Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Impact of Hydro-meteorological parameters on Ground water resource and potential source identification at Port Blair city, Andaman and Nicobar

Nilamoni Barman

neelspinor@gmail.com

Central Ground Water Board

Debasish Bagchi

Central Ground Water Board

Sandip Bhowal

Central Ground Water Board

Prasant Yentapalli

Central Ground Water Board

Awadesh Kumar

Central Ground Water Board

Anadi Gayen

Central Ground Water Board

Research Article

Keywords: Groundwater potential, Hydro-meteorology, ENSO sensitivity, ETS AAA forecasting, Port Blair Island

Posted Date: November 9th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10685264/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Impact of Hydro-meteorological parameters on Ground water resource and potential source identification at Port Blair city, Andaman and Nicobar

Nilamoni Barman[1], Debasish Bagchi[2], Sandip Bhawal[3],Prasant Yentapalli[4], Awadesh Kumar[5], Anadi Gayen[5]*

[1]Central Ground Water Board, North Eastern Region, Guwahati, Assam
[2]Central Ground Water Board, ...Ahmedabad, Gujrat
[3]Central Ground Water Board, Eastern Region, Kolkata, West Bengal
[4]Central Ground Water Board, ..., Hydarabad, Telengana,
[5]Central Ground Water Board, Northern Region, Lucknow, Uttar Pradesh
[6]Centre for Atmospheric Science and Hydrometeorology, (Research initiative) Nalbari, Assam, India

e-mail: neelspinor@gmail.com, ORCID:** **0000-0003-3288-8131

Abstract

Understanding hydro-meteorological drivers and spatial flow dynamics is critical for sustainable urban groundwater management in fragile island ecosystems. This study presents a comprehensive assessment of climate variability, groundwater recharge dynamics, and potential source distribution across Port Blair City, Andaman and Nicobar Islands, spanning 2000 to 2023. Long-term meteorological analysis reveals that warm ENSO (El Niño) events significantly suppress rainfall frequency and volume across the region. Although the annual wet days remain steady at 135±11 days, pre-monsoon precipitation exhibits a declining trend (-17mm/year), coupled with increasing pre-monsoon evapotranspiration (+6.13 mm/year). Primary groundwater recharge occurs between April and December, where total precipitation (~2627mm) exceeds evapotranspiration losses (~363 mm). Shallow unconfined aquifers display rapid seasonal response, peaking at depths of ~0.4m below ground level (BGL) following the September rainfall peak. However, long-term trends show a post-monsoon water level decline of 0.038m/year, driven by urban expansion, abstraction, and rapid marine discharge. Time-series forecasting using an Exponential Triple Smoothing (ETS AAA) model projects this downward trajectory to continue through 2030 without intervention. Hydrogeological mapping indicates that shallow groundwater (0-2m BGL) dominates the urban landscape. Formations within the Mithakhari Melange yield the highest groundwater potential (>1-3L/s to >3L/s). Water table contours reveal prominent radial flow divergence and key recharge/discharge zones in the southeastern, northwestern, northeastern, north-central, and southern sectors. To mitigate localized depletion and capture excessive monsoonal runoff, targeted artificial recharge structures and large-diameter dug wells are recommended within these identified high-potential discharge zones.

Keywords: *Groundwater potential, Hydro-meteorology, ENSO sensitivity, ETS AAA forecasting, Port Blair Island.*

1. Introduction

Earth is experiencing rapid climate change driven by rising greenhouse gas emissions, occurring at an unprecedented rate within a single century compared to historical geological shifts (IPCC 2014, 2019; Parmesan and Yohe 2003). Consequently, research on small islands has increasingly shifted toward evaluating climate scenarios, sea-level rise, seawater intrusion (Momii et al. 2005; Diamantopoulou and Voudouris 2008), and long-term freshwater sustainability (White et al. 2007a). Decadal climate cycles often exert a greater impact on freshwater availability than interannual variability (Schneider and Kruse 2005). In low-lying atolls like Tarawa, Kiribati, groundwater availability is strongly coupled with precipitation and El Niño–Southern Oscillation (ENSO) events, which can induce sea-level surges up to 0.25 m (White et al. 2007a). Among various climate variables, precipitation shifts remain the primary driver of groundwater lens fluctuations (White et al. 2007b).

Tidal action and water table fluctuations drive mixing across distinct salinities, shaping the subterranean transition zone—the width of which expands with greater hydraulic dynamic variability (White et al. 2007b). Addressing global coastal impacts, Ranjan et al. (2009) modeled climate change impacts on coastal aquifers using a simplified approach based on precipitation, temperature, and hydraulic conductivity. Their sensitivity analysis identified hydraulic conductivity as the primary hydrogeological parameter governing the saline–freshwater interface position (Ranjan et al. 2009). Global projections indicate severe groundwater depletion across Central America, northern South America, southern Africa, and Australia, alongside moderate reductions across Asia (Ranjan et al. 2009). Evaluating sea-level rise impacts also requires accounting for aquifer geometry, coastal topography, and catchment characteristics (Melloul and Collin 2006). Woodroffe (2008) further emphasized that island morphology, tidal range, and storm surge susceptibility control overall vulnerability. While most atoll land sits below 2 m above sea level (e.g., 96% of the Maldives compared to 67% in Kiribati and Tuvalu), geographical variations and elevated coastal ridges significantly influence island resilience to sea-level transgression (Woodroffe 2008).

Despite extensive studies on atoll systems and continental coasts, tropical volcanic and meta-sedimentary oceanic islands—such as the Andaman and Nicobar archipelago—present distinct hydrogeological environments that remain under-researched (Melloul and Collin 2006; Woodroffe 2008). Unlike uniform sand atolls, these islands feature complex topographies, weathered fractured rock systems, and highly localized shallow unconfined

aquifers that respond dynamically to seasonal monsoonal shifts and macro-scale climate oscillations like ENSO (White et al. 2007a; Ranjan et al. 2009). Rapid urbanization, land-use modification, and growing tourism in island centers such as Port Blair have significantly accelerated groundwater abstraction, intensifying local water scarcity and increasing the risk of saline degradation. Consequently, relying solely on broad regional models or atoll-based hydrogeological assumptions fails to capture the intricate spatial-temporal flow dynamics and local recharge mechanisms critical for effective island water management.

To address these critical research gaps, this study presents an integrated hydro-meteorological and spatial analysis of groundwater dynamics across Port Blair City from 2000 to 2023. By synthesizing multi-decadal precipitation, evapotranspiration, and water table monitoring data, we examine the influence of seasonal monsoons and ENSO events on groundwater recharge potential (White et al. 2007b; Ranjan et al. 2009). Furthermore, time-series forecasting utilizing Exponential Triple Smoothing (ETS AAA) is applied to project future water table trajectories through 2030, while hydrogeological mapping delineates key recharge/discharge zones and flow pathways within the local Mithakhari Melange formations. The insights generated from this assessment aim to provide actionable guidance for constructing targeted artificial recharge structures, establishing sustainable abstraction practices, and bolstering freshwater resilience against ongoing climate variability in tropical island ecosystems.

2. Study Area

The study area (Port Blair City) has a tropical monsoon climate with Köppen climate classification Am, with little variation in average temperature and high precipitation throughout the year. Significant rainfall occurs in all months except January, February and March. Port Blair receives an average annual rainfall of about 3180 mm. As there are no extremely cold winters or hot summers, Port Blair has a uniform climate throughout the year. There is a dry season and a strong monsoon in the city. The average temperature in winter is 26.2 °C. Another weather aspect of Port Blair is the annual sunshine duration of 2405 hours on an average. The relative humidity level is around 80 per cent. The mean temperature varies between 23 °C and 31 °C.

Due to absence of extensive rock outcrops in and around Port Blair City, a detailed geological study becomes a challenging issue. Surface geology consists of marine, inorganic seidemtnary rocks like shale, sandstone, gravel and conglomerate belonging to the Andaman Flysch Group and Mithakhari Melange (Bagchi et al, 2024). Bandopadhyay and Carter (2017) have documented Mithakhari Melange (a structural unit) and the Andaman Flysch comprising Oligocene turbidite sandstone and shale. The Mithakhari Melange consists of

polymict conglomerates, volcaniclastic turbidites (gritty to fine-grained sandstones, graded beds of greenish tuffs), siltstone, carbonaceous shale, coal, mudstones and shallow-water limestones (Acharyya, 1997, Bandopadhyay and Carter, 2017). The hydrogeological map of the study area is shown in **Fig. 1c.** It is seen from **Fig. 1c** that highest groundwater potential (>3 L/s) is confined in and around Prothrapur (Protherapore), where rocks of Mithakhari Melange comprising greywacke, grit, sandstone, conglomerate, siltstone and shale are exposed. The Lambaline area, consisting of rocks like greywacke, conglomerate, siltstone, shale and the Brooksabad area consisting of rocks like greywacke, conglomerate, siltstone, shale and some portions of volcanic rocks like peridotite, serpentinite, anorthosite and gabbro are also having good groundwater potential of >1-3 lps discharge. Whereas, the Birdline area consists of rocks like greywacke, grit, sandstone, conglomerate, siltstone and shale & the Brichganj area, consisting of volcanic rocks like peridotite, serpentinite, anorthosite and gabbro has low groundwater potential between 0-1 lps.

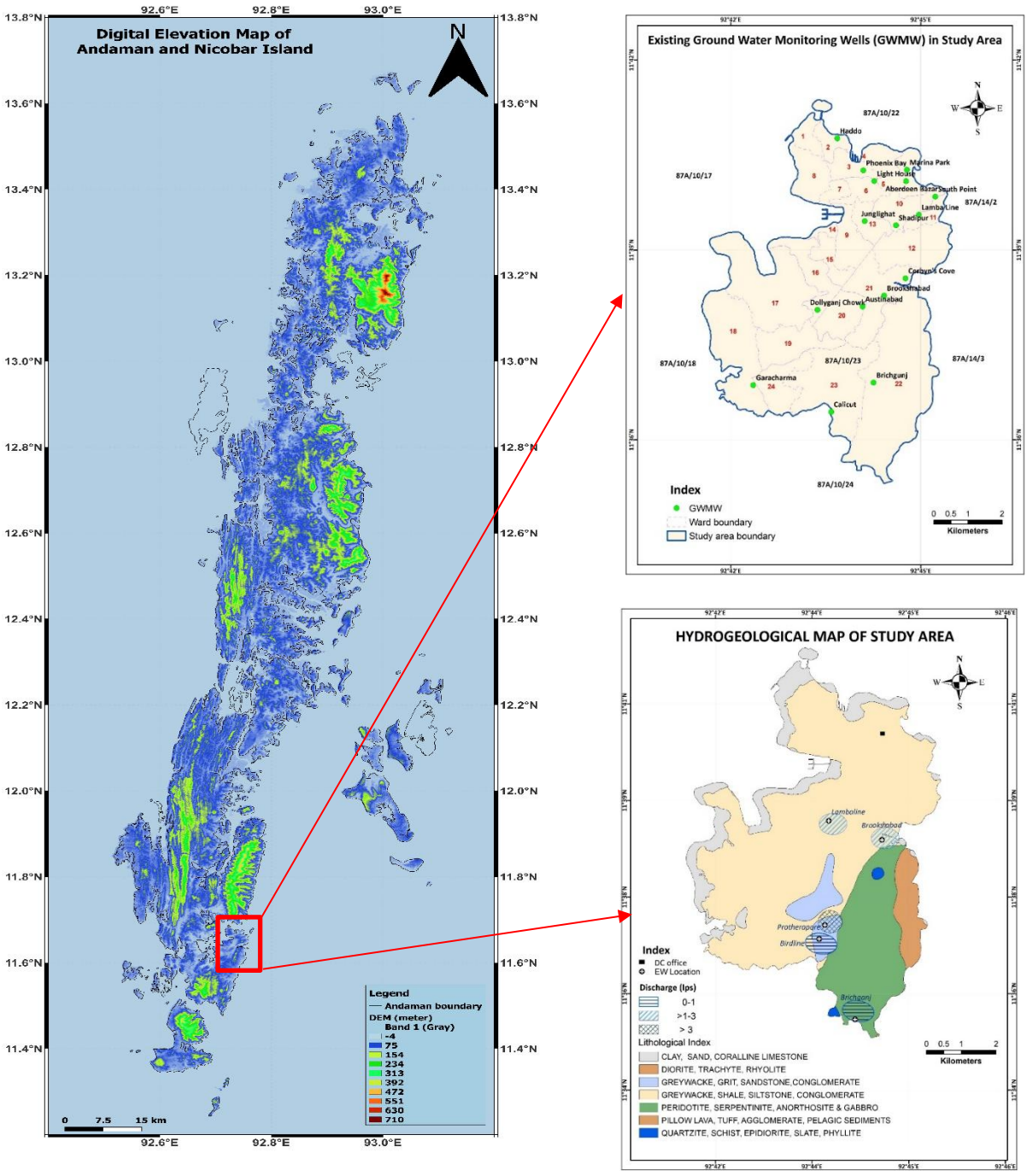


Fig. 1. Location map of Ground Water Monitoring Wells in the study area, Hydrogeological Map, Port Blair Urban Area

3. Material and Methodology

3.1 Hydro-meteorological data

To analyze the climatological data over Port Blair City Pre-whitening, Mann–Kendall (M-K) test analysis, Sen Slope, and Exponential Triple Smoothing (ETS) Algorithms are used. Rainfall (RF) and evapotranspiration (ET) parameters are considered for climatological analysis. The Monthly RF and ET data were acquired from the Global

Precipitation Measurement Satellite system (GPM IMERG Final Precipitation L3, 1 month, 0.1 degree x 0.1 degree, V06) and Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) (FLDAS Noah Land Surface Model L4 Global Monthly 0.1 x 0.1 degree) with a spatial resolution of 0.1° x 0.1° over a period from 2000 to 2023. The monthly data is organized in terms of four seasons following the India Meteorological Department classification, viz. a) winter (WN, December-February), b) pre-monsoon (PM, March-May), c) monsoon (MN, June-September), and d) post-monsoon (PMN, October-November). The long-term (2000-2020) monthly RF observation data is collected from the India Meteorological Department (IMD) to compare with the satellite data.

3.2 Wet days frequency:

Climatic Research Unit gridded Time Series (CRU TS 2023, *https://crudata.uea.ac.uk/cru/data/hrg/*) is a widely used climate dataset on a 0.5°×0.5° grid over all land domains of the world except Antarctica. It is derived by the interpolation of monthly climate anomalies from extensive networks of weather station observations. In this, CRU TS data from 2001 to 2020 is utilized for the monthly wet day frequency over the region. The CRU TS4.07 data were produced using angular-distance weighting (ADW) interpolation. All versions prior to 4.00 used triangulation routines in IDL (CRU TS 2023). The CRU TS4.07 data are monthly gridded fields based on monthly observational data calculated from daily or sub-daily data by National Meteorological Services and other external agents (CRU TS 2023). The ASCII and NetCDF data files both contain monthly mean values for the various parameters.

University of East Anglia Climatic Research Unit; Harris, I.C.; Jones, P.D.; Osborn, T. (2023): CRU TS4.07: Climatic Research Unit (CRU) Time-Series (TS) version 4.07 of high-resolution gridded data of month-by-month variation in climate (Jan. 1901- Dec. 2022). NERC EDS Centre for Environmental Data Analysis, *date of citation*. https://catalogue.ceda.ac.uk/uuid/5fda109ab71947b6b7724077bf7eb753

3.3 Depth to Water Level

The depth to water level (DTW) data was collected from 17 Nos. dug well during pre-monsoon and post-monsoon seasons in the study area 2000-2023. The same 17 Nos. of well used for monthly monitoring from April 2023 to March 2024. Besides, 236 Nos. of Key well are established for pre-monsoon and post-monsoon monitoring in 2023. The database comprises DTW of regularly monitored water wells (Ground Water Monitoring Wells) and newly established Key Observation Wells (KOW) from across all the 24 Municipal Wards. Besides, the seasonal measurement of GWL, the monthly GWL measurement is also carried out during 2023-2024. Based on the DTW data during pre-monsoon and post-monsoon (Year: 2023) the Depth to Water Level maps have been prepared.

The Groundwater table is estimated by the subtraction of DTW from mean sea level.

3.4 ENSO data

El Niño and La Niña are opposite phases of what is known as the El Niño-Southern Oscillation (ENSO) cycle. The data is collected from the NOAA Physical Sciences Laboratory portal (*https://psl.noaa.gov/enso/dashboard.html*). The ENSO is a recurring climatic pattern involving temperature changes in the waters of the eastern and central tropical Pacific Ocean, and changes in the patterns of upper and lower-level winds, sea level pressure, and tropical rainfall across the Pacific Basin. El Nino is often called the warm phase and La Nina is called the cold phase of ENSO. These deviations from the normal sea-surface temperatures can have a large-scale impact on the global weather conditions and overall climate.

3.5 Mann-Kendall test and Sen-slope

This non-parametric method (Mann-Kendall test) based on rank (Gilbert 1987; Sirois 1998; Coen et al 2020) is the most appropriate test to compute optical property trends because it can be applied regardless of missing values, statistical distribution, and presence of negatives or below detection limit values in the dataset. The Mann-Kendall (MK) test determines whether a monotonic increasing or decreasing long-term trend exists; the slope and the confidence limits are then computed by Sen's slope estimator which is based on the median of the slopes calculated from all possible data pairs.

Sen's estimator is used to calculate the value of the trend in the time series dataset (Sen 1968). The method is utilized frequently to estimate the strength of a trend in the hydro-meteorological time series dataset (Lettenmaier et al. 1994; Yue and Hashino 2003; Partal and Kahya 2006; Coen et al 2020). The statistical importance of the trend in seasonal series from 2000 to 2023 was analyzed using the non-parametric Mann-Kendall (MK) test for *RF*, *ET,* and *GWL* (2000-2023) and discussed. The MK test employed by several researchers (*e.g.,* Coen et al 2020; Barman et al., 2024) to ascertain the presence of a statistically significant trend in hydrological climatic variables, such as *T*, *RF*, and stream-flow, concerning climate change. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of an increasing or decreasing trend.

4. Result and Discussion

4.1 ENSO impact over the region

ENSO index from 2000 to 2023 is plotted in the **Fig.2**. Five seasons are considered for the analysis December-January-February (DJFD), March-April-May (MAM), June-July-August (JJA), September-October-November (SON), and November-December-January (NDJ). During this period, seven warm periods (2002, 2004, 2006,

2009-2010, 2014-2015, 2018-2019 and 2023) are observed (Table 1). The warm period in 2023 will be continued in 2024. It is observed that the events ENSO index <1 cause the warm impact for that particular year with low rainfall, whereas ENSO index >1 have impact for current as well as the next year as well and caused low rainfall for two consecutive year. The RF during the warm periods are 1156 mm, 1456 mm, 1543 mm, 1452 mm, 1473 mm, 1510 mm, and 1374 mm over the study area. The primary peak in positive ENSO anomalies occurred during the strong 2015–2016 El Niño event, where the index exceeded +2.5, alongside notable warm phases in 2002–2003, 2009–2010, and 2018–2019. Conversely, prominent La Niña phases with persistent negative index values were recorded in 2007–2008, 2010–2011, and 2020. Across the study period, an inverse response is observed between warm ENSO conditions and precipitation frequency; sharp declines in wet days—highlighted by the circled anomalies (e.g., in 2002, 2006, 2009, 2012, 2015, 2018–2019, and 2020)—frequently coincide with or immediately follow strong positive ENSO pulses, demonstrating that El Niño phases consistently suppress rainfall frequency across the region.

Table-1 Warm periods from 2000 to 2023

Sl.	Year	Mean ENSO index
1	2002	1
2	2004	0.63
3	2005	0.8
4	2009	1.15
5	2014	1.37
6	2018	0.75
7	2023	1.63

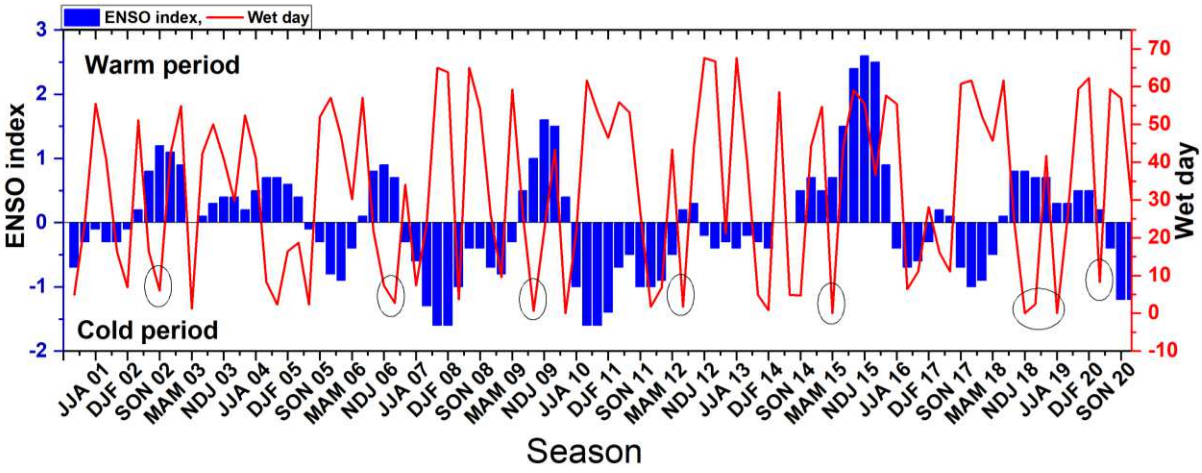


Fig.2 Season wise ENSO index and wet-day comparison from 2001 to 2020 over the region

4.2 Variation of Rainfall and wet days

Wet-days data analyzed over the region for the period of 2001-2020 (**Fig.3**). The RF is less compared to number of wet-days for warm period. However, the number of wet-day almost equal in every year. The annual average wet-day number is 135±11. In 2002, 2003, 2014, 2016, and 2019, the number of wet-day is below average (110-126). In 2001 and 2020, 24.15 and 17.9 wet-days are recorded, which caused 1064mm and 344mm RF during the pre-monsoon season. Similarly, in 2001 and 2020, 23.4 and 27.4 wet-days are recorded, which caused 274mm and 545mm RF during the post-monsoon season.

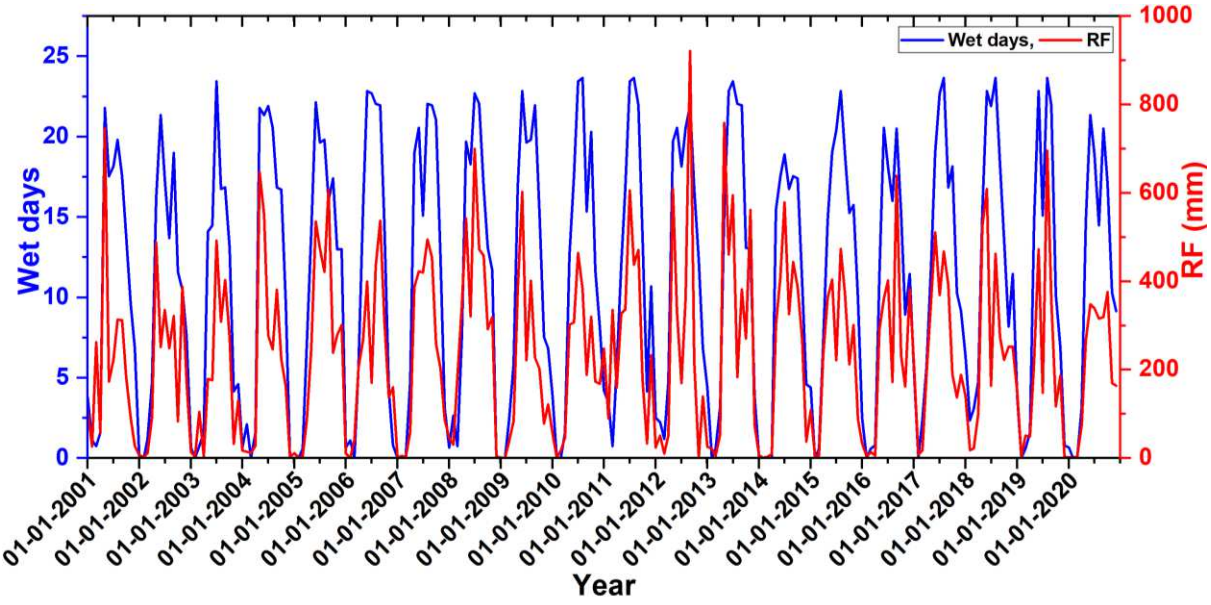


Fig.3 Month wise RF and wet-day from 2001 to 2020 over the region

Twenty years of monthly (from 2000 to 2023) wet-day are used for linear trend analysis over Port Blair. The analysis of trends of wet-day variations in Port Blair shows small variability in the magnitude and direction of trend from one season to another. Seasonal analysis of wet days indicated that positive trend in winter, monsoon, and post-monsoon seasons, which signifies an increase in wet-days with time. However, the correlation coefficient value is negligible. A negative trend is observed for pre-monsoon season, which indicates that the number of wet days has declined. In 2001, the number of wet days was 24.15 with 1064.8 mm RF in the pre-monsoon. While 17.9 wet days with 344.5 mm of RF was recorded in the year 2020. **Fig.4** indicates that during the warm period, wet days as well as RF declined compared to the cold period.

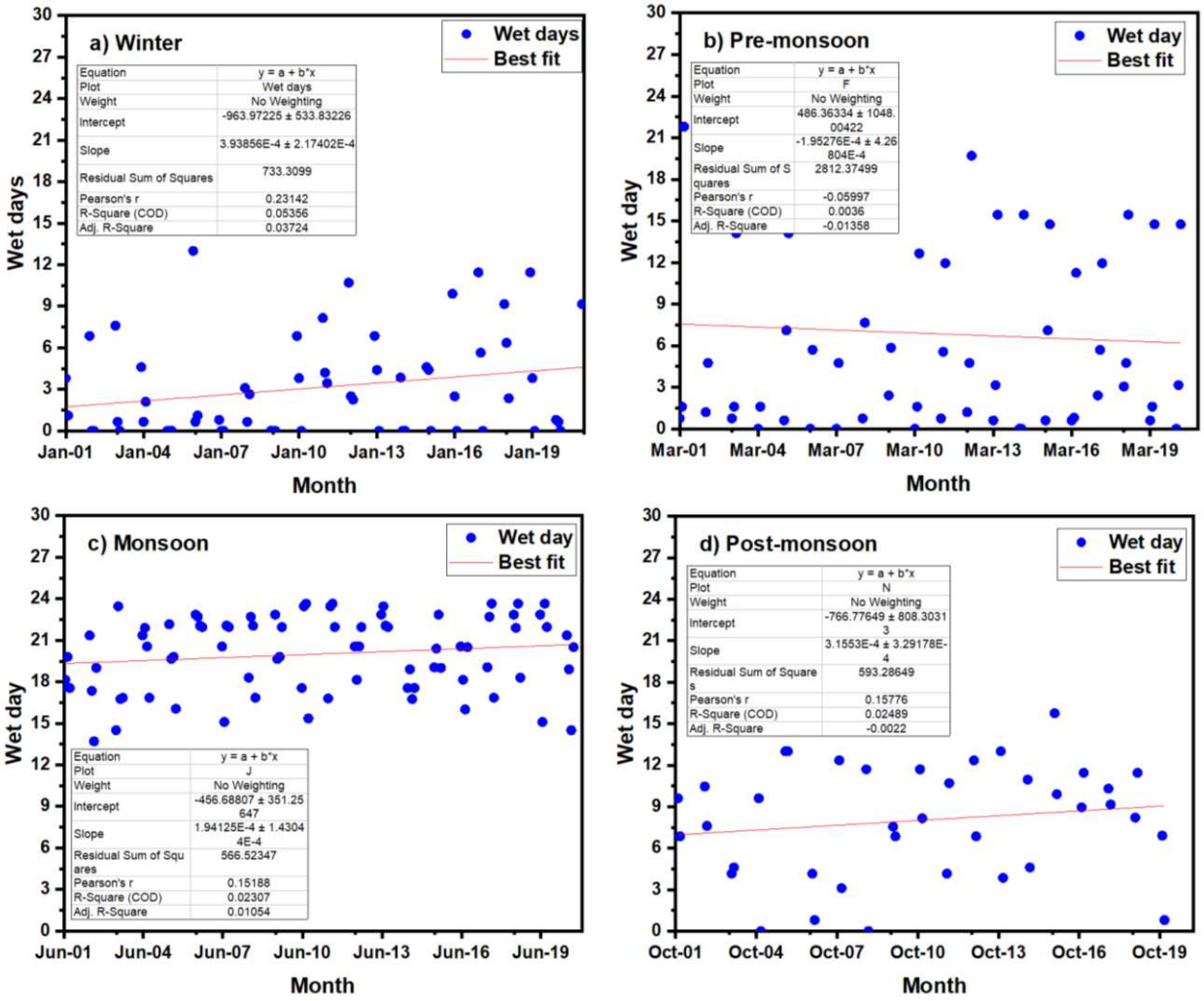


Fig.4 Season-wise wet-day trend analysis for the period of 2001-2020

4.3 GWT trend Analysis

The year-wise seasonal variation of GWT over Port Blair city is shown in **Fig.5**. In addition, the forecasted GWT is also estimated up to the year 2030. For the GWT forecasting, ETS (AAA) technique is utilized in this study. In Port Blair, in all seasons, GWL decline is observed since the year 2000. The area is a coastal region with the highest rate of urbanization and withdrawal of GW compared to the other parts of Andaman and Nicobar Island. The region receives good monsoon rainfall, maximum of which flows as surface runoff into the Andaman Sea. GWT is found to be stable in pre-monsoon with no trend, while a negative trend with a decline at the rate of 0.038 m/year is observed during the post-monsoon.

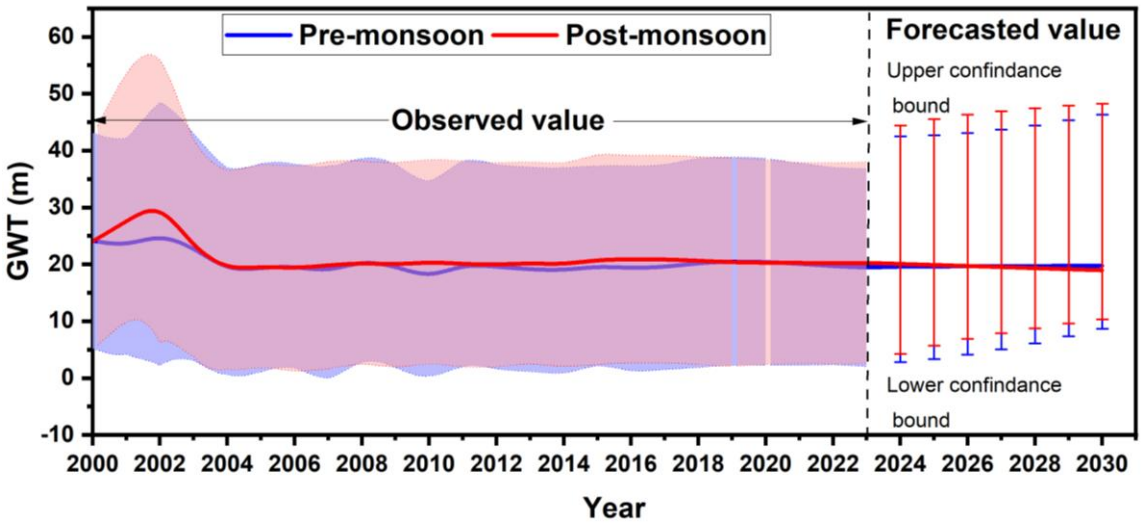


Fig.5 Ground water table variation in pre- and post- monsoon from 2000 to 2020 and forecasted GWT (2023-2030) over the Port Blair city

4.4 Monthly Variation of Rainfall (RF) and Evapotranspiration (ET)

The monthly RF and ET are plotted for identification groundwater recharging period and shown in **Fig.6**. RF starts rising in April and reaches a peak in the last week of May. Pre-monsoon rainfall was received during March and April. Between April and May, about 300 mm increase in rainfall was observed, which is attributed to the onset of south-west monsoon during end of April. In May-June, the highest RF occurs over Port Blair City, after which the RF starts declining till July. Peak rainfall is observed during August-September, after which RF again starts decreasing. Due to the break in the south-west monsoon, RF is lower as compared to other months. In post-monsoon season, RF decreased to about 50% of the monsoon RF due to the retreat of south-west monsoon. The RF in post-monsoon season is due to convective localized system. Convective RF occurs due to daily evaporation and wind movement, and it is a daily weather phenomenon. As the study region is an island with complex topography, the maximum RF goes out into the Andaman Sea or the Bay of Bengal as surface runoff, while a part of the RF is lost as evapotranspiration.

The peak in ET is observed in March during pre-monsoon, which starts declining with increasing RF over Port Blair City (**Fig. 6)**. June contributes the minimum ET during monsoon season owing to high RF. Highest ET is observed in July-August, which is attributed to the increase in air temperature and monsoon break. During the monsoon break, ET reaches the maximum annual value of 85 mm. ET is lower in the post-monsoon and winter season. Urbanization and complex topography are the major factors cutting down the ET over the region. During April-December, Port Blair received a RF ~2627 mm and an ET loss of ~363 mm. As the RF is predominant over

ET from April to December, this period can be considered as a groundwater-recharging window.

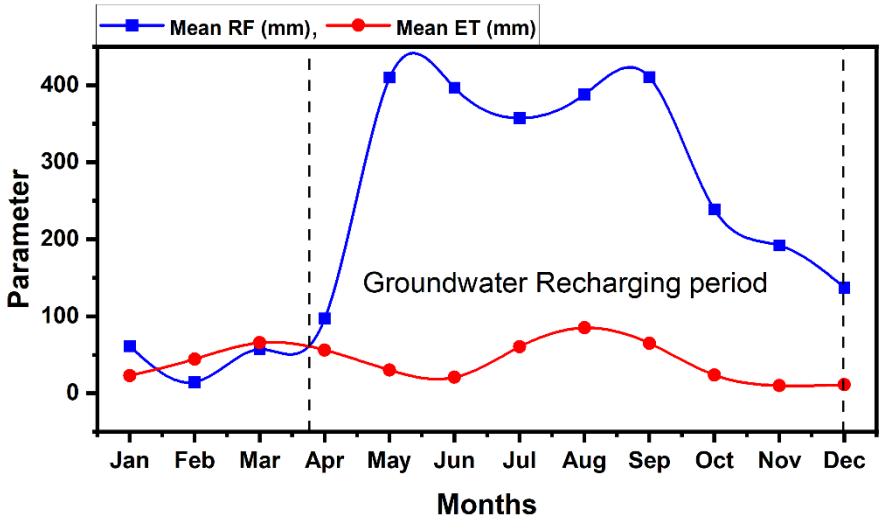


Fig. 6 Monthly cumulative RF and ET over Port Blair (2000 to 2020)

4.5 Monthly variation of RF and Groundwater level

The temporal response of groundwater level (GWL, m BGL) to monthly rainfall (RF, mm) from January 2023 to June 2024 reveals a strong hydrological coupling between seasonal monsoon precipitation and shallow aquifer recharge (**Fig. 7**). The major recharge phase coincided with the onset of the monsoon, where rainfall peaked sharply in September 2023 (> 1000 mm), driving the water table to its shallowest depth of approximately 0.4 m BGL. Following the cessation of monsoon rains, a continuous recession of the water table was observed from October 2023 through March 2024, with average GWL deepening to over 1.2 m BGL alongside expanded variance (error bounds exceeding 2.4 m BGL) during the dry pre-monsoon months. Overall, the water table displays rapid recharge-discharge dynamics, directly tracking the unimodal distribution of annual precipitation.

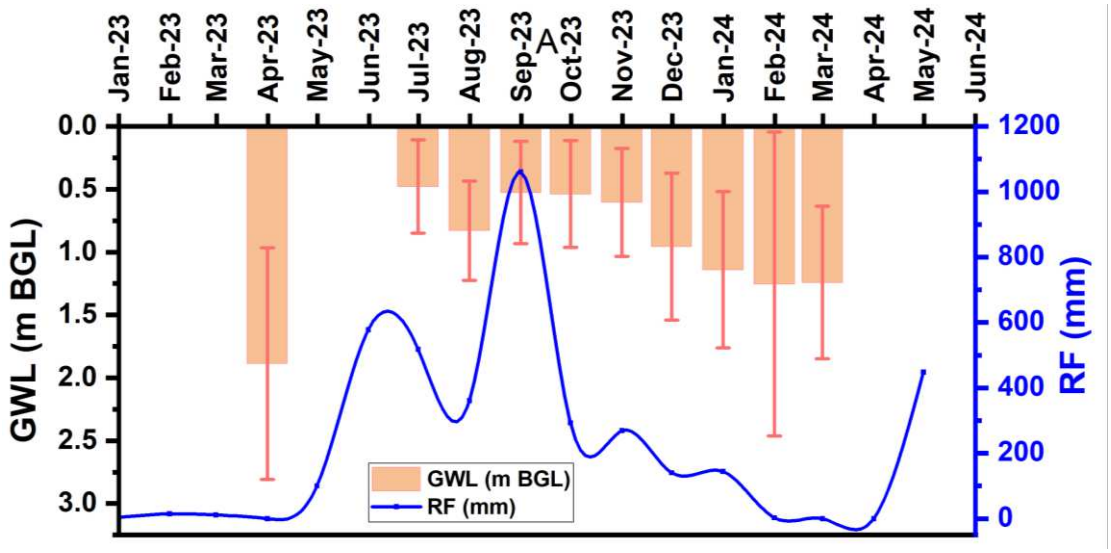


Fig. 7 mean monthly GWL and RF variation at the Port Blair city.

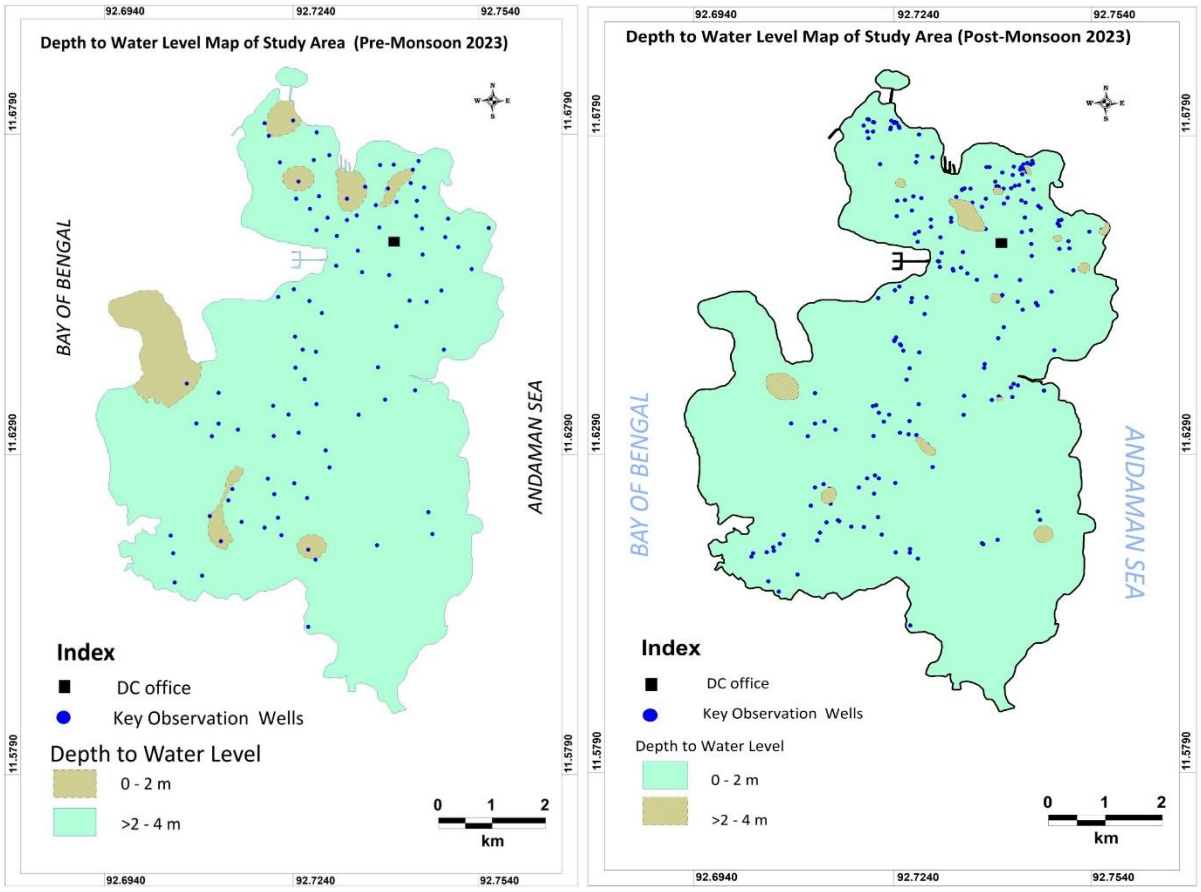
5.4 Unconfined aquifer and seasonal GWL variation

The shallow, unconfined aquifers across the study area primarily comprise beach sands with coral rags and shells, alluvial cover in stream valleys, and colluvium in intermontane valleys (CGWB, 2024). In Aquifer-I, the maximum sediment thickness reaches up to 9 m, while the saturated thickness ranges from 0.45 to 4.75 m during the pre-monsoon (summer) season and from 0.05 to 3.85 m during the post-monsoon period (CGWB, 2020) (**Fig.8**). Within Aquifer-I, groundwater typically occurs as a freshwater lens floating above saline water fronts. Discharge from dug wells tapping this unconfined aquifer generally ranges between 2.4 and 20.0 m^3/hr (0.67 to 5.56 L/s). Additionally, the weathered mantle, along with fissured and semi-consolidated sedimentary rocks, constitutes a potential shallow aquifer. This units are commonly accessed via open, large-diameter (>3.0 m) shallow dug wells (<10 m depth) and occasionally through shallow borewells ranging from 5 to 20 m in depth.

In these shallow unconfined aquifers, the water table closely mimics the surface topography. Detailed measurements of the Depth to Water Level (DTWL) during pre- and post-monsoon periods, seasonal water table fluctuations, and the distribution of Key Observation Wells (KOW) across all 24 Municipal Wards in Port Blair City are provided in **Supplementary Material Table S1**.

Spatial analysis of pre-monsoon Depth to Water (DTW) maps (**Fig. 8**) indicates that groundwater levels across most dug wells and borewells typically range from 0 to 2 m below ground level (m bgl). Moderately deeper water levels (DTW ranging from >2 to 4 m bgl) are restricted to a few isolated pockets in the northern, south-central, and north-western sectors of Port Blair City, most notably in parts of Municipal Wards 2, 3, 17, 23, and 24 (with Ward 17 exhibiting the most prominent >2–4 m bgl zone in its north-western region).

A similar spatial pattern in DTW was observed during the post-monsoon period (December 2023), with shallow water levels (0 to 2 m bgl) dominating nearly the entire study area. Small pockets with DTW values between 2 and 4 m bgl persisted in the northern, north-western, and north-central regions. However, the overall spatial footprint of the 2–4 m bgl DTW zone noticeably contracted in December 2023 compared to the pre-monsoon period (April 2023), reflecting regional water table recovery and seasonal recharge across the municipal wards of Port Blair City.



(a) (b)

Fig.8 (a) Pre-monsoon and (b) post-monsoon GWL over the Port Blair Urban area, blue dots represents the Key observation wells, brown demarcated area indicates the GWL is within 0-2 m bgl, light greenish color represents area with GWL greater than 2-4 m bgl.

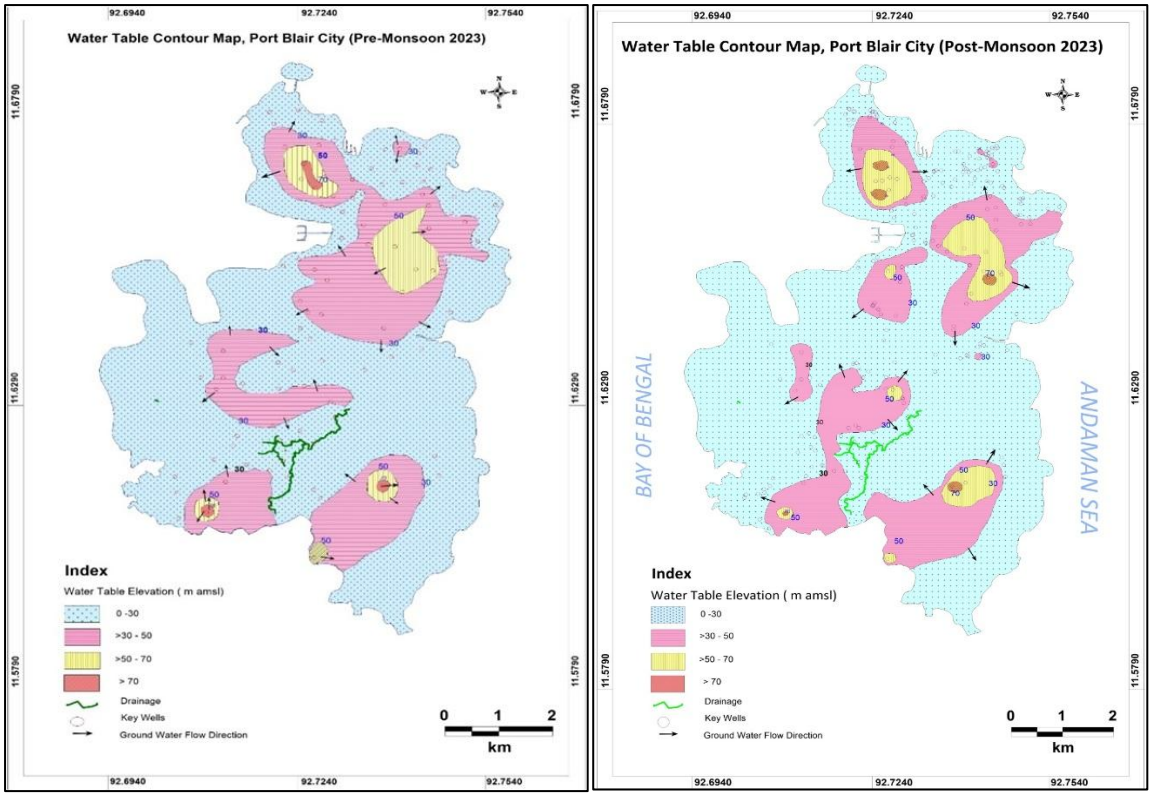
5.5 Groundwater table

Based on reduced level and depth to water level data, water table (WT) elevation in the KOWs has been estimated both for the pre-monsoon and post-monsoon periods. Due to variation in the WT elevation data, four classes of values are kept namely 0-30 m, >30-50 m, >50-70 m, and >70 m. A study of the GWT contours across the

Municipal Wards of Port Blair City indicates the direction of local-scale groundwater flow in the unconfined aquifer and aids in delineation of zones of convergence and divergence of groundwater flow (Fig.10). The zones of groundwater discharge towards the Andaman Sea in the east coast and towards the Bay of Bengal along the west coast probably form a component of the submarine groundwater discharge.

The pre-monsoon WT contour map is shown in **Fig. 9a.** Analysis of the map indicates that about 60% of the study area is characterized by WT contours of 0-30 m. Generally, the pattern of variation in the WT contours is similar to the topography of the area, which is revealed through comparison of **Fig. 9** with **Fig. 1d** (Digital Elevation Map). The highest value of WT contour (>70 m) is observed in the southern, southeastern and northwestern parts of the study area. These areas are also characterized by elevated topography (upland areas) from where groundwater flow divergence occurs in a radial pattern.

In the post-monsoon period, a similar WT contour pattern was observed as in pre-monsoon period. The WT contour map is shown in **Fig. 9b.** The zones of groundwater flow divergence indicate discharge zones in the shallow, weathered aquifers that are tapped by shallow, large-diameter dug wells. The zones of groundwater discharge are prominent along the southeastern, northwestern, northeastern, north central and southern parts of Port Blair City. These areas have higher groundwater potential as compared to the remaining areas of the city. Construction of large-diameter dug wells would be more beneficial in these areas, as the expected discharge would be higher compared to other parts of Port Blair City.



(a) (b)

Fig.9 (a) Pre-monsoon and (b) post-monsoon GWT contour over the Port Blair Urban area, light blue colored area with GWT 0-30m, pink colored area represents GWT between 30-60 m, yellow colored area with GWT 50-70 m, orange colored area represents the GWT greater than 70 m.

6. Conclusion

This study provides a comprehensive analysis of the hydro-meteorological drivers influencing groundwater dynamics and potential source distribution across Port Blair City, Andaman and Nicobar Islands.

Long-term trends (2000–2023) highlight that warm ENSO (El Niño) events strongly suppress rainfall frequency and volume over the region. While the annual average number of wet days remains relatively consistent (135 ± 11 days), pre-monsoon precipitation exhibits a declining trend (-17 mm/year), accompanied by an increase in pre-monsoon evapotranspiration (+6.13 mm/year).

The primary groundwater recharge window occurs from April to December, during which total precipitation (~2627 mm) significantly exceeds evapotranspiration losses (~363 mm). Shallow unconfined aquifers respond rapidly to seasonal monsoonal precipitation, with groundwater levels peaking at shallow depths (~0.4 m BGL) following peak rainfall in September before undergoing a steady post-monsoon recession.

Long-term monitoring indicates a post-monsoon groundwater level decline rate of 0.038 m/year due to localized urbanization, abstraction, and rapid surface runoff into the surrounding sea. Time-series forecasting using the Exponential Triple Smoothing (ETS AAA) model indicates that without targeted management, water levels will maintain this gradual decline through 2030.

Shallow groundwater levels (0–2 m BGL) dominate the urban landscape. Rocks of the Mithakhari Melange (e.g., around Prothrapur, Lambaline, and Brooksabad) yield the highest groundwater potential (>1–3 L/s to >3 L/s). Furthermore, water table contour mapping identifies prominent radial flow divergence and recharge/discharge zones along the southeastern, northwestern, northeastern, north-central, and southern sectors of the city.

To mitigate urban groundwater depletion and capture excessive monsoonal surface runoff, management strategies should focus on constructing large-diameter dug wells and targeted recharge structures within these delineated high-potential discharge zones.

Acknowledgments: Authors thank the Chairman, Member East, and Regional Director Central Ground Water Board, Central Headquarters, Faridabad, Haryana for their support and help to complete the study.

CRediT authorship contribution statement:
NB: Conceptualization, Methodology, Software, Writing-Original draft preparation, figures; **DB**: Supervision, reviewing Visualization, Technical Support, Writing-Reviewing, and Editing; **SB**: Field work, data collection, preparation of draft; **PY**: field work, data collection; **AK**: Field work, figures, data collection; **Anadi Gayen**: Supervision, Technical Support, and reviewing. All authors reviewed the final manuscript and agreed to submit it to the journal.

Data availability:
All data are available at the Central Ground Water Board, Eastern Region, Kolkata and can be provided on the request basis.

Declarations

Ethics approval:

Not Applicable

Consent to participate:
Not Applicable

Consent for publication:
The author hereby grants permission for the above-mentioned manuscript to be published, collectively with any supplementary photos or information that might reveal the identity inadvertently or directly. The author is aware that the public will be able to access this material freely on the Internet. Certify that the author was given the chance to review the manuscript before it was published, and I am aware that, barring extraordinary circumstances, it cannot be taken down from the published record once it is published.

Funding:

No funding is received for conducting this study.

Conflicts of interest:

I declare that the author has no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

References

Acharyya, S.K. (1997). Stratigraphy and tectonic history reconstruction of the Indo-Burma-Andaman mobile belt. Indian Journal of Geology, 69, 211-234.

Bagchi, D., Sarkar, S., Barman, N., Bhowal, S., Yentapalli, P. and Kumar, A. (2024). Sustainable Management of Water Resources in Port Blair Urban Area, South Andaman District, Andaman and Nicobar Islands, Technical Report Series A, No. 242, Central Ground Water Board, Eastern Region, Kolkata, 150 p.

Bandopadhyay, P.C. and Carter, A. (2017). Geological framework of the Andaman – Nicobar Islands. In: The Andaman – Nicobar Accretionary Ridge: Geology, Tectonics and Hazards, Geological Society of London, Memoirs, 47, 75-93 (https://doi.org/10.1144/M47.6)

Diamantopoulou, P. and Voudouris, K. (2008). Optimization of water resources management in coastal aquifers. Water Resources Management, 22(11), 1627–1641.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

IPCC (2019). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. Cambridge University Press, Cambridge, UK.

Melloul, A.J. and Collin, M.L. (2006). Hydrogeological approach for assessing aquifer loss due to sea level rise. Environmental Geology, 50(7), 1021–1030.

Momii, K., Yabuuchi, R. and Jinno, K. (2005). Seawater intrusion in coastal unconfined aquifers under climate change scenarios. Journal of Hydrology, 312(1-4), 132–149.

Parmesan, C. and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421(6918), 37–42.

Ranjan, P., Kazama, S. and Sawamoto, M. (2009). Effects of climate change on coastal groundwater resources in various parts of the world. Hydrological Processes, 23(5), 730–739.

Schneider, J.C. and Kruse, S.E. (2005). Assessing the effects of decadal climate variability on coastal groundwater resources. Groundwater, 43(6), 827–837.

White, I., Falkland, A., Perez, P., Zhou, Y., Metutera, T. et al. (2007a). Climatic and human influences on groundwater in low atolls. Vadose Zone Journal, 6(3), 581–590.

White, I., Falkland, A., Metutera, T., Erena, B., Taojo, M. et al. (2007b). Sustainable water management in small island states. Hydrological Sciences Journal, 52(4), 621–637.

Woodroffe, C.D. (2008). Reef-island topography and the vulnerability of atolls to sea-level rise. Quaternary Science Reviews, 27(27-28), 2588–2596.

394

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryPortblair.docx