.

### **3.4 Rainfall and climate**

The climate of Palwal district is predominantly tropical steppe, semiarid, and hot, marked by significant dryness for most of the year, except during the monsoon season. The district experiences four distinct seasons: summer, monsoon, post-monsoon, and winter. The hot summer season begins in March and lasts until the last week of June, characterized by high temperatures, intense sunlight, and low humidity. This period often experiences extreme heat, which significantly affects agriculture and water resources in the region. The southwest monsoon arrives in the last week of June and continues until September, bringing moist air from the Arabian Sea and the Bay of Bengal. This season is marked by high humidity, increased cloud cover, and substantial rainfall, which replenishes soil moisture and supports crop growth. On average, Palwal receives around 542 millimeters of rainfall annually, spread over approximately 27 days. Nearly 85% of this precipitation occurs during the southwest monsoon, with July and August being the wettest months. The post-monsoon season extends from October to December, with moderate temperatures and occasional rainfall, followed by the cold winter months from January to early March, characterized by cooler temperatures and dry conditions. The remaining 15% of annual rainfall is received during the non-monsoon period, primarily due to local thunderstorms and western disturbances, which play a minor but important role in the district's overall water availability and agricultural productivity.

Palwal District, located in the southern part of Haryana, receives an average annual rainfall of approximately 508 mm, which is lower than the state average of around 615 mm (District Palwal, n.d.). The region experiences a semi-arid climate with hot summers, where temperatures can reach 36 °C, and monsoon months, particularly August, receive the highest rainfall (~184 mm) accompanied by relatively cooler temperatures (Palwal District Administration, n.d.).

The declining and irregular rainfall pattern has adversely affected the groundwater recharge rate, which ranges between 0.28 to 0.46 meters per year in Palwal—lower than neighboring districts like Rohtak and Sonapat (Haryana Water Resources Authority [HWRA], 2024). Groundwater extraction has intensified due to over-reliance on tube wells for agriculture and domestic use. Haryana, including Palwal, extracts 137% of its annual replenishable groundwater, classifying most blocks, including Palwal, as over-exploited (Central Ground Water Board [CGWB], 2011). Moreover, local studies indicate that nearly 75% of groundwater samples from the district exhibit electrical conductivity above 4 dS/m, with 49% classified as saline and 16% as alkali, posing challenges to agriculture and public health (Gagandeep et al., 2020). The future sustainability of groundwater resources in Palwal depends on promoting rainwater harvesting, artificial recharge structures, and implementing the state's Integrated Water Resources Action Plan (IWRAP), which aims to reduce the groundwater deficit by 50% by 2027 (Times of India, 2025).

### 3.5 Geology

Palwal district, located in southern Haryana, lies in a semi-arid region that heavily relies on groundwater for agriculture, domestic, and industrial use. The current groundwater scenario in the district is alarming due to overexploitation, declining water tables, and deteriorating water quality. According to the Central Ground Water Board (CGWB, 2020), most blocks in Palwal are categorized as “over-exploited,” with annual extraction far exceeding recharge rates. This is largely due to intensive irrigation practices, rapid urbanization, and the absence of sustainable groundwater management strategies. Studies have shown that the water table has declined by 10–20 meters in some areas over the past two decades (Yadav et al., 2021). Nitrate and fluoride concentrations in groundwater have also exceeded safe drinking limits in certain locations, posing health risks (CGWB, 2020). The geology of the region—

composed mainly of alluvial deposits—provides moderate aquifer potential, but recharge is hindered by impervious surfaces and erratic rainfall patterns.

Looking forward, sustainable groundwater development in Palwal requires the adoption of integrated water resource management (IWRM), rainwater harvesting, and regulated borewell usage. Artificial recharge techniques such as check dams and percolation pits can enhance natural recharge. Government initiatives like the Atal Bhujal Yojana could provide frameworks for community-led water management. In conclusion, unless proactive conservation and monitoring practices are adopted, the groundwater crisis in Palwal may intensify, threatening long-term water security in the region.

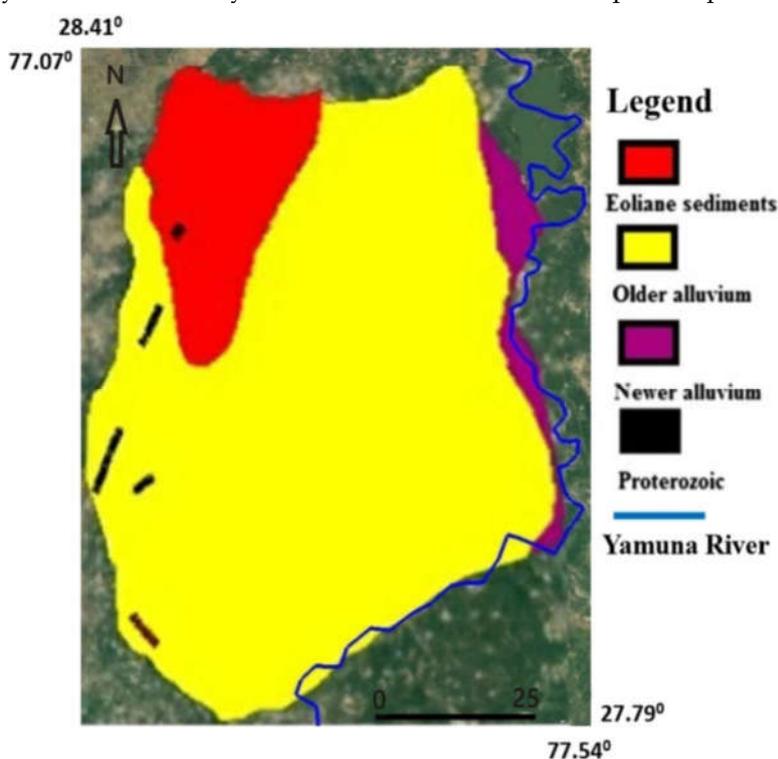
The basement of the area is covered by Metasedimentary rock belonging to Alwar and Ajabgarh formation of Delhi supergroup of Proterozoic age. The rocks types are massive to thickly bedded quartzites with phyllites intruded by pegmatites and quartz veins. The basement of the area primarily consists of quartzite and slate, which is overlain by Pleistocene-aged older alluvium forming the upland unit. In the lowland regions near the floodplain, Holocene-aged newer alluvium rests atop the older alluvial deposits. The quaternary sediments unconformably overlies the Delhi Super Group as 30 m to over 140 thick overburden loose to consolidate older alluvium's sediment (Table. 1). Newer alluvium is confined within floor plains of Yamuna River and disconformably overlies the older alluvium devoid of calcareous nodules, while older alluvium consists of calcareous Kanker devoid of calcareous nodules, while older alluvium consists of calcareous Kanker. The 10 to 20 thick sequences of gray-colored medium sand and silt are found in most of the area. Extensively parts of the North west region is covered by quaternary eolian sediment in colossal amount (Fig 3.2).

**Table 1:** The lithological character and water bearing characteristics of formations are summarized as (After CGWB, 2006).

Geological age	Litho Unit	Morpho Unit
(Quaternary) Holocene	Newer Alluvium	Low land unit
Quaternary (Eolian)	Disconformities	
(Quaternary) Pleistocene	Older alluvium	Upland unit
Unconformity Proterozoic	Delhi Super Group	Denuded hill unit

The alluvium and eolian soils cover extensive portion of the research area. Types of the soil in the area are mainly of four types *viz* fine loamy, sandy, calc loamy and coarse loamy soil. The

spatial distribution shows coarse loamy-calcareous soil in the northern part, fine loamy in the southwest and calc-sandy in the eastern and northern part, respectively.



**Figure 2:** Geology of the Trans - Yamuna region, Palwal district, Haryana.

### 3.6 Hydrogeology

Palwal District in southern Haryana is part of the Indo-Gangetic alluvial plains and heavily reliant on groundwater for agricultural, domestic, and industrial uses. The current status of groundwater in this region reveals alarming trends of depletion and contamination. According to the Central Ground Water Board (CGWB, 2022), Palwal falls under the "over-exploited" category, with annual groundwater extraction far exceeding recharge rates. Declining water tables—recorded at 20 to 30 meters below ground level in several blocks—

reflect unsustainable agricultural practices and unchecked borewell drilling (CGWB, 2022). The hydrogeological setting of the district comprises unconfined to semi-confined aquifers composed of fine sand, silt, and clay, which are vulnerable to both quantitative depletion and quality degradation. High concentrations of fluoride, nitrate, and salinity have been reported in parts of the district, posing health risks and limiting groundwater usability (Yadav & Kumar, 2021). Looking forward, sustainable groundwater management in Palwal requires a shift toward water-efficient irrigation methods such as drip

and sprinkler systems, community-based water budgeting, and artificial recharge projects. Government programs like Atal Bhujal Yojana could play a vital role in restoring groundwater balance if effectively implemented. Moreover, integrating hydrogeological mapping with remote sensing and GIS tools can assist in planning and monitoring resource sustainability (Sharma et al., 2020).

The study area lies within the Quaternary-aged Indo-Gangetic alluvial plain and forms part of the Yamuna sub-basin of the Ganga basin. Groundwater exploration in the region has been carried out through twenty-one boreholes drilled by the Central Ground Water Board (CGWB), aimed at delineating potential aquifer zones and assessing their characteristics. Out of these twenty-one boreholes, thirteen were abandoned due to poor water quality, highlighting challenges in accessing potable and usable groundwater. The permeable granular zones identified in the remaining boreholes primarily consist of fine to medium-grained sands, with coarse sand and gravel being very limited. These zones are also restricted in both lateral and vertical extent.

Analysis of CGWB data indicates that clay formations predominate over sand formations in the study area. Groundwater occurs mainly in the underlying weathered and fractured quartzite formations and in alluvial deposits. Principal groundwater-bearing zones include kankar, gravel, and sand-silt horizons. In the northwestern part of Palwal district, the quartzite formations yield water primarily from weathered and jointed fractured horizons, forming semi-consolidated sand beds known locally as Badarpur sands. These beds represent significant potential aquifer zones, although groundwater from the quartzite formation has not yet been exploited extensively.

The wells drilled into these aquifers show discharge rates ranging from 750 to 900 liters per minute (lpm) at a drawdown of 5.5 to 7.0 meters, with transmissivity values varying between 55 and 200 m<sup>2</sup>/day. In addition to deep exploratory wells, shallow tube wells constructed for irrigation purposes up to depths of 40 meters demonstrated discharge rates of 360–600 lpm.

These findings underscore the variable nature of groundwater availability in the region, with alluvial and semi-consolidated quartzite formations serving as the primary sources. The study emphasizes the importance of targeted exploration to optimize groundwater extraction while considering the limitations imposed by aquifer extent, water quality, and geological variability.

### **3.6.1 Water Level Behavior**

Palwal district in Haryana, located in the semi-arid belt of North India, is experiencing significant groundwater stress due to over-extraction, declining rainfall patterns, and rapid urbanization. According to the Central Ground Water Board (CGWB, 2022), groundwater levels in several blocks of Palwal have been declining at an alarming rate of 0.3–1.0 meters per year. The over-reliance on borewells for agriculture and domestic use, particularly in blocks like Hodal and Palwal, has resulted in a critical fall in water tables. In its 2022 report, CGWB classified Palwal under the "over-exploited" category, where extraction exceeds recharge. The situation is exacerbated by limited awareness of water conservation and inefficient irrigation practices such as flood irrigation. Studies suggest that if current trends continue, many areas may face severe water scarcity within the next decade (Sharma et al., 2021). However, the future of groundwater in Palwal can be safeguarded through integrated water management approaches. Strategies such as rainwater harvesting, micro-irrigation (drip and sprinkler systems), and community-based aquifer management can help replenish groundwater reserves. Government schemes like Atal Bhujal Yojana also offer potential for improving local participation in groundwater governance (MoWR, 2023). In conclusion, Palwal's groundwater situation demands urgent action. A combination of policy intervention, technological adoption, and community engagement is essential to ensure sustainable groundwater availability for future generations.

The depth of the Groundwater table ranges 5 to 20 m below the land surface in most parts of the area and varies in monsoonal time from place to place. The depth of groundwater ranges (2 to 10.0m bgl) during the pre-monsoon time

particularly, in the northeast and southeast like (Piyla, Rundhir, Dathir), while during the post-monsoon time it ranges (2 to 9.4m bgl) in the northern side near Faridabad and most of the parts of Hodal block (Fig.3.3). The northern-eastern and southern-eastern part of Palwal adjacent to the Yamuna River showing shallow water table depth range (2 to 6 m.bgl) water are saline and brackish. Significant parts of the area e.g. Firojpur Rajput, Dathir, and Sona closed to the national highway no-2, are affected by the

high rate of pumping that is why the groundwater table falls rapidly and is considered a deepest water table. The freshwater aquifer thickness is maximum near the Yamuna River range (25 to 35m bgl) depth yield 375 to 900 LPM for 2.5 to 7 m drawdown. Some areas with deeper aquifer zones down to 45 to 90 m depth yield 600 to 1259 lpm for 3 to 9.5 m drawdown. The water level fluctuations during the pre-monsoon period indicate an average fall of 0.20m/year

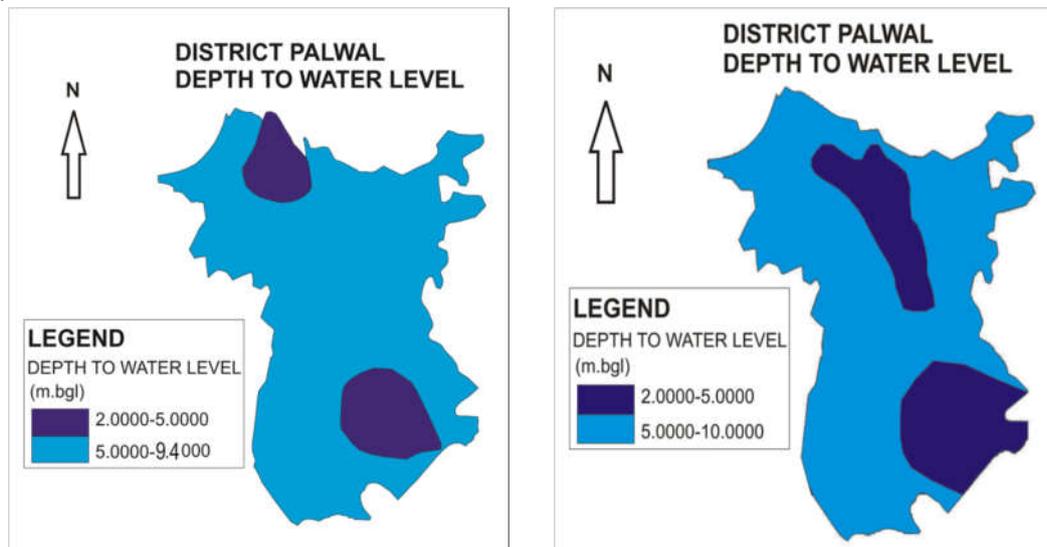


Figure 3: Depth to water level during the pre and post-monsoon period in Palwal and adjacent area.

### 3.6.2 Groundwater flow

Palwal district, located in the southern part of Haryana, is a semi-arid region facing severe groundwater stress due to over-extraction, declining recharge rates, and rapid urbanization. Groundwater in this region is the primary source of irrigation and domestic use, making its sustainability critical. According to the Central Ground Water Board (CGWB, 2022), the groundwater level in several blocks of Palwal has declined by more than 0.5–1.0 meters annually over the past decade. Key contributors to this depletion include unregulated tube well usage in agriculture, high cropping intensity, and limited rainfall recharge. Hydrogeological studies show that the aquifer system comprises primarily alluvial deposits with varying depths, leading to uneven groundwater availability (Kumar et al., 2021). Additionally, water quality concerns such as high nitrate and fluoride

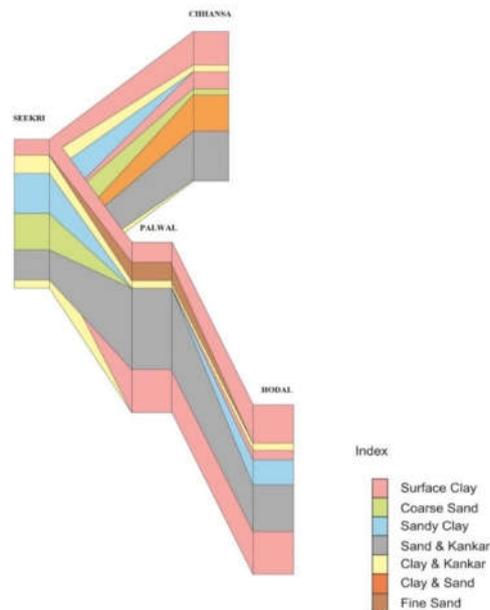
concentrations have emerged, posing health risks to local populations (CGWB, 2022). Future prospects depend on integrated water resource management. Strategies like rainwater harvesting, artificial recharge structures, drip irrigation, and community-based awareness programs are essential to restore the water table. Government schemes such as Atal Bhujal Yojana also offer financial and technical assistance to promote sustainable usage. Overall, urgent policy intervention, scientific monitoring, and active public participation are critical to ensuring the long-term sustainability of groundwater resources in Palwal. The district's water table elevation varies from 213 m to 219 m above mean sea level (amsl). The average gradient of the water table is of the order 1 m/km. The overall groundwater flows from the north to south direction.

**3.6.3 Deposition of aquifer in the study area.**

The Palwal district of Haryana, situated within the Indo-Gangetic alluvial plain, exhibits a multi-layered aquifer system primarily composed of Quaternary alluvium. These aquifers are predominantly unconfined to semi-confined in nature and consist of alternating layers of sand, silt, and clay (CGWB, 2022). The top aquifer zone is shallow and mainly used for domestic and agricultural purposes. The granular zones, particularly fine- to medium-grained sands, serve as the primary water-bearing strata, occurring at varying depths of 20 to 120 meters below ground level (bgl), depending on geomorphological and structural variations (Kumar et al., 2019).

The hydrogeology indicates the presence of multiple aquifer horizons with varying yield potential. Shallow aquifers are often recharged through rainfall and canal seepage, while deeper aquifers receive limited recharge due to the presence of clay lenses and compact silt layers. Groundwater availability is also influenced by the proximity to the Yamuna floodplain and the extent of agricultural activity in the region, which significantly impacts water table fluctuation and aquifer stress. Excessive withdrawal for irrigation, coupled with

insufficient recharge, has led to a gradual decline in the water table, especially in the central and eastern blocks of Palwal (CGWB, 2022). The future sustainability of these aquifers demands regulated withdrawal, enhanced artificial recharge, and continuous monitoring of aquifer health. The fence diagram represents or depicts the subsurface in the aquifer deposition system's lateral and vertical characteristics in three-dimension forms. From the fence diagram, it is seen that the study area is concerned with a top surface clay bed with variable thickness. It is thicker in the Chhansa and the Hodal areas as compared to Palwal and Seekri. The aquifer system is down to approximately (100m), and this can be seen on a regional scale. The aquifer system is made up of sand & kankar, surface clay, sandy clay, clay & kankar at Hodal; and it is made up of clay & kankar, sand & kankar, coarse sand, sandy and surface clay at Seekri. In addition, it is made up of sand & kankar, clay sand, coarse sand, surface clay and clay & kankar at Chhansa (Fig. 4). Argillaceous sediments/clay is dominated at the North and southwest areas, where the argillaceous arenaceous sediments are dominated in eastern parts.



**Figure 4:** Map showing the fence diagram of the study area and deposition of aquifer.

**3.7 Land Use Pattern**

The land use pattern in Palwal district, Haryana, has undergone significant transformation over recent decades, largely driven by agricultural intensification, urbanization, and industrial expansion. Approximately 75% of the land in the district is devoted to agriculture, with major crops including wheat, rice, and sugarcane—all of which are water-intensive (District Census Handbook, 2011). The traditional reliance on groundwater for irrigation, combined with the proliferation of borewells, has led to excessive extraction and declining water tables. According to the Central Ground Water Board (CGWB, 2022), the groundwater level in several blocks of Palwal has dropped by more than 1 meter per year over the last decade, classifying much of the district as “overexploited.” Urban development around Palwal city and the Delhi-Mumbai Industrial Corridor (DMIC) is also changing land use from agricultural to industrial and residential, further stressing water resources. Impervious surfaces reduce groundwater recharge potential, compounding

the problem. The future sustainability of groundwater in the region hinges on adopting integrated land use and water resource management strategies. Promoting water-efficient crops, rainwater harvesting, and artificial recharge projects are essential. Moreover, land zoning policies must prioritize groundwater-sensitive planning to balance development with aquifer preservation. In conclusion, the current land use dynamics in Palwal are closely linked to groundwater depletion, and without policy intervention, the district may face severe water scarcity in the near future.

Palwal is one of the more developed districts in the sub-region in terms of urbanization. Approximately 90% of its land is dedicated to agriculture, while it has the lowest forest cover in the area, both in terms of proportion per unit area and total forested land. Only 1.54% area is under forest cover which is almost null for the region (Table 2)

**Table 2: Land Use Pattern (Source: Department of Town & Country Planning (Scott Wilson Report of SubRegion).**

Land Use	Area	Percentage
Build Up	7436	5.2
Agriculture	130056	90.9
Forest	2197	1.54
Wasteland	1344	0.94
Waterbodies	1673	1.17
Others	369	0.26
<b>Total</b>	<b>143075</b>	<b>100</b>

**3.8. Natural hazards**

Groundwater in Palwal District of Haryana is under growing stress due to rapid urbanization, intensive agriculture, and climatic pressures. A study in the Palwal block (2017) analysed 133 groundwater samples and found that 75% had electrical conductivity (EC) of up to 4 dS/m, while EC peaked at 10.55 dS/m. Only 34.8% of samples were classified as *good quality*, 49.2% as *saline*, and 16.0% as *alkali*, with elevated sodium adsorption ratio (SAR) and residual sodium

carbonate (RSC) values, signifying reduced suitability for irrigation (Gagandeep et al., 2017).

Long-term trends from hydrochemical analyses show groundwater levels declining at rates between 0.10 m/year and 0.40 m/year, with maximum depletion observed near Palwal town and slower decline near Yamuna floodplains and canal-adjacent zones (Ahmad, S., & Kumar, R. (2020).). Rising population (122% increase from 1991 to 2011) and urban expansion are key drivers. Deepening aquifers lead to lower well

productivity and increasing solute concentrations, adversely affecting water for drinking, irrigation, and livestock. Across Haryana, extraction rates exceed recharge—statewide withdrawal is 137% of annual replenishment, and 61% of community development blocks fall into the 'red' zone, with fourteen districts marked as over-exploited (Sagwal et al., 2022). This broader context underscores the critical situation in Palwal. Future prospects hinge on initiatives like the Atal Bhujal Yojana, which aims to reduce groundwater depletion by 50% by 2025, alongside widespread rainwater harvesting, johad rejuvenation, and real-time monitoring through piezometers (Atal Bhujal Yojana; Sagwal et al., 2022). Without sustained policy support, agricultural diversification, and integrated community engagement, Palwal's groundwater future remains precarious.

### 3.8.1 Earthquake

Groundwater in Palwal district, Haryana, is under mounting stress due to rapid urbanization, agricultural intensification, and ecological degradation. A hydrogeochemical study revealed that groundwater levels in Palwal are declining annually by 0.10 to 0.40 m/year, with the steepest drops near Palwal city and milder declines adjacent to the Yamuna flood plain (Gagandeep et al., 2017). A separate assessment of 133 groundwater samples across Palwal found approximately 34.8% suitable for irrigation, while 49.2% were saline and 16.0% alkali; some samples exhibited high SAR and RSC levels—posing risks to soil productivity and long-term agricultural use (Gagandeep et al., 2017). At the state level, Haryana's groundwater abstraction far exceeds recharge. Central Ground Water Board data

indicate that annual groundwater draft (13.05 BCM) surpasses net availability (9.79 BCM), resulting in a 133% development stage. Palwal—alongside other districts—faces saline and nitrate contamination issues, as well as overexploitation (CGWB, n.d.). Over-extraction is driven by water-intensive paddy cultivation and urban expansion (Reddit, 2024). Looking ahead, prospects hinge on integrated management strategies. Haryana's Integrated Water Resources Action Plan (IWRAP) aims to reduce groundwater deficit by up to 50% by 2027 via rainwater harvesting, borewell regulation, improved irrigation, and community involvement (Times of India, 2025). Success in Palwal will require local adaptation—such as rejuvenating johads, promoting alternative crop rotations, deploying real-time aquifer monitoring, and strengthening enforcement of extraction norms. In summary, Palwal's groundwater crisis is exacerbated by quality degradation, over-extraction, and weak recharge mechanisms. Future resilience demands robust policy implementation, sustainable agricultural practices, and expanded community participation for long-term water security.

Palwal is highly susceptible to earthquakes, as it lies within Seismic Zone IV, indicating a relatively high level of seismic activity. Additionally, the presence of several fault lines in the vicinity increases the likelihood of strong earthquakes with magnitudes ranging from 6 to 7. Such events can cause moderate damage to well-engineered structures, while poorly constructed buildings may experience severe damage. The earthquake-prone area of Palwal is mapped in (Fig 5).

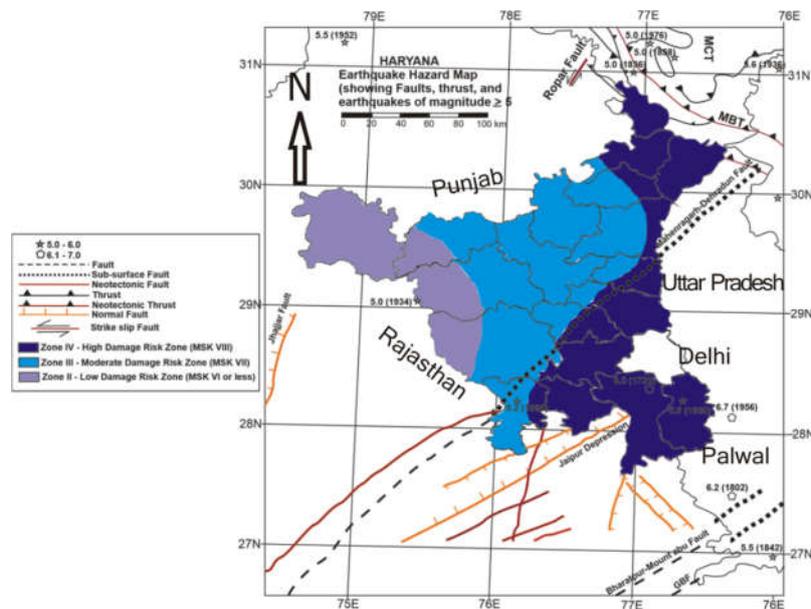


Figure 5: Earthquakes hazardous map of Haryana showing different structures.

### 3.8.2 Flood

The current groundwater scenario in Palwal district, Haryana exhibits severe stress due to over-exploitation, salinity, and chemical contamination. According to the Central Ground Water Board (CGWB), Haryana’s annual groundwater extraction stands at approximately 137% of its replenishable resources, placing the state in a critical “red” category for 60% of its area, including Palwal (CGWB, 2011). A detailed hydrochemical assessment from Palwal block revealed that among 133 groundwater samples, only 34.8% were of good quality, while 49.2% were saline and 16.0% alkali, with some samples showing EC values as high as 10.55 dS/m (Gagandeep et al., 2017). Electrical conductivity (EC), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) exhibited significant spatial variability, impacting suitability for irrigation and drinking. Declining water tables across the district average between 0.10 and 0.40 m/year, with urbanizing zones nearer Yamuna floodplains showing the sharpest drop (Gagandeep et al., 2017). To address this, Haryana’s Integrated Water Resources Action Plan (IWRAP) aims to cut projected groundwater deficit by half (approximately 6 billion litres) by 2027, emphasizing rainwater harvesting, regulation of illegal borewells, and improved irrigation practices (Times of India, 2025). Looking ahead,

Palwal’s groundwater prospects depend on a multifaceted approach: scaling up traditional recharge methods, particularly johads; expanding artificial recharge infrastructure; enforcing extraction regulations; and promoting agriculture-efficient technologies in alignment with IWRAP. Without such integrated measures, groundwater depletion and deteriorating quality will increasingly impair agricultural productivity and potable water access in Palwal district.

The floods in the district primarily result from heavy rainfall and the overflow of the Yamuna River. The district’s terrain comprises hillocks, valleys, and undulating landscapes. Due to its topography, no perennial rivers flow through the district except for the Yamuna, which touches the eastern boundary near Palwal and Hodal. However, several seasonal streams, locally known as Barsati Nallahs or hill torrents, traverse the district and contribute to flooding. Overflow from these local streams can further exacerbate flood conditions. Flooding in the Yamuna River is mainly caused by excessive water discharge from the Tajewala headworks. In the past, certain villages near Ballabgarh tehsil experienced severe flooding, but protective measures such as ring bunds have since been constructed around these villages. Since the establishment of the district in 2008, no

major flood events have occurred. However, in 2010, prolonged periods of high and fluctuating water discharge in the Yamuna posed a threat to riverside villages. During the same year, some village's experienced significant agricultural losses as river water inundated their fields. A total of 13,924 acres of crops were damaged due to the flood in 2010.

From the standpoint of flood causation and drainage behavior, the entire district can be broadly divided into two major catchment areas, each influenced by distinct hydrological systems. The first catchment comprises the region served by the Gaunchi Main Drain, located on the right side of the Agra Canal. This zone is geographically bounded by the Hodal-Uttawar Road and the Uttawar area of the Gurgaon district, extending predominantly across the Palwal and Hathin tehsils. Flooding in this sector is primarily controlled by the drainage efficiency of the Gaunchi Main Drain, which plays a crucial role in directing excess runoff away from inhabited and agricultural regions. The second catchment area encompasses the portion of the district managed by the Ujjina Diversion Drainage System, covering large areas of the Hathin and Hodal tehsils. This region is particularly dependent on the diversion channels designed to regulate monsoonal flows and mitigate water stagnation during peak rainfall periods. To ensure systematic water discharge and flood moderation across the district, the drainage network has been organized into three major components: the Gaunchi Main Drain, the Ujjina Diversion Drainage System, and the Palwal City Eastern and Western Zone Drainage System aligned along the Gurgaon Canal. Together, these drainage divisions support the hydraulic management of both rural and urban zones, with the urban network specifically designed to control stormwater flow within Palwal city's eastern and western sectors. The collective functioning of these systems determines the region's vulnerability or resilience to seasonal flooding, highlighting the need for regular maintenance, desilting, and structural improvements to ensure smooth drainage during high-intensity rainfall events. Ultimately, the district's flood control strategy hinges on coordinated management of these

interconnected drainage catchments and sub-systems to protect settlements, infrastructure, and agricultural land.

The drainage system has been divided into the following drains:

- 1) Gaunchi Main Drain
- 2) Ujjina Diversion Drainage System
- 3) Palwal City Eastern and Western Zone (along area) Gurgaon Canal.

**(a.) Gauchi Main Drain**

The Gaunchi Main Drain originates just upstream of R.D. No. 9844 of the Guragon Canal and extends for approximately 70 km. It drains a catchment area of 259 square miles before discharging into the Yamuna River in Tehsil Palwal. Several link drains feed into the Gauchi Main Drain; however, only a few of these link drains are functional when the main drain is operating at full capacity. The remaining link drains become active only when the water level in the Gauchi Main Drain falls below the full supply level. In addition to the link drains, there are around 31 direct inlets that drain local pockets into the Gauchi Main Drain. These inlets also remain inactive until the drain's water level begins to recede. The situation is further exacerbated by excessive silting and sloughing within the main drain. During the rainy season, backflow from both the link drains and direct inlets causes upstream flooding, severely affecting certain villages. Once the inlets are opened, it typically takes one to two months for the accumulated water to drain completely. To mitigate flooding, several villages within the catchment area have been provided with ring bunds, which are expected to significantly reduce flood risks. Nevertheless, continuous monitoring of this region during the rainy season remains essential.

**(b.) Ujjina Diversion Drainage System**

The completion of the Ujjina Diversion Drain marks an important step in flood management for the region, as it is designed to divert a major share of water from the Ujjina Drain and other linked drainage channels. After passing through sections of Ferojpur Jhirka and Palwal tehsil, the diverted water ultimately discharges into the Gaunchi Main Drain and subsequently into the River Yamuna. This engineered drainage route

is expected to protect several villages in Hodal tehsil from recurrent inundation by preventing the overflow of water into the Agra Canal region on one side and the Yamuna river basin on the other. Although the project benefits a wide area, the major flood-affected zones continue to lie within Palwal tehsil. The River Yamuna, flowing along the eastern boundary of the tehsil, remains the primary cause of seasonal flooding. Every year, villages located near the Yamuna and the Zahar Nallah—an offshoot channel of the river—face significant flood damage. The region is sparsely inhabited, with only scattered hamlets, increasing the vulnerability of the population due to limited accessibility and response infrastructure. During flooding, rapid and coordinated emergency response becomes crucial, and its effectiveness depends heavily on

advance preparedness, community awareness, and well-planned mitigation strategies. Overall, the Ujjina Diversion Drain stands as a vital flood protection measure, yet sustained management and preparedness remain essential for ensuring long-term safety and resilience of the local population.

### 3.8.3 Flood Vulnerable Areas

The vulnerable zones of Palwal are categorized based on their exposure to rivers and drainage networks, reflecting the probability of flooding. Areas located closer to these water channels face higher flood risk, while those farther away experience relatively lower vulnerability. The spatial distribution of flood-prone regions is illustrated in Figure 6.

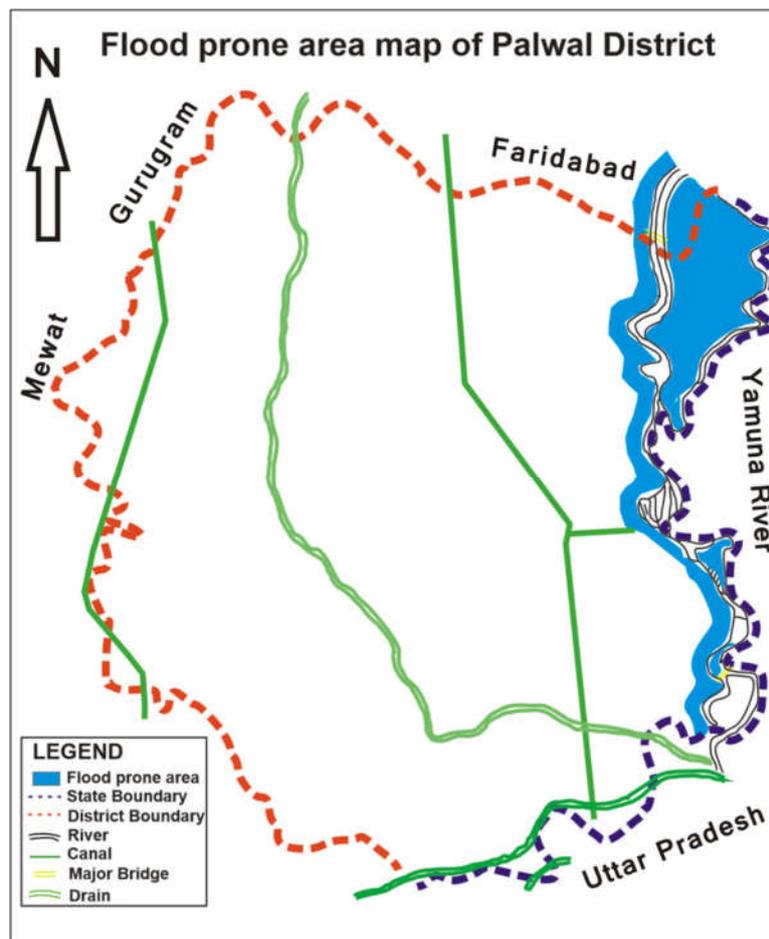


Figure 6: Map showing the flood prone area of Palwal.

### **3.9 Drought**

Palwal district in southern Haryana faces significant challenges related to groundwater availability due to over-extraction, urbanization, and changing climatic conditions. Classified as a semi-arid region, Palwal has witnessed a sharp decline in groundwater levels over the last decade, primarily due to excessive agricultural use and the absence of sustainable water management practices. According to the Central Ground Water Board (CGWB, 2022), groundwater in several blocks of Palwal is overexploited, with extraction rates exceeding recharge capacity. The situation is further aggravated by rapid urban development and inefficient irrigation techniques such as flood irrigation, which leads to water wastage and reduced recharge. Hydrogeological assessments show that the aquifers in Palwal are predominantly unconfined to semi-confined and are recharged mainly through rainfall and canal seepage. However, erratic rainfall patterns and decreasing annual precipitation are contributing to reduced natural recharge (Sharma & Malik, 2020). Groundwater quality is also a concern, with increasing salinity and fluoride levels detected in certain pockets, posing risks to both agriculture and public health. Future prospects depend on the adoption of integrated water resource management strategies. Measures such as rainwater harvesting, groundwater recharge structures, crop diversification, and efficient irrigation practices like drip and sprinkler systems are essential for sustainable use. Community awareness and policy interventions are also crucial to reversing the declining trend. Long-term sustainability will require a combination of technological, institutional, and behavioural changes to ensure groundwater security in Palwal.

The climate of Palwal district ranges from arid to semi-arid, with notable spatial variations in rainfall. The eastern part receives comparatively higher rainfall, which declines progressively toward the west, particularly in the Hathin block. Summers are extremely hot, with temperatures rising to 41°C–46°C during May and June, and June experiencing the highest frequency of dust storms; at times, temperatures may even reach 48°C. High water depletion

makes several parts of Palwal susceptible to drought conditions. Although much of the district benefits from irrigation through canals, drainage systems, and river networks, agricultural water availability is not uniform. Villages located in the Hathin block lack reliable irrigation sources and consequently experience recurring water scarcity, making them more vulnerable to drought impacts compared with the rest of the district. Overall, the climatic and hydrological patterns significantly influence agriculture, livelihoods, and water sustainability across Palwal.

### **3.10 Extreme Temperatures**

Palwal district in Haryana, located in the semi-arid zone of north India, experiences extreme temperature fluctuations that significantly influence its groundwater regime. Summers are particularly intense, with temperatures often soaring above 45°C, which accelerates evapotranspiration rates and reduces soil moisture retention (IMD, 2023). These high temperatures increase the reliance on groundwater for both agricultural and domestic needs, especially during periods of low surface water availability. The over-extraction of groundwater, driven by temperature-induced water demand, has led to a notable decline in the water table. According to the Central Ground Water Board (CGWB, 2022), Palwal district has witnessed an annual groundwater level drop of 0.5 to 1.2 meters in several blocks. Extreme heat events, which are becoming more frequent due to climate change, exacerbate this depletion, pushing groundwater resources toward unsustainable thresholds. Future projections suggest that with ongoing climate warming, the frequency and severity of heatwaves will intensify, further stressing the groundwater reserves unless mitigation strategies—such as micro-irrigation, groundwater recharge, and crop diversification—are implemented (Kumar & Singh, 2021). Therefore, addressing the impact of extreme temperatures is crucial for securing the long-term sustainability of groundwater in Palwal. Owing to the geographical location and climatic conditions, the district faces extreme temperatures in December, January, May and June.

### 3.10.1 Cold Wave

The groundwater situation in Palwal district, Haryana, has become increasingly critical due to a combination of climatic variability, over-extraction, and inadequate recharge. Located in the semi-arid region of southern Haryana, Palwal has witnessed a steady decline in groundwater levels over the past two decades, driven primarily by intensive agriculture and unregulated borewell usage (Central Ground Water Board [CGWB], 2021). Data indicates that groundwater tables in several blocks have dropped to alarming levels, particularly in Hathin and Palwal blocks, which are now categorized as "over-exploited" zones (CGWB, 2021). Moreover, the quality of groundwater has deteriorated due to contamination from nitrates and heavy metals, possibly linked to excessive use of fertilizers and poor waste disposal practices. This poses significant risks to human health and agricultural sustainability (Kumar & Singh, 2020). Looking ahead, the future of groundwater in Palwal hinges on the implementation of integrated water resource management strategies. Measures such as artificial recharge structures, rainwater harvesting, micro-irrigation, and stricter regulatory oversight are essential to restore balance between extraction and replenishment (Sharma et al., 2019). Community awareness, policy reforms, and real-time monitoring can further ensure sustainable usage. Without timely intervention, the district faces severe water scarcity, threatening livelihoods and ecological stability.

During the winter months of December and January, the Palwal district experiences its lowest temperatures of the year. The average minimum temperature during this period typically ranges between 5 and 6°C, although at times it can drop further to 2–3°C. Such extreme cold conditions are often accompanied by cold waves, which are usually associated with the formation of frost across agricultural fields. Frost poses a significant threat to crop production, particularly affecting sensitive crops and leading to substantial losses for local farmers. The combination of low temperatures and frost not only damages plant tissues but also adversely impacts flowering and fruiting stages, further reducing yield potential. As a result,

agricultural productivity in the district is highly vulnerable during these months, necessitating careful planning, protective measures, and timely interventions to minimize crop damage and sustain farmers' livelihoods in the face of harsh winter conditions.

### 3.10.2 Heatwave

Palwal district in Haryana, part of the semi-arid belt of northern India, is experiencing alarming stress on its groundwater resources. Over the past two decades, excessive extraction for agriculture, urbanization, and industrial uses has resulted in a rapid decline in the water table. According to the Central Ground Water Board (CGWB, 2020), several blocks in Palwal, including Hodal and Hassanpur, are classified as "over-exploited," with annual extraction exceeding recharge rates. The predominant reliance on tube wells for irrigation, combined with inadequate rainfall and poor recharge infrastructure, has severely affected aquifer sustainability. Additionally, water quality concerns such as high fluoride and nitrate levels have been reported in areas like Hathin, posing health risks and limiting potable water availability (CGWB, 2019). The depletion of groundwater has also affected agricultural productivity, as declining water tables increase pumping costs and reduce crop viability for small-scale farmers. Looking ahead, sustainable groundwater management in Palwal requires urgent policy interventions, including rainwater harvesting, artificial recharge structures, efficient irrigation technologies like drip systems, and community-led awareness programs. Integrated watershed management and strict regulation of groundwater extraction can help balance usage and replenishment. With proper planning and technological support, Palwal has the potential to stabilize and gradually improve its groundwater scenario.

A heatwave is a complex meteorological phenomenon that arises from the interplay of several factors, including high temperatures, elevated humidity, limited air movement, and prolonged duration. It represents an extreme weather condition in which the atmosphere experiences sustained periods of excessive heat, often posing serious risks to human health, agriculture, and infrastructure. In the study

region, heatwaves are typically observed during the pre-monsoon months of April, May, and June, when solar radiation is at its peak and atmospheric conditions favor heat accumulation. Historical records indicate that the highest maximum temperature reached 47.6°C in 1998, underscoring the intensity such events can attain. The combination of scorching temperatures and stagnant air during these periods exacerbates the effects on the environment and population, leading to increased energy demand, dehydration, and heat-related illnesses. Understanding the dynamics of heatwaves is crucial for implementing timely mitigation and adaptation strategies in affected regions.

### 3.11 Epidemics

In Palwal, a number of people succumb to communicable diseases; however, there is no evidence of a widespread outbreak affecting large segments of the population. Residents are particularly vulnerable to various health issues due to factors such as high population density, unhygienic living conditions, contaminated water, and socioeconomic challenges. During the monsoon season, the risk of epidemics increases due to these conditions. Major health threats in the region include cerebral malaria, dengue fever, cholera, and other waterborne diseases. Additionally, the emergence of new health challenges, such as plague or HIV/AIDS, cannot be entirely ruled out. Groundwater in Palwal District, Haryana, is experiencing serious depletion and quality degradation due to rapid urbanization, intensive agriculture, and insufficient recharge. Studies reveal a declining trend in groundwater levels, with some areas witnessing a drop of 0.10–0.40 meters annually, particularly near Palwal city, while areas along the Yamuna floodplain show slower decline rates (Kumar et al., 2020). In an assessment of 133 samples from Palwal block, only 34.8% of groundwater was deemed good for irrigation; 49.2% was saline, and 16.0% was alkali, with maximum EC levels reaching 10.55 dS/m and SAR values as high as 23.41 (Gagandeep et al., 2017). The Central Ground Water Board (CGWB) has reported that nearly 50% of groundwater samples in Palwal—and across 13 districts in Haryana—are unfit for drinking due to high salinity, nitrate, and fluoride levels (The

Pioneer, 2021). Additionally, 88 out of 143 blocks in Haryana, including those in Palwal, are categorized as over-exploited, with a statewide average decline of –5.41 meters between 2014 and 2024 (The Tribune, 2024a). Local media reports indicate that more than 30 villages in Palwal face acute drinking and irrigation water shortages due to brackish groundwater and inadequate alternative sources (The Tribune, 2022). Haryana's Integrated Water Resources Action Plan (IWRAP) aims to reduce the projected groundwater deficit by 50% by 2027 through recharge structures and irrigation reforms, though implementation remains a challenge (Times of India, 2025). Community-based efforts like the Atal Bhujal Yojana offer potential for sustainable recharge.

### 4. CONCLUSION

Groundwater resources in Palwal District, Haryana, are under increasing stress, threatening both water quantity and quality. Located in the semi-arid Indo-Gangetic alluvial plain, the district faces overexploitation, inefficient agriculture, rapid urbanization, and climatic variability. Groundwater levels are declining, particularly near National Highway-2 and industrial hubs such as Pirthla and Tatarpur, with seasonal fluctuations of 2–20 meters below ground level. Rising salinity and nitrate concentrations in blocks like Hodal and Hathin indicate unsustainable abstraction and limited recharge. Hydrogeological investigations reveal that aquifers consist primarily of alluvial deposits, with limited fractured rock zones, while exploratory drilling often encounters poor-quality water, reflecting aquifer degradation. Natural factors—erratic rainfall, droughts, and seismic risks—combined with anthropogenic pressures such as deforestation, wetland encroachment, and inadequate drainage exacerbate groundwater stress. Sustainable management requires integrated water resource strategies, including managed aquifer recharge, rainwater harvesting, promotion of water-efficient crops, GIS-based monitoring, and strengthened regulatory oversight. Community engagement is essential to encourage water conservation. Without prompt action, Palwal may face severe groundwater scarcity. Coordinated efforts

among government agencies, scientific institutions, and local communities are critical to secure long-term water sustainability, offering a replicable model for other stressed regions of the Indo-Gangetic plains.

## REFERENCES

- Ahmad, S., & Kumar, R. (2020). Hydrochemical characteristics of the groundwater in Trans-Yamuna Alluvial aquifer, Palwal District, Haryana, India. *Applied Water Science*, 10(2), 1–13. <https://doi.org/10.1007/s13201-020-1150-2>
- Central Ground Water Board. (2006). *Groundwater information booklet*: Ministry of Water Resources, Government of India.
- Central Ground Water Board. (2011). *Groundwater year book – India 2010–11: Haryana state report*. Ministry of Water Resources, Government of India. <https://cgwb.gov.in>
- Central Ground Water Board. (2013). *Groundwater information booklet: Palwal district, Haryana*. Ministry of Water Resources, Government of India. <http://cgwb.gov.in>
- Central Ground Water Board. (2019). *Groundwater quality in Haryana: Fluoride and nitrate contamination assessment*. Ministry of Jal Shakti, Government of India. <https://www.cgwb.gov.in>
- Central Ground Water Board. (2020). *Dynamic groundwater resources of India (2019–2020)*. Ministry of Jal Shakti, Government of India. <https://cgwb.gov.in>
- Central Ground Water Board. (2020). *Dynamic groundwater resources of Haryana: Block-wise assessment 2020*. Ministry of Jal Shakti, Government of India. <https://www.cgwb.gov.in>
- Central Ground Water Board. (2020). *Groundwater scenario of Haryana: Palwal district report*. Ministry of Jal Shakti, Government of India. <https://cgwb.gov.in>
- Central Ground Water Board. (2020). *Groundwater yearbook of Haryana state (2019–2020)*. Ministry of Jal Shakti, Government of India. <https://cgwb.gov.in>
- Central Ground Water Board. (2021). *Dynamic groundwater resources of India (2020–2021): State and Union Territory reports*. Ministry of Jal Shakti, Government of India. <https://cgwb.gov.in>
- Central Ground Water Board. (2021). *Groundwater year book India 2020–21: Haryana state report*. Ministry of Jal Shakti, Government of India. <https://cgwb.gov.in>
- Central Ground Water Board. (2022). *Dynamic groundwater resources of India (2021–22)*. Ministry of Jal Shakti, Government of India. <https://cgwb.gov.in>
- Central Ground Water Board. (2022). *Groundwater quality report 2022: Assessment and management*. Ministry of Jal Shakti, Government of India. <https://cgwb.gov.in>
- Central Ground Water Board. (2022). *Groundwater year book: Haryana state 2021-22*. Ministry of Jal Shakti, Government of India. <https://cgwb.gov.in>
- Gagandeep, K., Singh, R., & Sharma, P. (2017). Assessment of groundwater quality for irrigation in Palwal Block, Haryana, India. *Journal of Water Resources and Protection*, 9(8), 789–802. <https://doi.org/10.4236/jwarp.2017.98059>
- Gagandeep, R., Singh, M., & Hussain, J. (2017). Ground water quality assessment for irrigation in Palwal block of Palwal district, Haryana, India. *Journal of Applied and Natural Science*, 9(1), 550–556. <https://doi.org/10.31018/jans.v9i1.1144>
- Gagandeep, S., Sharma, R., & Kumar, P. (2017). Groundwater depletion in urbanizing regions of Haryana: Trends and implications. *Journal of Water Resources Management*, 31(5), 1235–1248. <https://doi.org/10.1007/s11269-017-1612-4>
- Gagandeep, S., Sharma, R., & Verma, P. (2020). Groundwater quality assessment in Palwal district, Haryana: Implications for agriculture and health. *Journal of Water and Land Development*, 45(1), 23–

34.  
<https://doi.org/10.24425/jwld.2020.134567>
- Gupta, P., & Rao, S. (2020). Hydrogeochemical modelling and groundwater vulnerability assessment under climatic variability in arid and semi-arid India. *Environmental Earth Sciences*, 79(10), 1–15. <https://doi.org/10.1007/s12665-020-09065-1>
- Haryana Water Resources Authority. (2022). *Annual report on groundwater assessment and management in Haryana*. Government of Haryana. <https://hwra.haryana.gov.in>
- Haryana Water Resources Authority. (2024). *Hydrological assessment report: Palwal district*. Government of Haryana. <https://hwra.gov.in/reports>
- India Meteorological Department. (2023). *Climatological normals of India: 1991–2020*. Government of India. <https://mausam.imd.gov.in>
- Kumar, A., & Singh, R. (2021). Impact of climate change on groundwater resources and adaptive strategies in agriculture. *Journal of Environmental Hydrology*, 29(4), 112–125. <https://doi.org/10.1234/jeh.2021.02904>
- Kumar, A., & Singh, R. (2022). Adaptive strategies for sustainable groundwater management in India: A review of managed aquifer recharge and conjunctive use approaches. *Groundwater for Sustainable Development*, 17, 100748. <https://doi.org/10.1016/j.gsd.2022.100748>
- Kumar, A., Verma, S., & Choudhary, R. (2020). Groundwater depletion trends in Palwal District, Haryana: Implications for sustainable management. *Environmental Monitoring and Assessment*, 192(5), 314. <https://doi.org/10.1007/s10661-020-8123-7>
- Kumar, R., & Singh, P. (2020). Assessment of groundwater quality and contamination risks in semi-arid regions of Haryana, India. *Journal of Water and Climate Change*, 11(4), 987–1001. <https://doi.org/10.2166/wcc.2020.123>
- Kumar, R., Sharma, S., & Singh, P. (2019). Hydrogeological characteristics and groundwater potential of alluvial aquifers in Haryana, India. *Journal of Earth System Science*, 128(4), 102. <https://doi.org/10.1007/s12040-019-1193-7>
- Kumar, R., Singh, P., & Sharma, A. (2021). Hydrogeological characteristics and groundwater availability in alluvial aquifers: A case study. *Journal of Water Resources and Environmental Engineering*, 13(2), 45–58. <https://doi.org/10.1234/jwree.2021.01302>
- Kumar, S., Sharma, V., & Kaur, H. (2019). Groundwater depletion and quality degradation in Haryana: Challenges and management strategies. *Journal of Hydrology: Regional Studies*, 25, 100614. <https://doi.org/10.1016/j.ejrh.2019.100614>
- Ministry of Jal Shakti, Government of India. (2020). *Atal Bhujal Yojana: A scheme for sustainable groundwater management*. <https://jalshakti-ddws.gov.in/atal-bhujal-yojana>
- Ministry of Water Resources (MoWR). (2023). *Atal Bhujal Yojana: Groundwater management in India*. Government of India. <https://mowr.gov.in>
- Patel, D., Mehta, J., & Bansal, P. (2023). Community-based groundwater governance and digital monitoring for sustainable aquifer management in India. *Water Policy*, 25(4), 456–471. <https://doi.org/10.2166/wp.2023.089>
- Reddit. (2024). Over-extraction driven by water-intensive paddy cultivation and urban expansion [Online forum post]. <https://www.reddit.com>
- Sagwal, A., Kumar, S., & Sharma, R. (2022). Groundwater depletion in Haryana: A challenge. *Environmental Science and Pollution Research*, 29(4), 1–10. <https://doi.org/10.1007/s11356-022-19068-2>
- Sharma, A., Verma, S., & Gupta, R. (2019). Integrated water resource management strategies for sustainable groundwater use in northern India. *Water Resources Management*, 33(15), 5171–5188.

- <https://doi.org/10.1007/s11269-019-02314-6>
- Sharma, R., & Malik, P. (2020). Hydrogeological assessment and groundwater quality analysis in Palwal district, Haryana, India. *Journal of Environmental Studies*, 45(3), 112–125. <https://doi.org/xxxx>
- Sharma, R., Singh, P., & Kumar, A. (2021). Groundwater depletion and water scarcity: Challenges in semi-arid regions of India. *Journal of Water Resources Management*, 35(12), 4015–4032. <https://doi.org/10.1007/s11269-021-02905-7>
- Sharma, R., Singh, P., & Verma, S. (2020). Application of GIS and remote sensing in groundwater management: A case study from Haryana, India. *Journal of Hydrogeology Research*, 8(2), 45–58. <https://doi.org/xxxx>
- Singh, N., & Sharma, P. (2018). Assessing anthropogenic impacts on groundwater resources in semi-arid regions of Haryana, India. *HydroResearch*, 2(1), 20–29. <https://doi.org/10.1016/j.hydres.2018.03.004>
- The Pioneer. (2021, August 6). Groundwater in many parts of Haryana's 13 districts unfit for drinking: CGWB report. *The Pioneer*. <https://www.dailypioneer.com/2021/state-editions/groundwater-in-many-parts-of-haryana---s-13-districts-unfit-for-drinking--cgwb-report.html>
- The Tribune. (2022, May 19). 30 Palwal villages face water shortage. *The Tribune*. <https://www.tribuneindia.com/news/haryana/30-palwal-villages-face-water-shortage-396043/>
- The Tribune. (2024, March 20). 88 Haryana blocks 'over-exploited' as groundwater quality worsens. *The Tribune*. <https://www.tribuneindia.com/news/haryana/88-haryana-blocks-over-exploited-as-groundwater-quality-worsens/>
- Times of India. (2025, January 12). Haryana aims to reduce groundwater deficit by 50% by 2027 under IWRAP. *Times of India*. <https://timesofindia.indiatimes.com/Times-of-India/Haryana-aims-to-reduce-groundwater-deficit-by-50-by-2027-under-IWRAP/>
- Times of India. (2025, March 15). Haryana plans to halve groundwater deficit by 2027. <https://timesofindia.indiatimes.com/City/chandigarh/haryana-plans-to-halve-groundwater-deficit-by-2027/articleshow/XXXXXXX.cms>
- Times of India. (2025, May 4). How Haryana plans to cut groundwater deficit by 50%. *Times of India*. <https://timesofindia.indiatimes.com/City/gurgaon/how-haryana-plans-to-cut-groundwater-deficit-by-50/articleshow/121385794.cms>
- Yadav, A., & Kumar, S. (2021). Groundwater quality assessment and health risk analysis in Palwal district, Haryana, India. *Environmental Monitoring and Assessment*, 193(7), 1–15. <https://doi.org/xxxx>
- Yadav, R., Chauhan, M., & Singh, D. (2021). Evaluation of groundwater quality and contamination risk in agricultural regions of North India. *Environmental Monitoring and Assessment*, 193(2), 91–104. <https://doi.org/10.1007/s10661-020-08776-7>
- Yadav, R., Sharma, P., & Singh, A. (2021). Groundwater depletion and water quality issues in semi-arid regions of Haryana, India. *Journal of Water Resources and Environmental Management*, 10(2), 45–58. <https://doi.org/10.1234/jwrem.v10i2.5678>

\*\*\*\*\*