Bangladesh Water Development Board
Directorate of Ground Water Hydrology

Report on
Groundwater Quality Assessment of the Multi-layered Aquifer System of Bangladesh
Down to the Depth of 335 Meters

December, 2022

Under the Project
Bangladesh Weather and Climate Services Regional Project Component-B:
Strengthening Hydrological Information Services and Early Warning Systems

Bangladesh Weather and Climate Services Regional Project Component-B: Strengthening Hydrological Information Services and Early Warning Systems, Bangladesh Water Development Board, 72 Green Road, Dhaka 1205, Bangladesh.

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Foreword

Bangladesh is one of the most densely populated, disaster-prone and climate vulnerable countries in the world, located at the delta of the Ganges-Brahmaputra-Meghan River systems. Despite the susceptibility of Bangladesh to weather and climate extremes, the county's hydrological and hydro-meteorological monitoring infrastructure over land, atmosphere and ocean, groundwater aquifers as well as forecasting, and multi-hazard end-to end early warning systems need to be strengthened. This would improve planning and decision making and to mitigate the adverse effects of climate variability and changes.

This project i.e. Strengthening Hydrological Information Services (SHEWS) under Bangladesh Weather and Climate Services Regional Project (BWCSRP) has been supporting modernization of the country's weather, water and climate information infrastructure, strengthening both the supply of hydro-meteorological data, Hydrological and hydrogeological information and services and delivery to sectors and communities. This will be done by strengthening hydro-meteorological monitoring and forecasting, and service delivery related to weather, water, agriculture and multi-hazard disaster risk management early warning systems at the national level, strengthening sector specific information services and targeted community-based hazard early warning activities in selected districts, while laying the foundation for strengthening resilience at the regional level.

The Bangladesh Water Development Board (BWDB) is an organization of the Ministry of Water Resources. BWDB's Hydrology Offices aims to investigate, monitor and assess the country's hydro-meteorological and hydrogeological conditions by collecting relevant data and information and provide flood forecast and early warning services. The Hydrological network, including groundwater monitoring stations, managed by the Ground Water Hydrology Directorate (GWH) and its Divisions and Subdivisions of the BWDB remains primarily manual. Through this project, BWDB is modernizing its network and improving the provision of Hydrological services in Bangladesh by strengthening hydrological and hydrogeological observation, forecasting and early warning systems. In this regard BWCSRP considered exploratory drilling at 69 new locations throughout the country to determine aquifer system and water quality down to the depths of 300 m and installed clustered wells (4 wells at each location at different aquifer units). Under this project, amongst 2222 nos. BWDB wells, 901 nos. wells have been modernized into automation by installing sensor, data logger and telemetry devices for automatic temperature, groundwater level and electric conductivity i.e. salinity recording and data transfer round the clock, preferably at one-hour intervals, for delivering of groundwater related hydrological services. For the strengthening of water chemistry laboratory facilities of Ground Water Hydrology, one Ion-Chromatograph, one Spectrophotometer and several field tests kits have been procured under this project.

Under Package no. BWDB NS-4, an initiative was taken for the assessment of the country's groundwater chemistry and quality of multi-layered aquifer system, down to the depths of about 350 meters. Groundwater samples were collected from 901 of the BWDB monitoring wells, both in wet and dry seasons and analyzed 28 nos. physio-chemical parameters in the field and BWDB laboratory under the Directorate of Ground Water Hydrology. The results and findings, presented in this report, would provide a baseline assessment of the country's groundwater quality in a multi-layered aquifer system down to the depth of about 350 meters. All concerned officials and professionals are acknowledged for their involvement and efforts to make this component successful.

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Preface

Because of its stable quantity and quality, groundwater has long been a reliable source for drinking, irrigation, and industrial water supply in Bangladesh. However, the present trend of water use is often not sustainable, mainly due to hydro-meteorological disasters as well as unwise development and over exploitation. The groundwater resource is increasingly facing quality problems in many areas of the country where the exposure to pollution from agriculture, urbanized areas and industrial sites as well as arsenic contamination in shallow groundwater and high salinity in coastal aquifers makes the water unfit for human consumption. This may hamper economic and agricultural development, causes widespread public health problems and disturbs a wide range of ecosystems. Therefore, effective use of the water stored in aquifers, preservation of water quality needs to be considered essentially. With increasing water scarcity and frequent occurrence of water-related conflicts, the institutional arrangements governing water resource development, allocation, and management are receiving increasing policy attention. The hydrogeological data and information are required for understanding of the groundwater conditions. Analysis and interpretation of hydrological and hydrogeological data and information can guide water resources planning and distribution of water. In broad terms, success of integrated water resources development and management, protection of water resources, water quality and aquatic ecosystems, sustainable water supply and sanitation in both urban and rural context, and overall resources assessment etc. largely depend on adequate data and information.

The mandate of Ground Water Hydrology, Bangladesh Water Development Board (BWDB) in groundwater management includes fundamental data collection and analysis, basic assessment and process to understand the groundwater system, development of analytical tools for water resource planning and monitoring. Bangladesh Water Development Board has 1272 groundwater observation wells throughout the country, maintained under 7 Ground Water Hydrology Sub-divisions and installed for decades, mainly at shallow depths (25-50 m). Considering the quality problems in shallow and main aquifers and necessity to use deep groundwater BWDB has installed 42 clustered monitoring wells and 510-line wells down to the depth of 335 and 100 m respectively, in 19 coastal districts under the BCCT project, ‘Establishment of Monitoring Network and Mathematical Model Study to Assess Salinity Intrusion in Groundwater in the Coastal Area of Bangladesh due to Climate Change’. Under the ‘Bangladesh Regional Weather and Climate Services Project (BWCSRP), Component B: Strengthening Hydrological Information Services and Early Warning Systems ‘, funded by the IDA, the World Bank, 69 clustered monitoring wells have been installed covering the entire country. Each unit consists of 4 wells having the maximum depth of 300 m. Under the same project, 901 monitoring wells, including all clustered wells are automated using data-logger for temperature, groundwater level and in some cases for electric conductivity i.e., salinity. Recorded real-time data is transferred to the database by telemetry.

The Directorate of Ground Water Hydrology has a regular program to collect groundwater samples from observation wells to determine water quality. During 2020-2021, both dry and wet season samples were collected from 901 automated wells throughout the country under BWCSRP, Component B project and mainly analytical results with few maps and figures are presented in this report. Further interpretation and analysis of findings could be done as per requirement and purposes. I would like to express my heartfelt gratitude to Geologists, Engineers and other supporting staff of BWDB, Consultants and Project Authority for their efforts and kind support in order to make this successful. For the regular assessment and monitoring of the country's groundwater quality, it is recommended to collect groundwater samples from 110 clustered wells (about 440 samples), both in wet and dry periods.

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Water is a national resource. It is also a renewable resource that is renewed each year through the natural process of the Hydrologic Cycle. The large cycle of the hydrosphere includes the evaporation of water from the surfaces of the oceans and the continents into the atmosphere, falls back to the land-surface in the form of precipitation, and the surface and subsurface runoff conveying the water back to the water bodies [5].

In Bangladesh, groundwater resources are generally available in large volumes of good quality. These basic hydrological advantages of groundwater give rise to several scale-neutral socioeconomic benefits. For a few decades, groundwater has been the main source of irrigation and one of the key factors making Bangladesh self-sufficient in food production. Before the 1970s, surface water (e.g., ponds, rivers), rainwater and dug wells were the main sources of potable and domestic water supplies in Bangladesh. During the late 1970s and early 1980s, groundwater was introduced to avoid contaminated surface water with pathogenic microorganisms [6]. Thousands of hand-operated tube wells were installed in rural areas of Bangladesh to provide a pathogen-free groundwater-fed drinking water supply. The exact number of hand tube wells is not known but an estimated 10 million tube wells [7].

The importance of groundwater irrigation increased with the introduction of HYV seeds in the late sixties to meet the food demand for the growing population [6].

The first major irrigation project was started in the early sixties in the northwest of Bangladesh under Bangladesh Water Development Board (BWDB). DTW and STW irrigation was extended rapidly during the late 1970’s and the 1980’s. In 1972, Bangladesh Agricultural Development Corporation (BADC) initiated capital-intensive methods for DTW installation in Bangladesh and provided well components for the rapid expansion of groundwater irrigation [8].

In the prevailing water market, the pump owners installed their wells or pumps in their own plots or other people’s plots to irrigate their own plots and sell excess water to other farmers under varied formal/informal contractual arrangements. Hence, groundwater-irrigated agriculture plays an important role in increased food production and also in poverty alleviation by providing jobs and small business opportunities in rural areas [9].

More use of surface water, when and wherever available, is highlighted in the National Water Policy of Bangladesh [10]. Water storage has a key role to play in both sustainable development and adaptation to climate change [8]. A vast area of Bangladesh suffers from a scarcity of water for irrigating its agricultural lands not only in dry months but also during monsoon. There is considerable scope for the collection of rainwater before huge losses due to evaporation, transpiration, runoff and drainage. To reduce the harmful effect of floods and to use the surplus water for irrigation, BWDB has constructed a number of embankments, barrages and canals. BWDB has already implemented projects to cover about 1.7Mha land area under surface water irrigation [11].

Surface water provides about 20% of dry-season irrigation. Construction of more surface water irrigation projects can reduce stress on groundwater. Obstacles to managed conjunctive use include differences in abstraction costs between surface and groundwater [8].

1.2 LOCATION AND ACCESSIBILITY

Under the 'Bangladesh Regional Weather and Climate Services Project (BWCSRP), Component B: Strengthening Hydrological Information Services and Early Warning Systems' funded by the IDA, the World Bank, 69 clustered monitoring wells have been installed covering the entire country. Each unit consists of 4 wells having the maximum depth of 300 m.

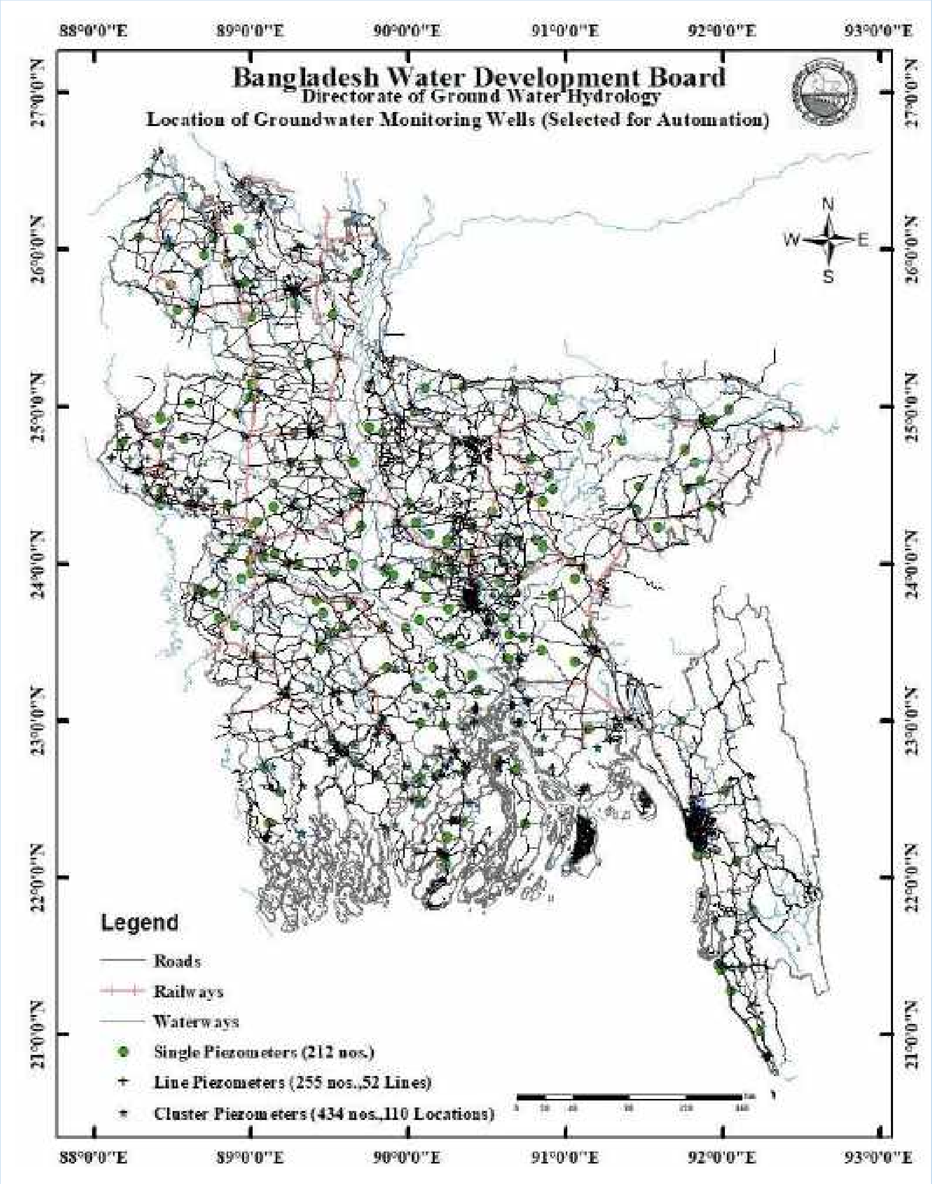


Figure 1-1: Map Showing Location and Accessibility.

Under the same project, 901 monitoring wells, including all clustered wells, will be automated using data-logger recording temperature, groundwater level and in some cases electric conductivity i.e., salinity. Recorded real-time data will be transferred to the database by telemetry. If these automated systems are installed and maintained properly, the data frequency and accuracy will be enhanced.

1.3 SCOPE OF SERVICES

The main objective of the Project "Bangladesh Weather and Climate Services Regional Project Component-B: Strengthening Hydrological Information Services and Early Warning Systems" was to provide comprehensive support to the Hydrology department of BWDB towards the modernization of its hydrological monitoring network and operations. The project aimed to procure hydrological equipment and improve flood forecasting covering the whole of Bangladesh, including flash floods and storm surge/cyclone-induced floods. It also aimed to develop other water-related hazard forecasting/prediction services and diversify and downscale forecast products.

To achieve the goal, there was a necessity to collect and test groundwater samples to monitor the time-variant changes in quality and other parameters. The collection and the testing of groundwater samples were identified as prime important parts of the project, and a necessary budget provision was made for these activities in the approved revised DPP. Therefore, as the Project Director (PD) acting as the Project Executing (PE) agency, it was planned to engage a Service Provider to procure the necessary services.

The main purpose of the service was to collect groundwater samples and test them for 25 parameters (5 physical and 20 chemical) to monitor groundwater quality and prepare a comprehensive report. The report aimed to enrich the database and provide significant support to the Project Planner and Researchers.

The existing 901 groundwater wells were located in different parts of Bangladesh. Each well had a separate ID number and GPS value.

The service included the collection of water samples from the 901 groundwater wells across Bangladesh and the conducting of immediate field tests after collection using the equipment supplied by the service provider. The field tests covered five parameters: EC, pH, DO, TDS, and Temperature.

The laboratory tests were performed at the BWDB Lab, located at 72, Green Road, Dhaka. The lab tests covered 20 parameters: Ca, Mg, Na, K, HCO3, CO3, Cl, NO3, PO4, SO4, B, Br, I, Fe, Mn, As, Cr, Al, Cu, and EC, using the equipment supplied by BWDB. The service provider was responsible for supplying the required reagents for the lab tests.

Additionally, the service included preparing and furnishing a comprehensive report. The report contained the test results, the name and quantity of reagents used (in parts per million), presented in tabular form, technical notes, problems and bottlenecks related to sampling and testing, still photography (of wells, sampling, and lab work), suggestions, comments, and other relevant information.

CHAPTER 2: DESCRIPTION OF THE STUDY AREA

2.1 PHYSIOGRAPHY

About 80% of the land area of Bangladesh is flat and low elevated, intersected by numerous rivers and their distributaries. Generally, four major physiographic units exist at the surface of Bangladesh. These are: a) Tertiary sediments in the northern and eastern hills; b) Pleistocene terraces in the Madhupur and Barind tracts in the center and west; c) Recent (Holocene) floodplains of the Ganges, the Brahmaputra and the Meghna rivers; and d) The Delta, covering the rest of the country. These major units can be classified into seven broad divisions i.e., a) Hilly Regions, b) Pleistocene Uplands, c) Tippera Surface, d) Tista Fan, e) Flood Plains, f) Delta Plain and g) Sylhet Depression and Inland Marshes. Each of these divisions can be subdivided with distinguished characteristics of its own [12].

2.2 DRAINAGE SYSTEM

The Bengal Delta occupies a unique position among the larger deltas of the world for its varied and complex drainage and river system. The whole delta is crisscrossed by innumerable large and small channels of which some are decaying; some are active, while some others are being drained only by the tidal flow. This drainage pattern also plays an important role in saline water encroachment in both surface water and groundwater environments. Another significant feature of the delta-rivers is their continual shifting of courses [13]. In the summer monsoon season when about 3 million cusecs of water pass through the delta, it behaves as a fluvial delta whereas in the winter when the volume of water passing through the delta drops to 250,000-300,000 cusecs it behaves as a tide dominated delta. These unusual features make this delta one of the most complex in the world. The southwestern portion of the Ganges delta which includes the world’s largest mangrove forest, the Sundarbans, is completely a maze of tidal creeks and channels and carries a substantial amount of water through its various distributaries which join these tidal channels and estuarine creeks [6].

As sea level continues to rise the associated effects of permanent inundation is likely to increase the salinity near coastal areas in Bangladesh. A direct consequence of sea level rise would be the intrusion of salinity with tide through the rivers and estuaries. It would be more acute in the dry season, especially when freshwater flow from the rivers would diminish [14].

2.3 REGIONAL HYDROGEOLOGY

Bangladesh is located at the mouth of the Bay of Bengal and occupies much of the Bengal Delta, formed by the deposition of the Ganges-Brahmaputra-Meghna (GBM) river system. The GBM rivers have the largest total sediment load in the world derived principally from the Himalayan and Indo-Burman ranges [15] and the fourth-highest water discharge to the oceans [16]. Most of Bangladesh had low elevation throughout its geological history that made it very sensitive to the sea-level changes which influenced geological processes of weathering, erosion and deposition of sediments. These processes were in operation throughout the Plio-Pleistocene and Holocene periods towards the making of the large delta and one of the largest deep-sea fans in the world. The Bengal Basin has more than 20 km of Tertiary-Holocene sedimentary fill below ground level, which consists predominantly of the orogenic sediments derived from both the eastern Himalayas to the north and the Indo-Burman Ranges to the east [17]. This generalized sequence is not common in all parts of the country and in some places, many formations are missing due to depositional, non-depositional, and post-depositional erosion. The sediment thickness is the shallowest in northern Bangladesh (100 m) [6].

The oldest rocks exposed in Bangladesh belong to the Tertiary Era. Quaternary sediments cover approximately 82% of the country and rocks from the Paleocene to the Pleistocene are exposed in 18% of the area in the hilly region [18].

2.4 AQUIFER SYSTEM

The unconsolidated near surface Pleistocene to Recent fluvial and estuarine sediments underlying most of Bangladesh generally form prolific aquifers. Thick semi-consolidated to unconsolidated fluvio-deltaic sediments of Miocene age to the Recent form many aquifers. But except for the Holocene and the Dupi Tila Sandstone Formation of the Plio-Pleistocene age, others are too deep to consider for groundwater abstraction. From the present available subsurface geological information, it appears that most of the aquifers occur between 30 to 130 m depth. These sediments are cyclic deposits of mostly medium to fine sand, silt and clay. However, due to arsenic contamination in shallow groundwater and salinity intrusion in upper aquifers, importance of exploitation of deep groundwater (down to 350-400 m bgl) has been increased [19]. The individual layers cannot be traced for long distances horizontally or vertically i.e., distribution of aquifer sediments in the subsurface is very complex. Aquifer-aquitard alteration is highly variable even within a short distance. Most of the groundwater withdrawn for domestic or agricultural purposes in the Barind and Madhupur Uplands areas is from the Dupi Tila aquifers. This aquifer is composed of light gray to yellowish brown, medium to coarse sand with pebble beds and is dated as about or more than 20,000 years old [20]. All of the water for Dhaka City is withdrawn from this aquifer and the water is as yet arsenic safe. The Dupi Tila Formation extends all over Bangladesh probably except for the western two-thirds of the Delta. Other than the Terrace areas, the remaining part of the Bengal Delta consists predominantly of Holocene alluvial and deltaic sediments. The age of Holocene aquifers ranges from 100 to more than 3,000 years. In the land above tidal inundation, these deposits are composed primarily of silt and sand of appreciable thickness extending to depth of more than hundred meters [19].

The main water-bearing zone extends down to 250-350 m and is generally underlain and overlain by silty clay beds, and composed mainly of fine to very fine sand, occasionally inter-bedded with clay lenses. It is either semi-confined/leaky or consists of stratified interconnected, unconfined water-bearing zones. The age of water from this aquifer is dated as about 3000 years old. Groundwater is drawn predominantly from these strata. The deep aquifer has been encountered to depths of 300-350 m, generally below a silty clay aquitard. This aquifer is composed mainly of grey to dark grey fine sand that in places alternates with thin silty clay or clay lenses [21].

The deep aquifers do not occur in some areas down to the investigated depth of 350 m, e.g., south and southeast of Khulna town, Satkhira, Cox’s Bazar and generally consist of a number of different stratigraphic layers. In the Chattogram coastal zone, the Pliocene sediments exposed in the escarpment hills dip under the Quaternary sediments of the coastal plain. Water in the shallow alluvial aquifers is of variable quality and contains pockets of intruded saline water from estuaries or coastal flooding. The erratic occurrence of small fresh water pockets at depth is reported all over the coastal belt [22].

All the above classifications do not take into account the sedimentological parameters or the depositional history of the aquifer sediments. Till now the aquifers of the delta plain and the flood plains of the GBM Delta Complex have been divided based on depth. But it is a well-established fact that the sedimentation rate and subsidence in the whole of the Bengal Basin were not uniform throughout the Quaternary period. This seems to be comparatively more logical than the conventional divisions based only on depth. The major divisions in this classification are: 1) Plio-Pleistocene Aquifers; and 2) Late Pleistocene-Holocene Aquifers: a) Late Pleistocene-Early Holocene Aquifers; b) Middle Holocene Aquifers and c) Upper Holocene Aquifers [21].

2.4.1 Plio-Pleistocene aquifers

The Plio-Pleistocene Aquifers of the Dupi Tila Formation lie beneath the Pleistocene Madhupur Clay Formation. This aquifer is composed of light gray to yellowish brown, medium to coarse sand with pebble beds. All of the water for Dhaka City is withdrawn from this aquifer but the water is as yet arsenic safe. This aquifer is confined to semi-confined [19].

2.4.2 Late Pleistocene-Holocene aquifers

The Late Pleistocene-Early Holocene Aquifers are not continuous all over the country. This to some extent corresponds to the Deep Aquifer [23], lower part of the Deep Aquifer [24] and the Third Aquifer has dated water from this aquifer as about 20,000 years old [25]. The sediments of this aquifer to some extent correspond to the Late Pleistocene-Early Holocene Unit of the sediment section. Water within this aquifer is found to be arsenic safe but heavy withdrawal from this aquifer needs further study [25].

2.4.3 Middle Holocene aquifers

Above the Late Pleistocene-Early Holocene Aquifer lies the fine sand which becomes coarser in the upper part. This sandy sequence varies greatly both vertically and horizontally. The upper part also contains silt and peaty organic matter. These Mid- Holocene Aquifers may be considered in a similar position in the geological section as the Main Aquifer [23], the Second Aquifer or the Lower Shallow Aquifer in the floodplain and deltaic areas of Bangladesh [24]. dated water from this aquifer as about 3000 years old. Most of the groundwater in Bangladesh is withdrawn from this aquifer and the water is severely affected by arsenic contamination. The sediment from the surface samples in the Chandina Formation areas (Tippera Surface) dates around 6,000 ka. In this area the Middle Holocene aquifer is encountered nearest to the surface, but in most of the river basin and the delta plain areas this is at different depths [6].

2.4.4. Upper Holocene aquifers

The Upper Holocene Aquifers are developed all over the deltaic and floodplain areas. This does not occur in the Chandina Formation areas (Tippera Surface) [18]. The lower part is composed of silt and clay at the bottom, and fine sand at the top. The upper part is composed of silt and clay, and is commonly found to be inter-bedded or mixed with medium sand. The water of this Upper Aquifer is also affected by arsenic contamination [19].

2.5 GROUNDWATER RECHARGE AND RESOURCE AVAILABILITY

2.5.1 Groundwater Recharge Potential

Rain water is the principal source of groundwater recharge in Bangladesh. Flood water which overflows the river and stream banks also infiltrates into the groundwater. Water from permanent water bodies (rivers, canals, wetlands, ponds, irrigated fields, etc.) that lie above the water table also percolates to the groundwater. In the Pleistocene terraces, the recharge occurs through the incised antecedent drainage channels that cut through near-surface clays into the underlying sands. The greatest scope of recharge is within the coarse-grained sediments and the least is within the fine-grained sediments like clay [19].

Study shows that recharge has increased substantially (5–15 mm/year) in northwestern and western districts but has slightly decreased (−0.5 to −1 mm/year) or remained unchanged in the rest of Bangladesh Increases in groundwater recharge may be possible where actual (net) recharge is less than potential recharge estimated previously [26]. The estimates of net recharge in northwestern and western parts of Bangladesh are much greater than in eastern parts where potential recharge is higher due to greater annual rainfall (>2000 mm). Net annual recharge in western parts of the country has substantially increased since the 1980s and now approximates potential recharge [26]. Numerical modeling of regional groundwater flow suggests that actual (net) recharge increased from around 70 mm/year prior to widespread groundwater-fed irrigation (before the 1970s) to around 250 mm/year more recently [26]. The estimates of net recharge show that mean recharge in Bangladesh has increased from 132 mm/year over a period from 1975 to 1980 to approximately 190 mm/year for the period 2002–2007 [26].

Model simulations for south-east Bangladesh show that flow paths and travel time of groundwater to different depth levels down to the depth of 400 m of multi-layered aquifer units are primarily controlled by hydrogeological characteristics i.e., anisotropy and the pattern of pumping [27]. The recharge zone for different aquifer units under different development stress is about the same in different geologic conditions. Aquifers are recharged by vertical percolation as well as water from long distance travel from highly elevated eastern hilly areas mainly to deeper aquifers. Huge irrigation and other pumping from the 1st i.e., the shallow (<50 m) and the upper part (50-100 m) of the 2nd i.e., the main aquifer units retard vertical percolation in deeper aquifers (>300 m), resulting increase of travel time in the lower part (100-250 m) of the 2nd and the upper part of the 3rd i.e., the deep aquifer units. Under current trend of groundwater development, the average travel time i.e., age of water for the upper and the lower parts of the 1st and the 2nd and the upper part of the 3rd aquifers at different geologic conditions are estimated between 37 and 234, 133 and 317, 832 and 2485, 1009 and 3027 and 1065 and 3543 years respectively (Table 1) [27].

Travel time of vertical percolation of recharge water will be decreased in the 1st aquifer with increased irrigation pumping in future from the lower part of the 1st aquifer. Average travel time and length of flowlines will be increased for the 2nd and the 3rd aquifers as huge pumping continues from the 1st aquifer. Groundwater level in the shallow aquifer varies from place to place mainly due to local-scale lithologic variations and pumping of groundwater. The 1st and the 2nd aquifers are greatly influenced by the irrigation abstraction and local cone of depressions are created depending on intensity of pumping that also influences water level in these aquifer units almost all over the year. Under natural conditions the groundwater gradient is almost flat and horizontal flow is relatively small compared to vertical movement. Therefore, water level does not follow the regular trend for the 1st and the 2nd aquifer units. Water from the 1st aquifer may move downward into the deeper freshwater zones through aquitard windows. Groundwater in the 3rd aquifer generally flows laterally [27].

Table 2-1: Travel times (age) of groundwater to different aquifer units at anisotropic and low anisotropic condition [27]

Unit	Aquifer	Pre-development			2004 Development			2014 Development		
		Max	Min	Ave	Max	Min	Ave	Max	Min	Ave
Anisotropic conditions										
Unit 3	1st (Upper)	2671	33	1972	121	8	37	30	5	14
Unit 4	1st (Lower)	2627	91	1983	2557	21	133	165	14	37
Unit 6	2nd (Upper)	2567	1264	1912	5881	122	2485	8140	130	3312
Unit 7	2nd (Lower)	2516	1237	1873	4853	1288	2454	8831	865	3527
Unit 9	3rd (Upper)	2413	1022	1757	3896	1150	2297	7334	1321	3496
Low anisotropic conditions										
Unit 3	1st (Upper)	2647	4	792	1143	3	234	3309	2	288
Unit 4	1st (Lower)	3157	11	782	3687	8	317	3899	6	289
Unit 6	2nd (Upper)	2510	28	883	3194	21	832	3517	19	956
Unit 7	2nd (Lower)	3006	55	878	3101	45	1009	4365	42	1111
Unit 9	3rd (Upper)	3027	124	956	2837	116	1065	4396	110	1209

2.5.2 Fluctuation of Groundwater Table

With increasingly growing demands on the groundwater supplies, areas of urban as well as rural Bangladesh have started facing water problems, including the drying up of wells during peak irrigation period and continuous lowering of water table mainly in city areas. Study has estimated that nearly 30 km^3 of groundwater was abstracted for irrigation throughout Bangladesh during the *Boro* rice season in 2006 [26]. Considering an average daily groundwater use of 50 liters per person for both drinking and domestic uses (total population of 150 million in 2006) an estimated domestic groundwater use is approximately 3 km^3 which is an order of magnitude less than irrigation abstraction. Analysis of long-term water table data of BWDB piezometers installed in the upper and deeper part of aquifers shows that hydrographs are very variable in different parts of the country [28].

The impact of groundwater development can often be observed from hydrographs. Groundwater recedes more during the dry season and the rise is often delayed. Generally, groundwater withdrawal from the shallow aquifer for domestic and irrigation purposes during dry periods is balanced with the vertical percolation of rain water and inflow from surrounding aquifers during monsoon when pumping is ceased. No permanent decline of the water table is observed, except in urban areas and in the Barind tract. Seasonal water table fluctuation is more in the central and northern parts of the country where groundwater irrigation is extensive and this fluctuation is low or even nil near the coastline as groundwater irrigation in the southern coast is negligible due to salinity problem in upper aquifers [19]. In Dhaka city, a permanent declining trend of groundwater level is observed due to excessive withdrawal for city water supply and around Dhaka city for industrial withdrawal. Groundwater table contour map of greater Dhaka shows that maximum depth to groundwater table in Dhaka city is more than 60 m and in surrounding industrial areas this is within 9 to 18 m during dry period. During monsoon, the groundwater table rises steadily until the levels are within 1-2 m of the surface. During the peak irrigation season in March and April, the hydrograph is fairly smooth for years and the steepest rise in the hydrograph is observed immediately after the irrigation pumps are switched off rather than at the start of the monsoon as might be expected [28].

Using weekly monitoring records of groundwater levels throughout Bangladesh shows that shallow groundwater levels are declining at a high rate in the recent time (1985 – 2005) [28]. Declining rates are highest (exceeding −0.5 m/year) in and around Dhaka City and Barind Tract region, and high (0 to −0.05 m/year) in areas south of the river Ganges. In the coastal areas, shallow groundwater levels are showing stable to slightly rising trends (0 to +0.1 m/year) over the same period. Withdrawal by shallow irrigation wells may also influence the huge fluctuations in water levels in the deeper aquifers. These levels in the deeper part recover rapidly when seasonal pumping stops [29].

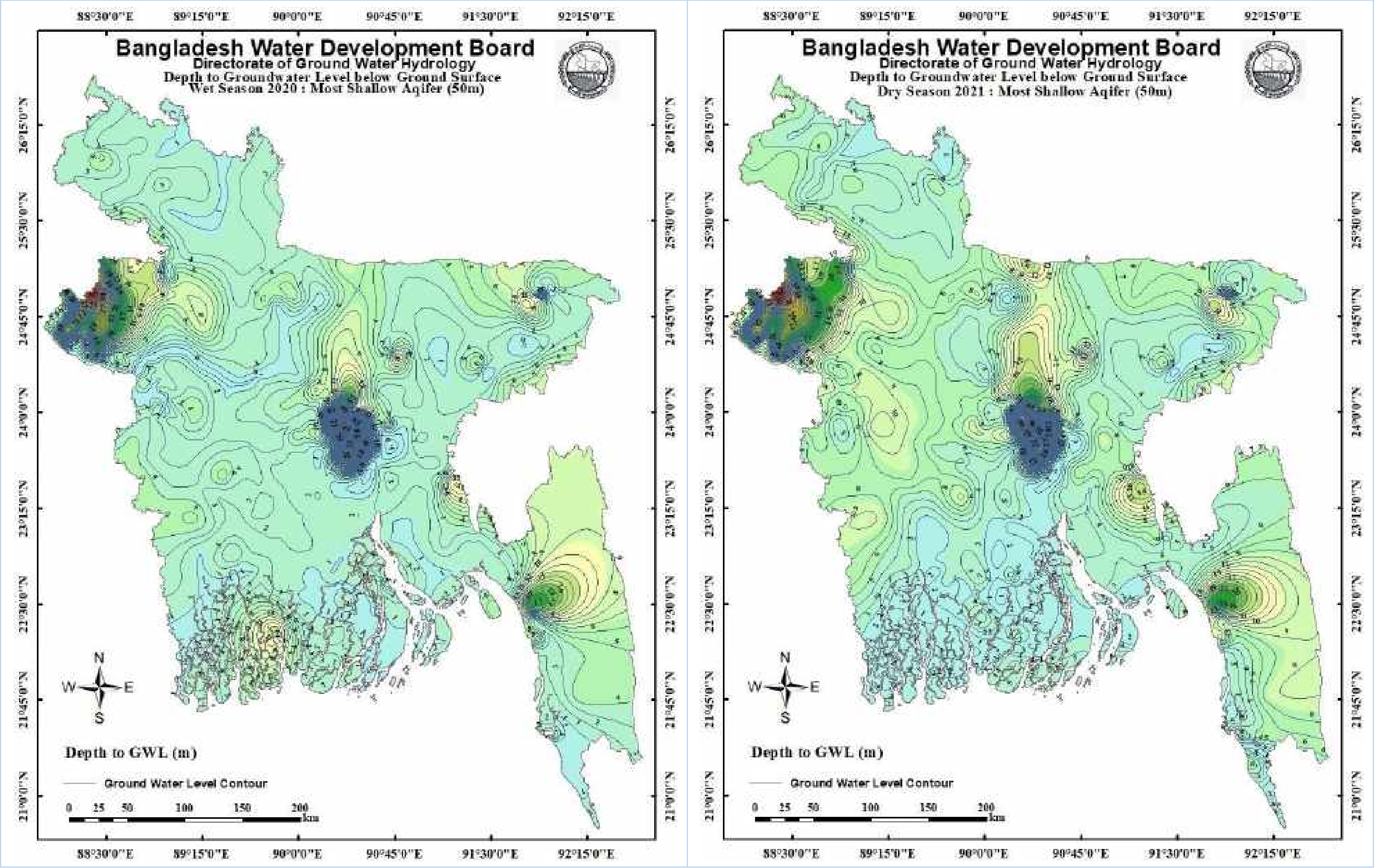


Figure 2-1: Depth to Groundwater Level Below Ground Surface (Very Shallow Aquifer 50m).

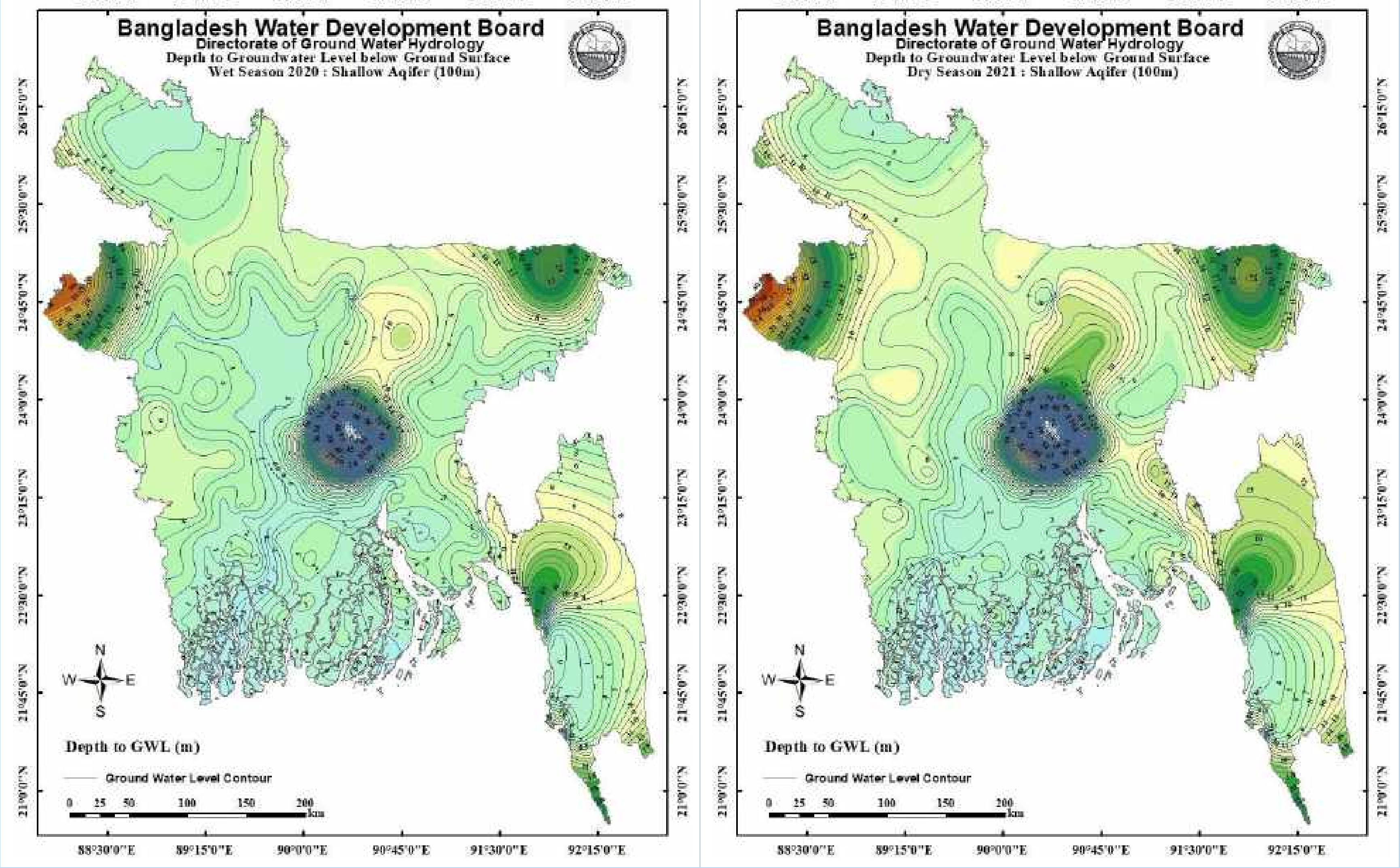


Figure 2-2: Depth to Groundwater Level Below Ground Surface (Shallow Aquifer, around 100m).

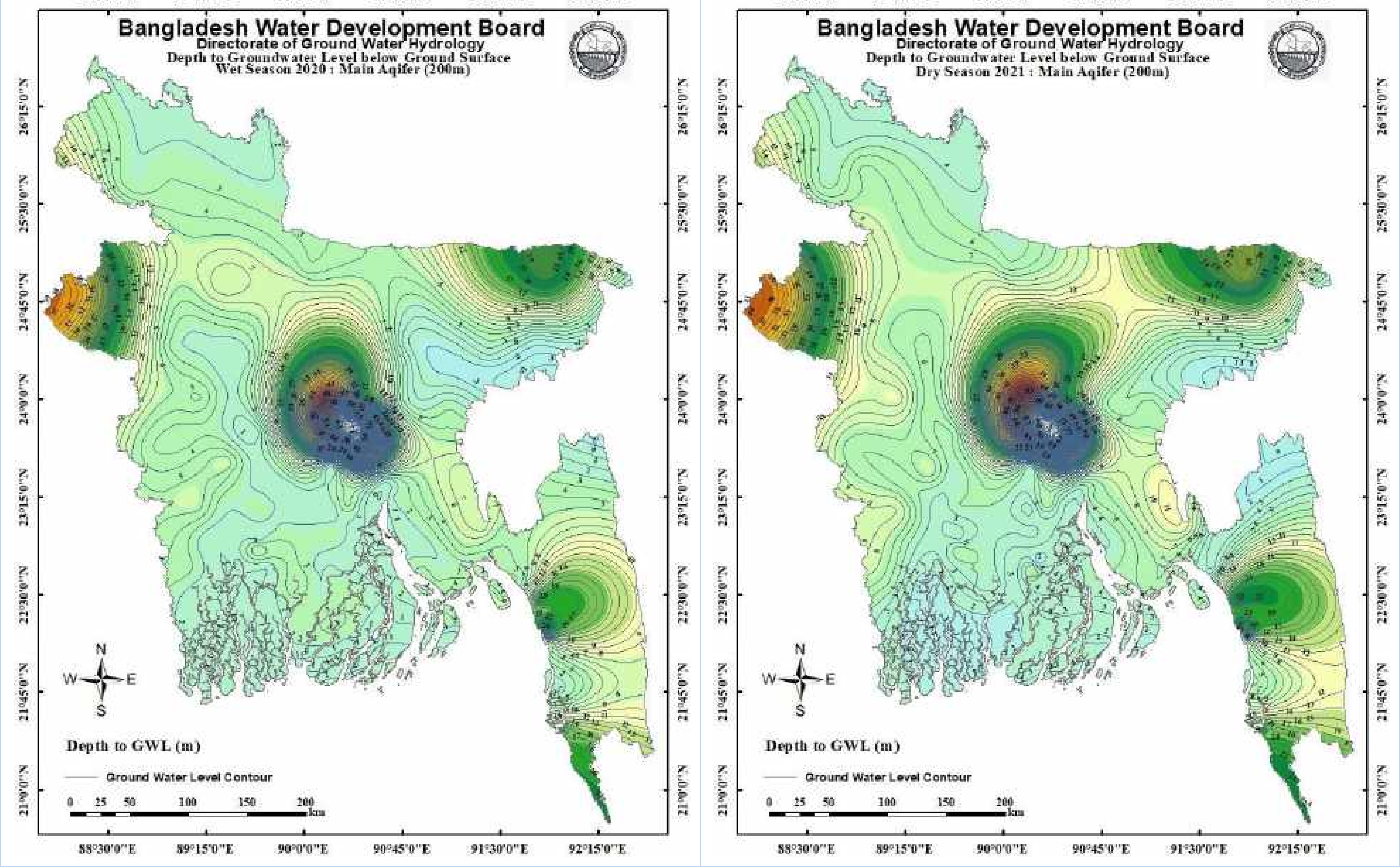


Figure 2-3: Depth to Groundwater Level Below Ground Surface (Main Aquifer, around 200m).

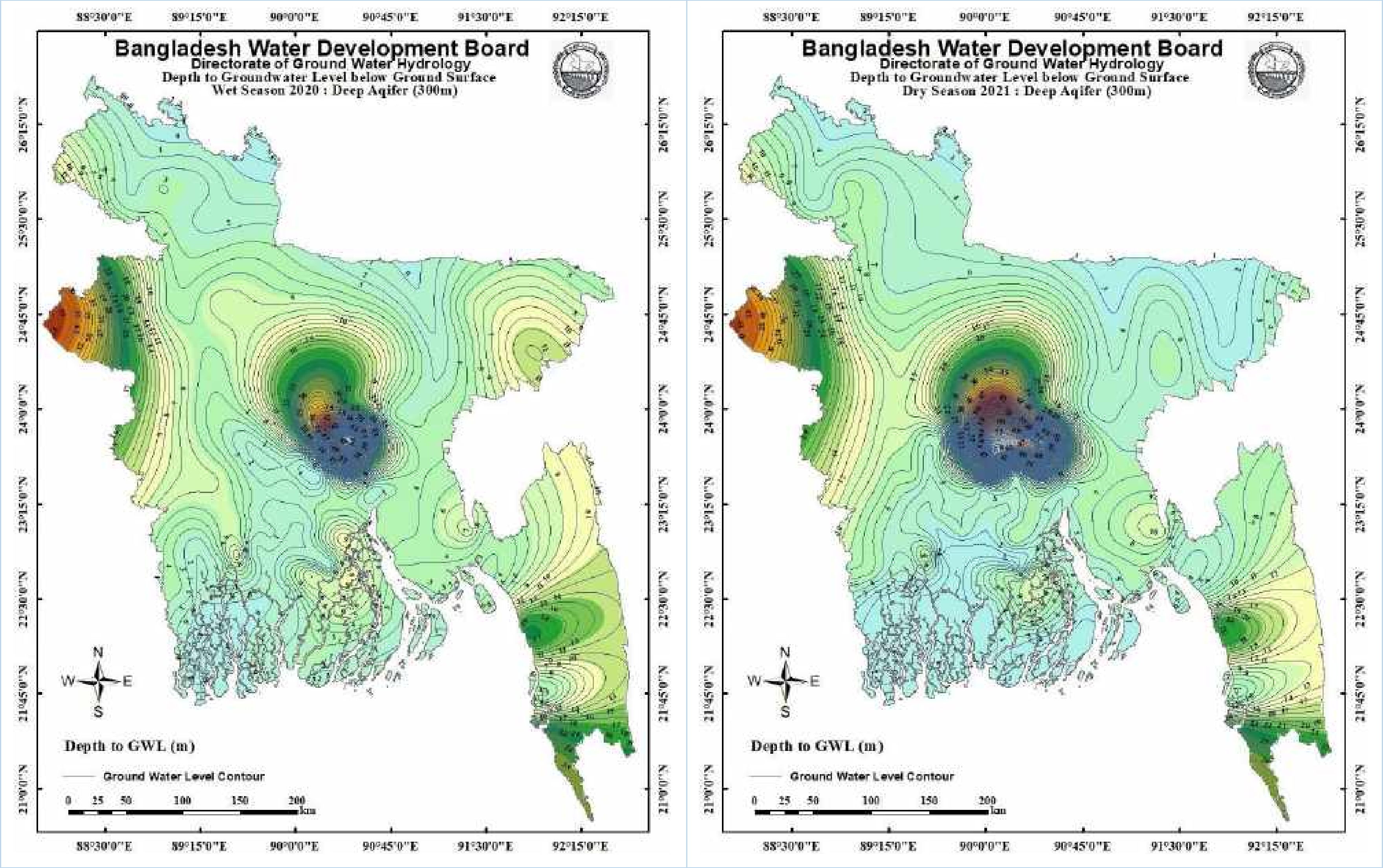


Figure 2-4: Depth to Groundwater Level Below Ground Surface (Deep Aquifer, around 300m).

This rapid recovery, parallel to water levels in shallow aquifers, reveals that shallow and lower aquifers are hydraulically connected. Huge irrigation abstraction of shallow groundwater during dry irrigation period has impact on groundwater levels in deeper part of aquifers (down to 350 m) and where abstraction is negligible like in coastal areas groundwater levels in deeper part remain steady and close to the surface.

2.6 EXPANSION OF GROUNDWATER IRRIGATION

In a small land area of 147570 km^2 with about 140 million populations in Bangladesh importance of groundwater irrigation has been increased to meet the food demand for growing population with the introduction of High Yield Varieties (HYV) seeds in late sixties [30]. Groundwater irrigation is rather new in the country though the surface water irrigation by indigenous method was in practice. Until 1950's farmers used only traditional means of irrigation, the swing baskets and down with the capacity of lifting water up to about 1 to 1.5 m. Persian wheels were also used in many parts of the Indian subcontinent to lift water from the dug wells [22].

The country started emphasizing groundwater irrigation in the mid-seventies with Deep Tube Wells (DTW), and soon shifted its priority to Shallow Tube Wells (STW). Groundwater is the main source of irrigation and one of the key factors making Bangladesh nearly self-sufficient in food production using submersible pumps in tube wells [20]. In our country, people with less than 0.5 acres of cultivable land comprise 66% of the population who are absolutely poor and rarely benefit from large water development schemes. About 90% of the total irrigated area is under private sector led ‘minor irrigation’ [8]. The minor irrigation involves different pumping technologies like STW, Deep Set Shallow Tube Wells (DSW), DTW, Force Mode Tube Wells (FMTW), Low Lift Pumps (LLP) etc. Majority of the technologies are STW and LLP. Minor irrigation using groundwater has, in fact, been the single most important driving force behind the steady expansion of agricultural output in recent years [19].

Total irrigated land in 2006 was 5.4 million hectares (Mha) where 3.8 Mha i.e., 70% was under minor irrigation and total cultivated land was 7.1 Mha [31]. Currently, the high-yielding *Boro* rice is grown in more than 4.0 Mha of net cultivable land (total of nearly 8.0 million ha) in the country that is primarily groundwater-fed [32]. In Bangladesh, the proportion of arable land irrigated by groundwater increased from <1% in 1965 to approximately 78% in 2007 [31]. By 2006, nearly 78% of the irrigated rice-fields were supplied by groundwater of which approximately 80% of the irrigation water derived from low-capacity (average discharge rate 10 L/s) shallow tube wells (STW; depth <80 mbgl); the rest was irrigated by high-capacity (average discharge rate 56 L/s) deep tube wells (DTW; depth >80 mbgl) to produce Boro rice [23,33]. Study shows that during the pre-developed groundwater-fed irrigation period (1975–1980), shallow tube well (STW) based irrigation covered an average area of 57,000 ha and deep tube well (DTW) covered an average area of 138,000 ha. The second period (2002–2007) i.e., the developed groundwater-fed irrigation period, STW-based average irrigated area increased to 3,044,000 ha and DTW-supplied area increased to 702,000 ha [34].

Irrigation expansion based on STWs development is still continuing. The dominant food crop of Bangladesh is rice. HYV seed, application of fertilizer, and irrigation have increased yields, although these inputs also raised the production cost. With the increasing use of irrigation, there has been a focus on Boro rice – growing season extending during the dry season from October to March. Total production of Boro rice in the country in 2005–06 was 13.8 million metric tons (MMT) that was 55% of total rice production BBS, 2006 [31]. The development of groundwater for irrigation has had a major positive impact on food grain production in Bangladesh. In Bangladesh, people with less than 0.5 acres of cultivable land comprise 66% of the population who are absolutely poor and rarely benefited from large surface water development schemes [8]. The growth of groundwater irrigation, especially privately supplied irrigation by STWs purchased by individuals for cash or credit at unsubsidized prices, led to the emergence of the irrigation water market [35]. The expansion of the groundwater market has created many associated businesses too, establishing local workshops for manufacturing irrigation pumps, pipes, spare parts and development of mechanic skills in rural areas. Hence, groundwater irrigated agriculture plays an important role not only in increased food production but also in poverty alleviation. GDP is highly dependent on the development of water resources in general [19].

2.7 QUALITY OF GROUNDWATER

The floodplain groundwater was classified into two groups, namely the Na–Cl type and the Na-Ca-Mg–HCO_3 type. The major ion trends of the Na–Cl type are $Na^+>Ca^{2+}>Mg^{2+}>K^+$, common for all aquifers down to 350 m bgl and $Cl^->HCO_3^->SO_4^{2-}$, mainly for deeper and $HCO_3^->Cl^->SO_4^{2-}$ for shallow samples [39]. Study shows that in the coastal delta groundwater samples down to the depth of 200 m, except Cox's Bazar and Feni samples, are distributed in the right central portion of the diagram and classified as Cl^--SO_4^{2-}, Cl^--SO_4^{2-}-HCO_3^-, Na^+-Ca^{2+}, Na^+-K^+ types dominated by Na^+-Cl^- and HCO_3^- type [6]. Seawater intrusion is the major phenomena till this depth. Deep water (down to 336 m) of Patharghata, Bhandaria and Mukshedpur aquifers is also classified with this cluster. Cox's Bazar and Feni samples of down to 200 m depth shows Na^+-Ca^{2+} and HCO_3^--Cl^--SO_4^{2-} types with the signature of the mixture of fresh water and seawater. Most of the deep groundwater samples between 201 and 336 m depth ranges are classified as HCO_3^--Cl^--SO_4^{2-}, Na^+-K^+-Ca^{2+} types, dominated by HCO_3^- type those are within the limit of fresh water. The major ion trends of the upper Na^+-Cl^- groundwater type is $Na^+>Ca^{2+}>Mg^{2+}>K^+$ and $Cl^->HCO_3^->SO_4^{2-}$ and for the deep groundwater ionic trend is $Na^+>Ca^{2+}>Mg^{2+}>K^+$ and $HCO_3^->Cl^->SO_4^{2-}$. In Sylhet basin the groundwater is of Ca^{2+}-Na^+ -HCO_3 -Cl^- type [6].

The groundwater resource of Bangladesh is facing different problems including quality hazards in many areas where the exposure to pollution from agriculture and arsenic contamination in shallow groundwater makes the water unfit for human consumption. It has been reported that out of 64 districts 61 are affected more or less. Surveys [35] show that about three million tube wells, installed at shallow depths (10 to 50 m), discharge groundwater with arsenic concentrations more than the Bangladesh drinking water standard of 50 µg/l. About 28 to 35 million Bangladeshis have been exposed to drinking water containing arsenic that exceeded the Bangladesh arsenic standard, and 46 to 57 million people have been exposed to drinking water containing arsenic that exceeded World Health Organization (WHO) arsenic standard of 10 µg/L [40,41]. More than 30,000 people have already suffered from arsenicosis and this number will be increased drastically within the next decades, if necessary, measures are not taken [42]. Deep tube wells, with the depth range between 100 and < 300m, were installed in the main aquifer in recent years as an attempt to find groundwater with insignificant or no arsenic concentration [43]. But these wells often contain high concentrations of iron, manganese and high salinity. Large-scale groundwater abstraction from deep aquifers could eventually result in contamination of the deeper fresh and safe groundwater resource by inducing relatively rapid downward flow from high-arsenic and saline regions. High concentrations of dissolved iron (Fe) are common in groundwater in many areas of Bangladesh [21]. However, there are no reported public health effects of high Fe in drinking water.

Turbidity and color may develop in piped water systems at concentrations >0.05–0.1 mg/l. The median Fe concentrations in Bangladesh groundwater are 1.1 mg/l and the maximum concentration was recorded at 61 mg/l [12]. In Bangladesh, groundwater is commonly treated for high Fe concentrations in drinking and industrial water supplies because of aesthetic reasons. High concentrations of dissolved manganese (Mn) in groundwater are another groundwater quality issue in Bangladesh. Study reports that about 73% of surveyed water wells have Mn concentrations exceeding 0.1 mg/l, and nearly 42% water wells exceed a concentration of 0.4 mg/l [44]. The occurrence, origin, release mechanism and mobility have received huge attention. Although adverse neurological effects of inhaled Mn have been well documented in humans the quantitative and qualitative details of exposure necessary to establish direct causation are lacking [40]. Adverse neurological effects (i.e., reduced children's intellectual function) as well as infant mortality with high exposure to Mn through drinking water have recently been reported from long-term monitoring of Mn exposure and public health impacts in central Bangladesh [28].

Under This project of BWDB, 901 nos. observation wells are considered from the BWDB monitoring wells all over Bangladesh from where the water sample collection would be performed for two times in a year i.e., one in Wet Season (August-October) and another in Dry Season (March-May) in order to assess depth-wise groundwater chemistry i.e., quality as well as find the time variant change of quality of water. From these collected ground water sample there are 25 parameters (EC, PH, DO, TD, Temperature & Ca, Mg, Na, K, HCO_3, CO_3, PO_4, SO_4, B, Br, I, Fe, Mn, As, Cr, Al, Cu, E.C) that would be analyzed by physical (5 nos.) & chemical (20 nos.) method both in the field as well as in the laboratory. From the analyzing data a comprehensive result found from the seasonal variation of water sample quality, which will enrich the database and finally will extend a big support to the Project Planners & Researchers.

2.7.1 Groundwater Arsenic contamination

Groundwater arsenic contamination has been identified in various parts of the world. Groundwater in the Ganges and Yellow River basin countries, such as, Bangladesh, India (West Bengal), Nepal, and China, contains dissolved arsenic in excess of the World Health Organization (WHO) and United States Environment Protection Agency (USEPA) recommended limit of 10 µg/l. Arsenic occurs as a major constituent in more than 200 minerals in association with the transition metals as well as Cd, Pd, Ag, Au, Sb, P, W and Mo [46]. Long-term exposure to arsenic in drinking water has the clinical effects of chronic arsenic poisoning, ranging from skin ailments, through damage to internal organs to gangrene and cancer. In terms of patients affected and populations exposed, some the Ganges and Yellow River basin countries have the worst cases of arsenic related health problems and the occurrences of high-arsenic groundwater is constrained to a restricted range of geological, hydrogeological and geochemical condition in aquifer [47].

Summary statistics of available laboratory analysis results compiled under the project of DPHE-BGS, 2001 [24] survey show that out of 9271 samples, arsenic concentration of 3242 samples exceeded the limit of Bangladesh standard of 0.50 µg/l which is 35% of all samples examined [6]. The 'Systematic Regional Arsenic Survey' under the study project covered initially 252 Upazilas (sub-district) in the country. During Phase-I, 2023 samples from 41 districts were collected and analyzed at the laboratories of BGS, UK, and 51% of total samples exceeded WHO guideline and 35% of total samples exceeded Bangladesh standard for arsenic concentration. Phase-II of DPHE-BGS (2001) hydro-chemical survey has been enriched with the results of 3534 tube well samples covering 433 sub-districts. This number of tube wells is perhaps 0.05-0.1% of all tube wells in the country. From the survey, 25% of the tube wells sampled exceeded 50 μg/l, 9% exceeded 200 μg/l, 1.8% exceeded 500 μg/l and 0.1% exceeded 1000 μg/l [6].

2.7.2 Encroachment of sea-water in the coastal belt

Saltwater intrusion has already been occurring in some areas of the coastal belt of Bangladesh due to previous rise in sea level and storm surges. As a result of historical sea-level rise in the last thousands of years, the subsurface saltwater has been moving inland, especially in the low-topography regions of central Bangladesh. Subsurface migration of seawater inland is a very slow process and will reach a state of equilibrium, but only after many thousands of years. In this state, fresh groundwater could only exist at shallow depths (less than 40 to 120 m in the coastal zone, where water table elevations are between 1 and 3 m above mean sea level). However, it was found that vertical infiltration of saltwater due to storm surges or intrusion from brackish tidal rivers can occur more quickly than lateral subsurface migration of saltwater, particularly when inundation events are repetitive [22]. All the different depth levels of aquifer units down to the investigated depths of 350 m have been affected by salinity in many areas. The BWDB, 2013 and DPHE-DANIDA, 2001 [53-55] studies indicate that the erratic occurrence of small fresh water pockets at depth is reported all over the coastal belt. The fresh bodies do not seem to be connected locally with each other, which would be the case if they have been built up by groundwater flow from the hinterland [56].

The salinity appears to be closely related to the relative amounts of saline and fresh water flooding from estuarine tidal effects. The shallow groundwater is generally too saline for domestic or irrigation use due either to connate salts or estuarine flooding. However, sufficient flushing of saline water has taken place in isolated pockets to enable a limited domestic use of fresh water in the shallow aquifer. The variation of shallow groundwater salinity i.e. Electric Conductivity (EC) in the coastal aquifer is about 200-250 µS/cm in many areas which is higher during dry periods. In the deep aquifer (>225 m) the pattern of salinity distribution is more uniform on a regional basis, as is the continuity of the aquifer [56].

Sea level rise is the most direct impact of climate change contributing to salinity intrusion or inundation of coastal freshwater resources, particularly for shallow alluvial aquifers. The implications of climate change for saltwater intrusion in the coastal region of Bangladesh have not been investigated in great detail. In the coastal area, drinking water is mainly derived from deep wells and irrigation is limited to surface water bodies. Fresh water is also available at shallow depth sourced from seasonal precipitation but turns to brackish condition during dry period. Therefore, assessment and monitoring of development stress and probable impact of climate change on freshwater resources is utmost important where mathematical models can play a vital role [57].

2.7.3 Excessive Withdrawal of Groundwater in Urban Areas

Although water supply in Dhaka has been organized for more than 100 years, systematic groundwater development started only in 1949 [60]. Based on the total population of over 12 million, presently more than 2.0 Mm^3 of water is required every day to fulfill the municipal demand of Dhaka City. Dhaka is dependent mainly on the groundwater resources of the fluvio-deltaic Plio-Pleistocene Dupi Tila Aquifer, which provides about 78% of the total water supply [21]. Groundwater is the first choice for city dwellers as it is superior in quality and easy to develop. To meet the demand, about 2.0 Mm^3 is withdrawn daily by about 690 DWASA

(Dhaka Water Supply and Sewerage Authority) tube wells and delivered to the inhabitants by a 2500-km-long pipeline network, in which system loss is assumed to be more than 25% [61].

It is estimated that the volume extracted by more than 900 private deep tube wells in the city area may be more than 50% of the DWASA withdrawal. Compared to the exploitation of groundwater, the renewable recharge to the aquifer is nearly negligible. Natural water recharge to the aquifer has not kept pace with the water withdrawal for more than three decades, causing a drop in the water table. The average annual rates of decline in different parts of Dhaka City range from 0.17 to 0.6 m/yr from 1970 to 1980, 0.15 to 0.69 m/yr from 1980 to 1990, 0.56 to 2.26 m/yr from 1990 to 2000 and 1.0 to 3.0 m/yr since 2000 [88]. The rate of lowering of the water table over the last 15 years in many parts of Dhaka city has been 3.0 m/yr. In the central part of the city the maximum depth to water table in the upper aquifer is more than 60 m bgl that was within a meter in 1960s. Thus, the aquifer is not being replenished in the city area. Due to alarming declination rate of groundwater table in upper aquifer (125-150 m depth) the depth of tube wells is now being extended to 300-320 m deep, which is generally below a significant aquitard. Already more than hundred tube wells have been installed in this deeper part by DWASA [61]. As a result, the groundwater table in the deeper aquifer has also started to decline continuously in many areas.

2.8 WATER SCARCITY AT BARIND DROUGHT-PRONE AREA

Barind is known for drought prone characteristics where average annual precipitation is low compared to the other part of Bangladesh. Moreover, the upper hard and almost impermeable clay layer has a thickness of 8 to more than 25 m that retards vertical percolation of precipitation water and reduces recharge rates. The BMDA has been implementing large scale groundwater irrigation schemes for a few decades that causes decline of groundwater table below the suction limit (7.5 m) of hand tube wells in many areas. The thickness of the lower aquitard i.e., clay is more than hundred meters and drilling with local methods is almost impossible. Therefore, the deep aquifer in the area is not well identified and needs to be explored to reduce stress on shallow groundwater. The maximum and minimum groundwater table in Nachole Upazilas area, measured in BWDB observation wells are recorded between 10.0 and 30.0 m and 7 and 22.0 m respectively with the seasonal fluctuation of about 3-10 m. Therefore, water table in most of the areas declines below the suction limit of hand tube wells (7.5 m) almost round the year which is mainly due to huge irrigation abstraction of groundwater from upper aquifers. Permanent declination is also noticed in many areas under Barind. In the High Barind area significant land gradients exist, which influence groundwater movement [62].

CHAPTER 3: STUDY AREA AND METHODOLOGY

3.1 ROLE OF BWDB IN GROUNDWATER MONITORING

The hydrogeological data and information are required for understanding of the groundwater conditions. The more of this information the better the assessment results regarding the aquifers, water levels, hydraulic gradients, flow velocity and direction, water quality, and simulations of groundwater models. The major success stories of development of groundwater were initiated by the Erstwhile EPWAPDA (present BWDB) in 1962 through the Hydrology Directorate. In 1967, EPWAPDA felt the need to increase the development of groundwater with a view to survey the groundwater resources of the country and collect basic data for its systematic and orderly development for different uses. In 1970, Ground Water Circle was then established to undertake a detailed survey of the groundwater resources of the country. The role of BWDB in groundwater management includes fundamental data collection and analysis, basic assessment and process to understand the groundwater system, development of analytical tools for water resource planning and monitoring.

With the UNDP assistance the Ground Water Circle executed the schemes in 3 (three) phases: (i) Groundwater Survey in Bangladesh (1970–1980), (ii) Groundwater Development Studies in Bangladesh (1980-1985) (iii) and one umbrella project (1985–1990). Total of 1272 groundwater observation wells and 20 auto recorders have been installed mostly at shallow depths (<50 m) and water table/level data have been collected once a week for about 55 years. Monitoring of groundwater quality has been conducted all over the country from 117 water quality stations.

3.1.1 Observation wells nests (clustered wells) installed in the coastal belt under BCCT Project

Evaluation of the spatial and temporal variations of groundwater levels (potentiometric surface) for each aquifer resulting from natural and man-made processes needs to be monitored by installing observation wells i.e., piezometers. In an area several aquifers at different depths may be separated by impervious layers of different thicknesses. Aquitards are sealed off by grouting from the aquifer lying above it. If the geology of the area and the depth to each of the aquifers are well known, it is important to drill and construct separate wells in each aquifer, i.e., well nests in each aquifer unit. In Bangladesh where a multi-layer aquifer system exists, installation of observation well nests is important to know water quality and hydraulic behavior of different aquifer units.

In the coastal areas where availability of fresh and safe water is a big problem due to arsenic contamination and saline water intrusion in upper aquifers, assessment and monitoring of probable impact of climate change i.e., sea-level rise on fresh water resource is utmost important. In this context this project “Establishment of Monitoring Network and Mathematical Model Study to Assess Salinity Intrusion in Groundwater in the Coastal Area of Bangladesh due to Climate Change” has been undertaken by BWDB, Ministry of Water Resources funded under the Climate Change Trust Fund (CCTF) of the Ministry of Environment and Forest. BWDB has installed 42 clustered monitoring wells (each cluster consists of 3-5 wells) and 510 line wells up to the depth of 350 m and 100 m respectively in 19 coastal districts under this project in addition to the existing permanent monitoring well network all over the country.

3.2 FIELD INVESTIGATIONS

Under the ongoing ‘Bangladesh Regional Weather and Climate Services Project (BWCSRP), Component B: Strengthening Hydrological Information Services and Early Warning Systems’ funded by the IDA, the World Bank, 69 clustered monitoring wells have been installed covering the entire country. Each unit consists of 4 wells having the maximum depth of 300 m. Under the same project, 901 monitoring wells, including all clustered wells, automated using data-logger for temperature, groundwater level and electric conductivity i.e., salinity. Recorded real-time data will be transferred to the database by telemetry. As these automated systems are installed and maintained properly, the data frequency and accuracy will be enhanced.

3.3 METHODS OF ANALYSIS

Elements are analyzed in different methods based on the equipment and element characteristics. Most of the cations are analyzed in Atomic Absorption Spectroscopy (AAS). Carbonate, Bi-carbonate and Chloride are analyzed in titration method. Anions are analyzed mainly in UV-VIS Spectrophotometry and VIS Spectrophotometer.

Table 3-1: Lab Analysis Method

Sl. No.	Water Quality Parameters (BWDB)	Method / Equipment Wet Season 2020	Method / Equipment Dry Season 2020
1	Iron (mg/l)	UV-VIS Spectrophotometry	Atomic Absorption Spectroscopy (AAS)
2	Copper (mg/l)	UV-VIS Spectrophotometry	Atomic Absorption Spectroscopy (AAS)
3	Manganese (mg/l)	UV-VIS Spectrophotometry	Atomic Absorption Spectroscopy (AAS)
4	Carbonate (mg/l)	Titration	Titration
5	Bi-carbonate (mg/l)	Titration	Titration
6	Calcium (mg/l)	Atomic Absorption Spectroscopy (AAS)	Atomic Absorption Spectroscopy (AAS)
7	Magnesium (mg/l)	Atomic Absorption Spectroscopy (AAS)	Atomic Absorption Spectroscopy (AAS)
8	Sodium (mg/l)	Atomic Absorption Spectroscopy (AAS)	Atomic Absorption Spectroscopy (AAS)
9	Potassium (mg/l)	Atomic Absorption Spectroscopy (AAS)	Atomic Absorption Spectroscopy (AAS)
10	Chloride (mg/l)	Titration	Titration
11	Nitrate (mg/l)	VIS Spectrophotometer	VIS Spectrophotometer
12	Phosphate (mg/l)	VIS Spectrophotometer	VIS Spectrophotometer
13	Sulphate (mg/l)	VIS Spectrophotometer	VIS Spectrophotometer
14	Boron (mg/l)	VIS Spectrophotometer	VIS Spectrophotometer

15	Bromide (mg/l)	VIS Spectrophotometer	VIS Spectrophotometer
16	Iodide (mg/l)	VIS Spectrophotometer	VIS Spectrophotometer
17	Aluminium (mg/l)	UV-VIS Spectrophotometry	Atomic Absorption Spectroscopy (AAS)
18	Arsenic (mg/l)	Atomic Absorption Spectroscopy (AAS)	Atomic Absorption Spectroscopy (AAS)
19	Chromium (mg/l)	Atomic Absorption Spectroscopy (AAS)	Atomic Absorption Spectroscopy (AAS)

3.4 PROCEDURES OF THE TEST METHODS

Detailed description of the Procedures of the test Methods are presented as Annexure A (3.4.1 to 3.4.13).

3.5 AQUIFER SYSTEM AT 69 LOCATIONS BASED ON THE EXPLORATORY DRILLING

Hydrogeological Investigation

The hydrogeological investigation was conducted based on the exploratory drilling at 69 locations in Bangladesh down to the maximum depth of 304 meter under the project of “Bangladesh Weather and Climate Service Regional Project Component-B: Strengthening Hydrological Information Services and Early Warning Systems”. Borehole lithologic logs have been prepared for all locations to define the aquifer system.

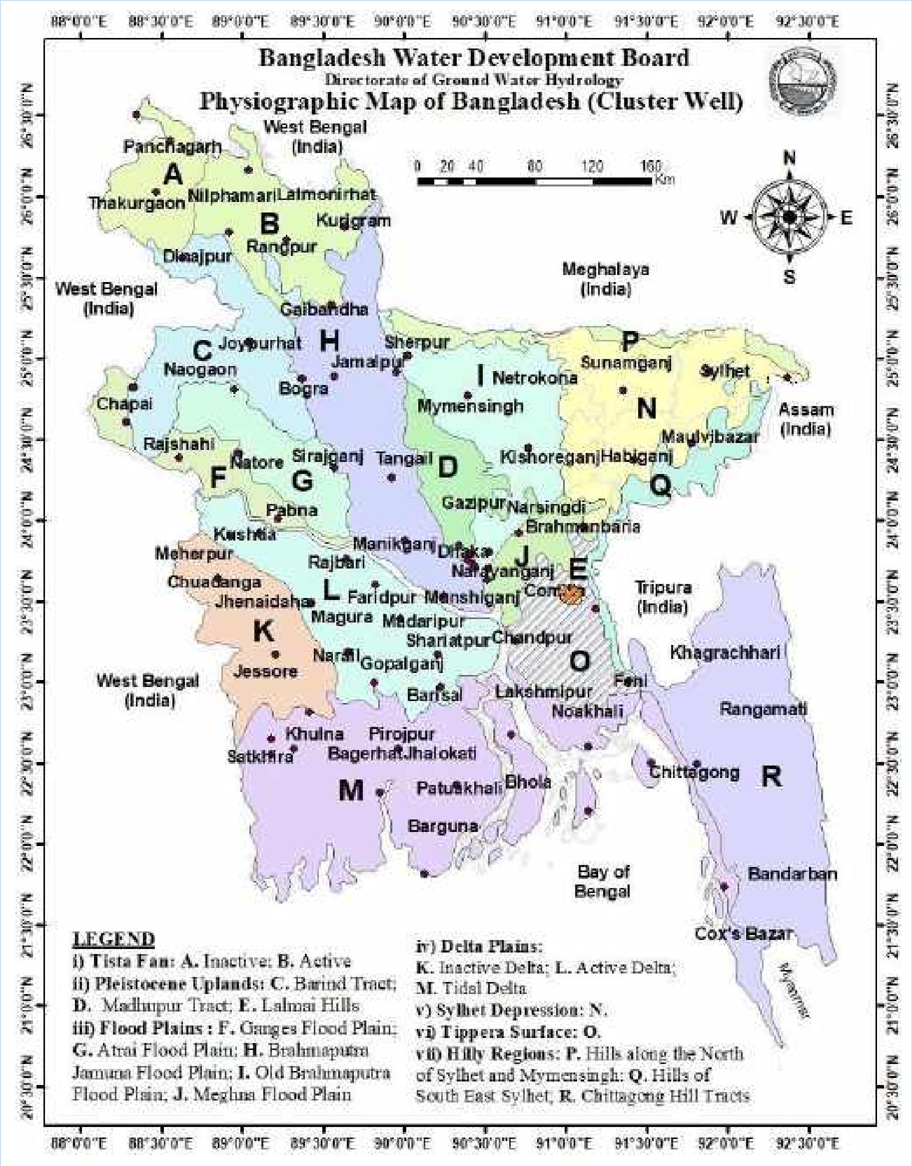


Figure 3-1: Locations of Exploratory Boring and Clustered Wells Allover Bangladesh.

Aquifers of Bangladesh can be described physio-graphically in 7 divisions. All these divisions are –

Physiographic Divisions

i) Hilly Regions
  a) Chattogram Hill Tracts; b) Hill Ranges of NE Sylhet;
  c) Hills along the Narrow Strip of Sylhet and Mymensingh
ii) Pleistocene Uplands
  a) Barind Tract rt; b) Madhupur Tract; c) Lalmai Hills
iii) Tippera Surface
iv) Tista Fan
v) Flood Plains
  a) Ganges Floodplain; b) Atrai Floodplain;
  c) Brahmaputra Jamuna Flood Plain; d) Old Brahmaputra Flood Plain; e) Meghna Flood Plain
vi) Delta Plain of the GBM Delta Complex
  a) Active Delta; b) Inactive Delta; c) Tidal Delta
vii) Sylhet Depression and Inland Marshes

3.5.1 Lithologic Characterization at Hilly Regions

The exploratory drilling was conducted up to the depth of 304.88 m at BWDB Subdivision Office Compound, Hathazari, Chattogram under the project of BWCSRP. From the strip log it can be perceived that there are two major aquifers present from 42.68-176.83 m and 246.95-304.88 m and consist of fine sand, very fine sand and medium sand material. These aquifers are separated with thick silty clay layers. The silty clay layers are interbedded with some thin fine or very fine sand layers.

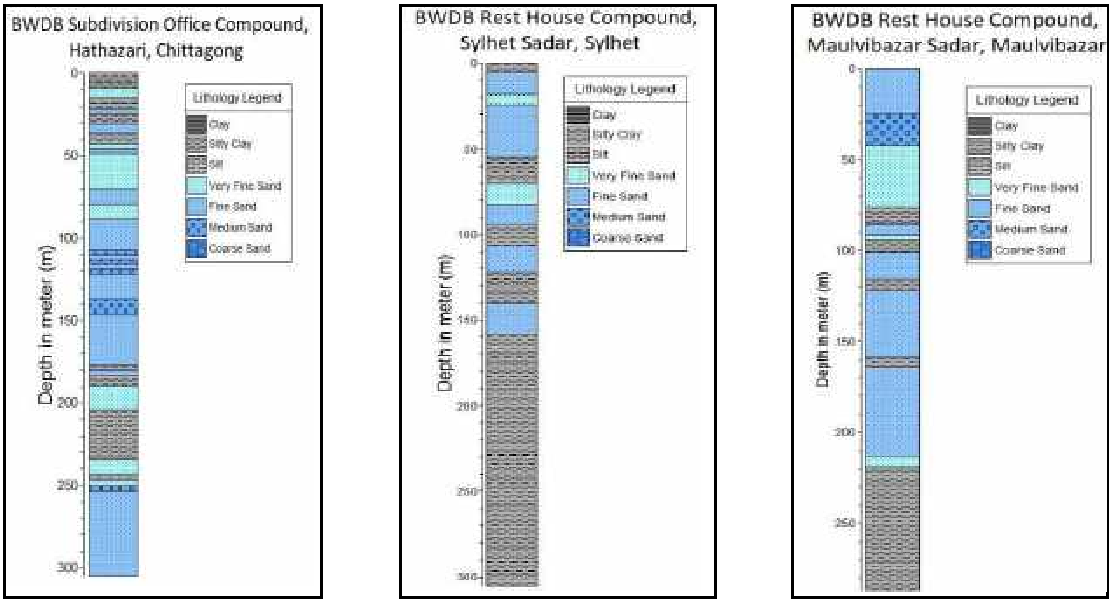


Figure 3-2: Borehole Lithological Logs of Hilly Regions.

3.5.2 Lithologic Characterization at Pleistocene Uplands

The exploratory drilling was conducted up to the depth of 292.68 m at WARPO Compound, Green Road, Dhaka under the project of BWCSRP. From the strip log, it can be perceived that there are two major thick aquifers present from 6.10-134.15 m and 189.02-292.68 m, separated with 30.48 m thick silty clay and Clay layers. The first aquifer is composed of fine sand and very fine sand. The second aquifer is composed of alternation of fine sand and very fine sand layer.

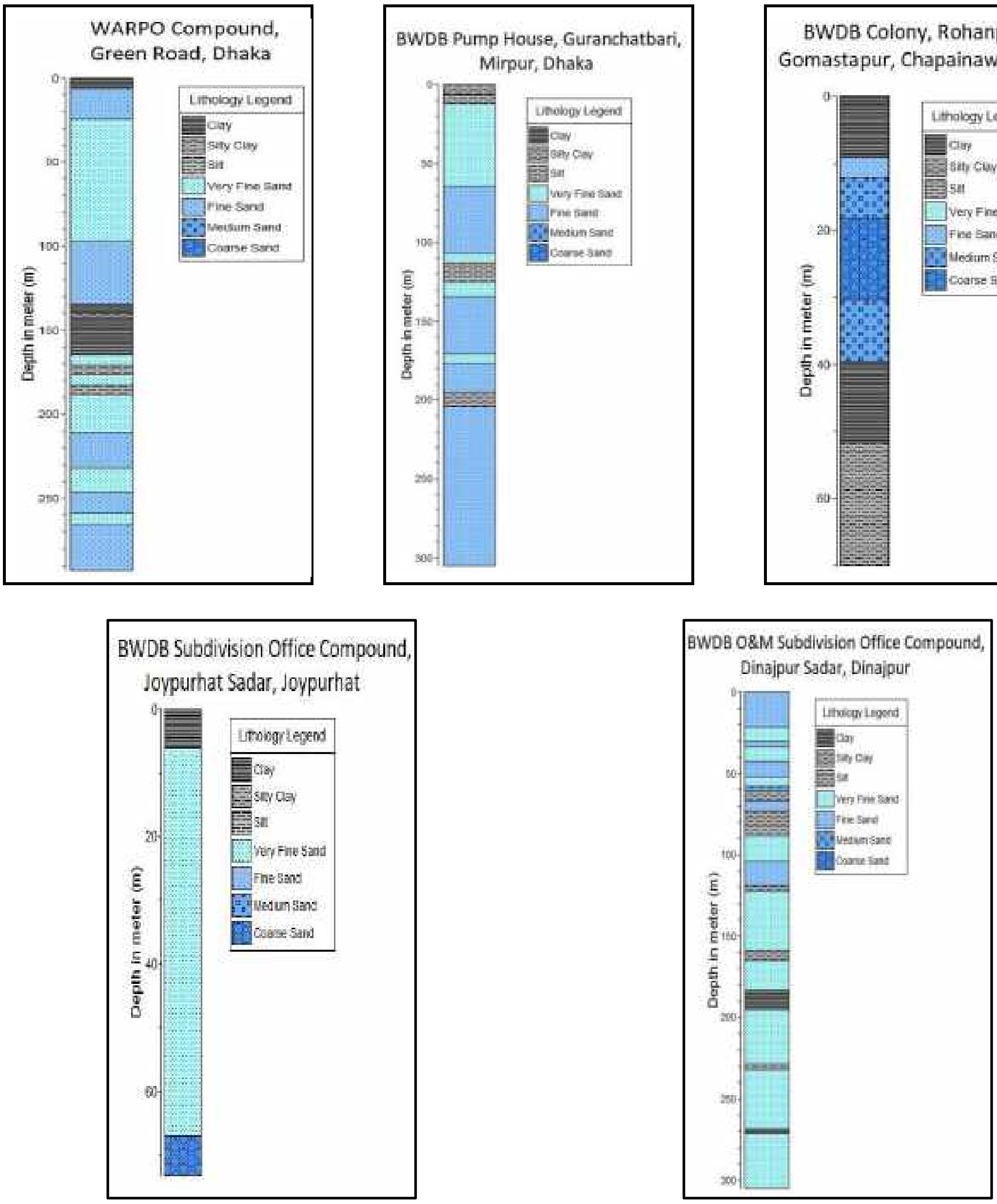


Figure 3-3: Borehole Lithological Logs of Pleistocene Upland Areas.

3.5.3 Lithologic Characterization at Tippera Surface

The exploratory drilling was conducted up to the depth of 304.88 m at BWDB Office Compound, Chandpur Sadar, Chandpur under the project of BWCSRP. From the strip log it is observed that there are two thick aquifers present from 0-60.98 m and 67.07-304.88 m, separated by a 7 meter thin silty clay layer. The first aquifer is composed of fine sand, very fine sand and medium sand material. The second aquifer is composed of mostly medium sand and coarse sand materials.

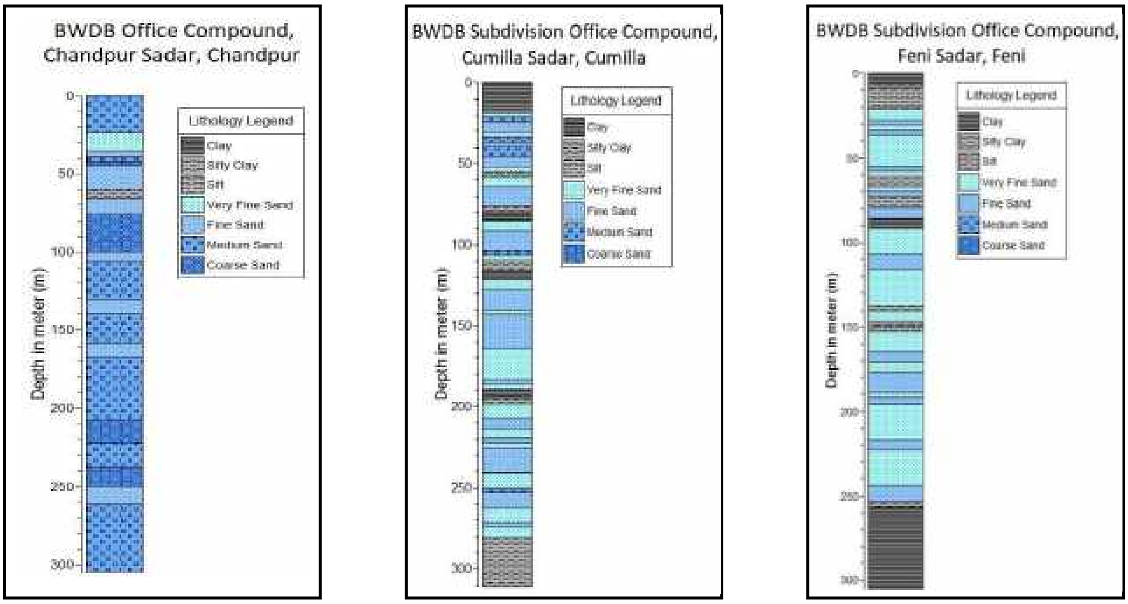
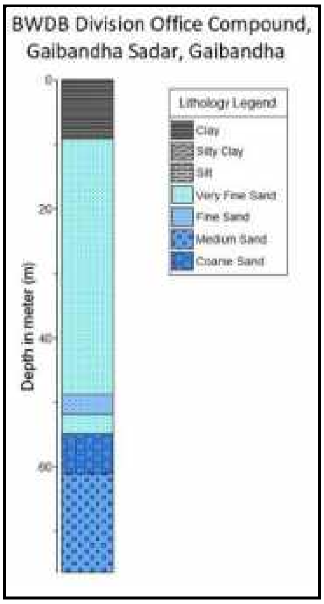
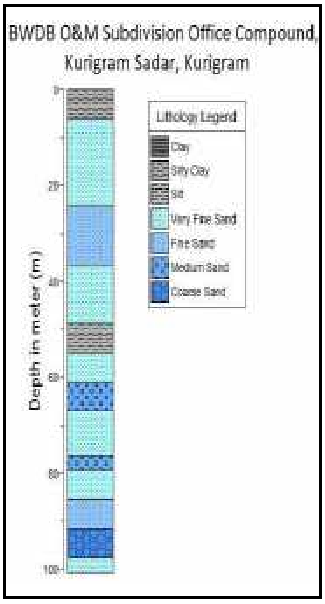


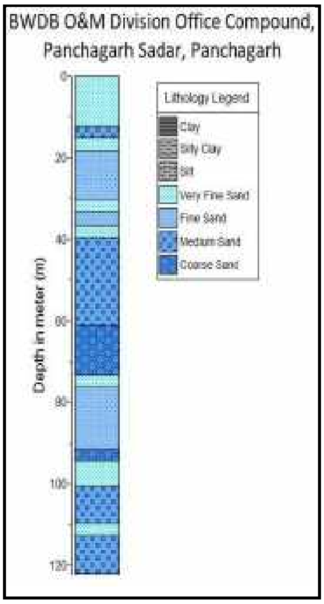
Figure 3-4: Borehole Lithological Logs of Tippera Surface.

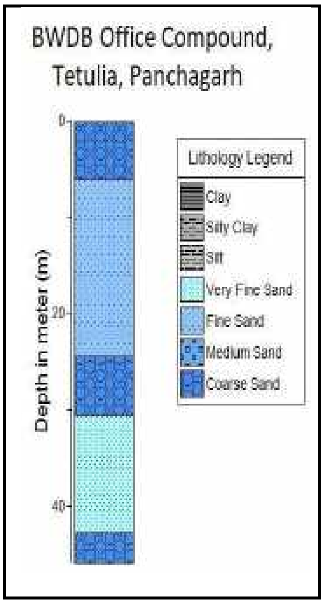
3.5.4 Lithologic Characterization at Tista Fan

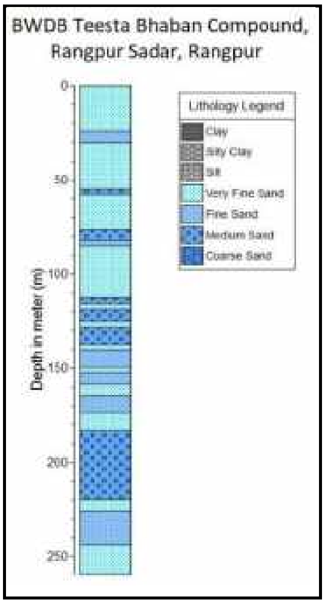
The exploratory drilling was conducted up to the depth of 75 m at BWDB Division Office Compound, Gaibandha Sadar, Gaibandha under the project of BWCSRP. From the strip log it is observed that there is only one aquifer present from 9-75 m below a clay layer at the top of the surface. The aquifer can be divided into two types based on the type of sediment. First one is present from 9-55 m which is mostly composed of very fine sand. Second one is composed of coarse sand and medium sand materials, which is considered to be a prolific aquifer for this area.

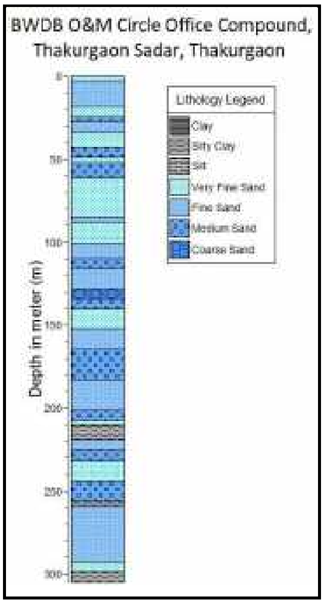












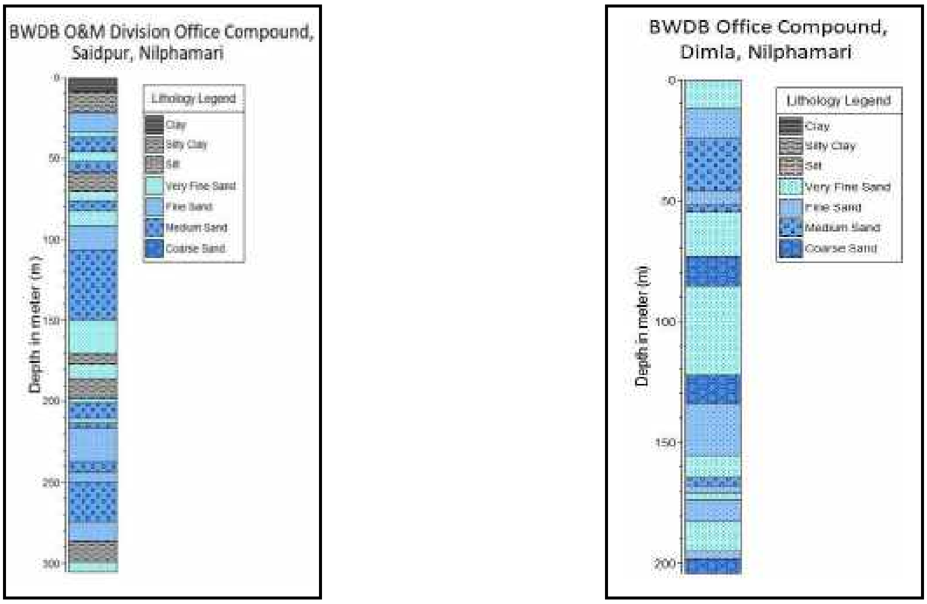
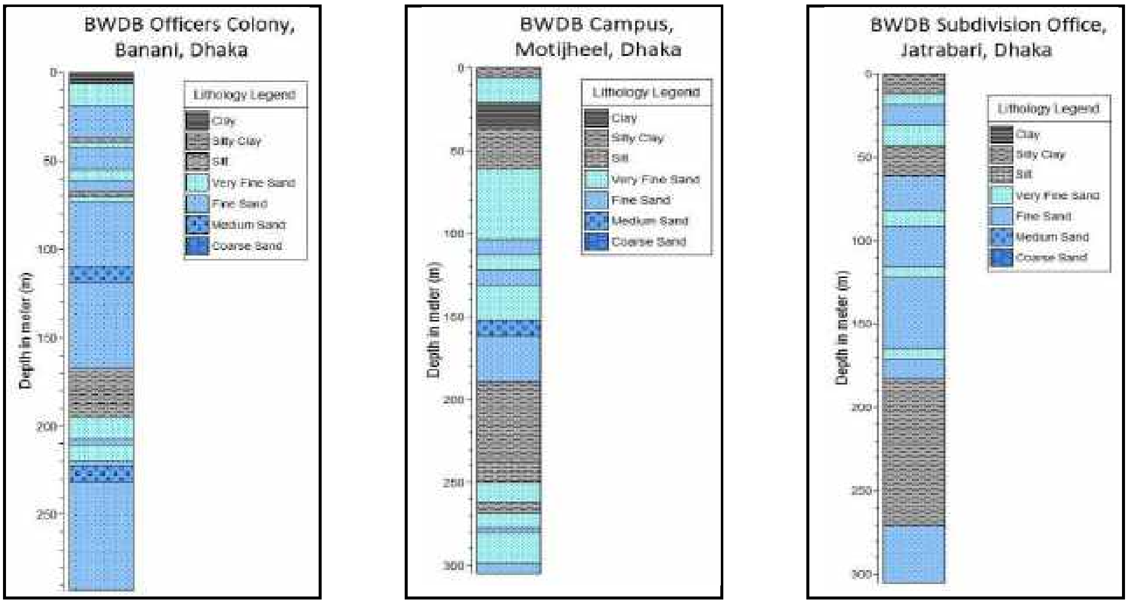
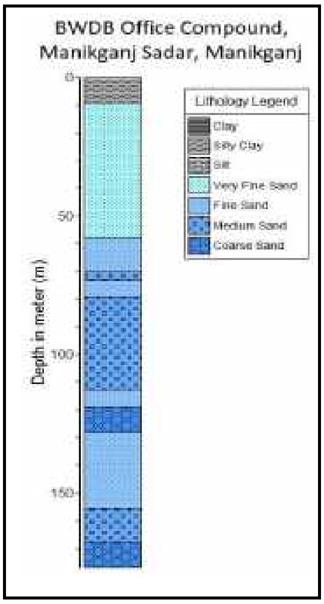


Figure 3-5: Borehole Lithological Logs of Tista Fan.

3.5.5 Lithologic Characterization at Flood Plain

The exploratory drilling was conducted up to the depth of 292.68 m at BWDB Officers Colony, Banani, Dhaka under the project of BWCSRP. From the strip log, it is observed that there are two thick aquifers present from 6.10-167.68 m and 195.12-292.68 m, separated with 28 m thick silty clay aquitard layer. The first aquifer is composed of mostly fine sand materials with two 3 m thick lenses of silty clay materials. The second aquifer is mostly composed of fine sand with some very fine sand and medium sand materials.

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150
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Silt
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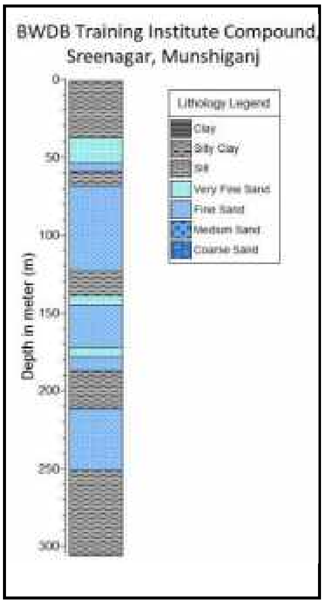
Fine Sand
Medium Sand
Coarse Sand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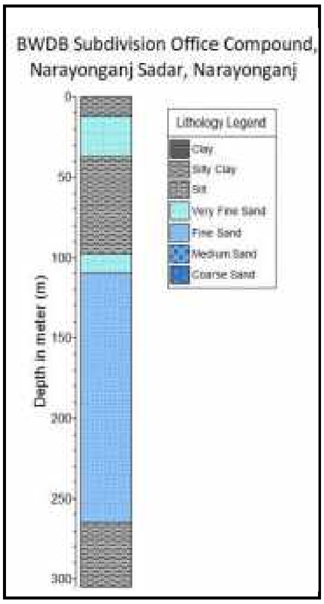
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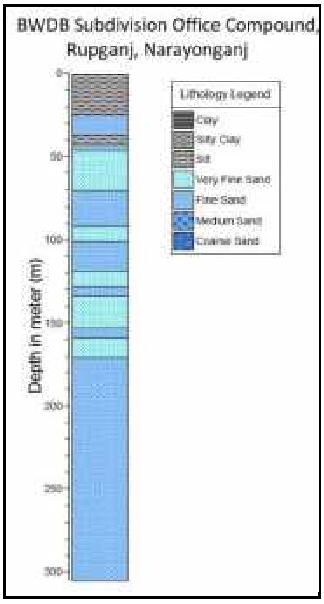
Medium Sand
Coarse Sand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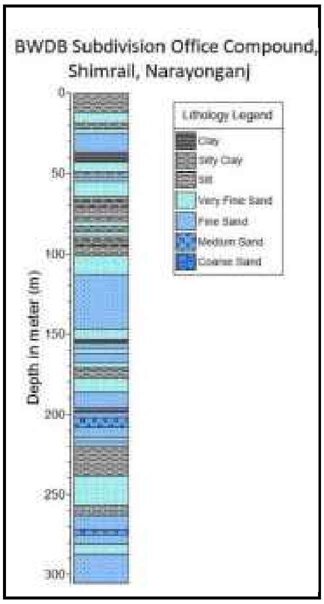
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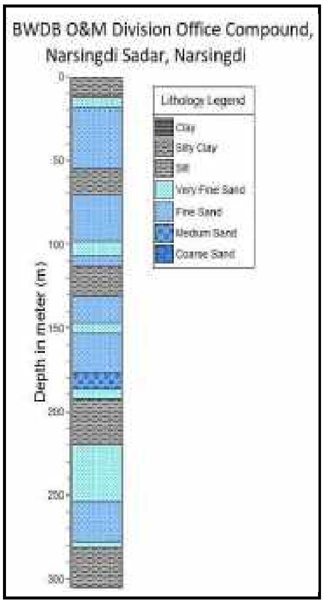
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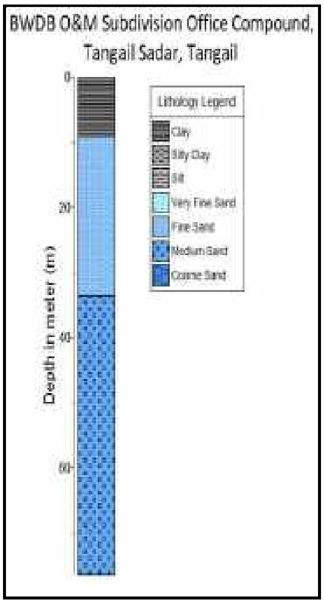
Coarse Sand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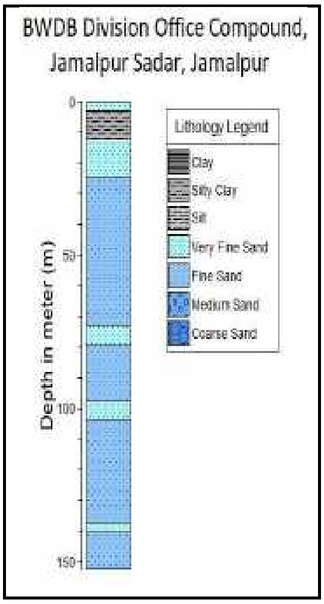
Coarse Sand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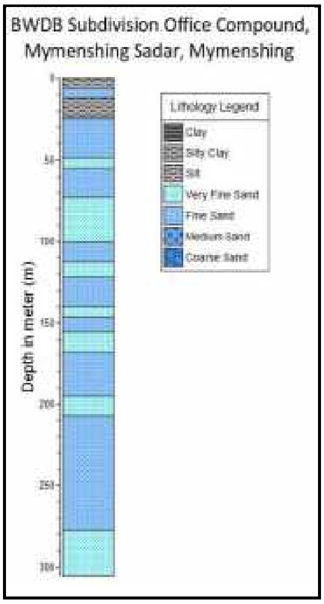
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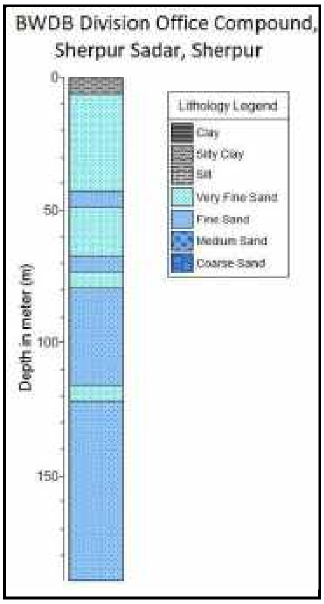
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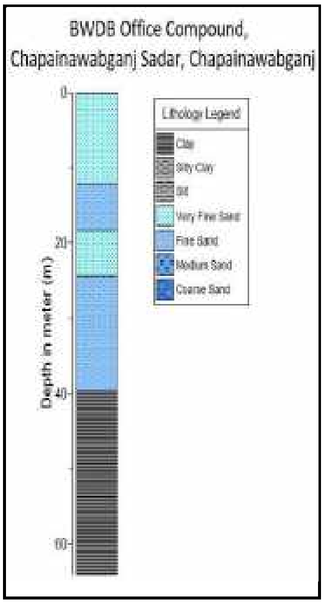
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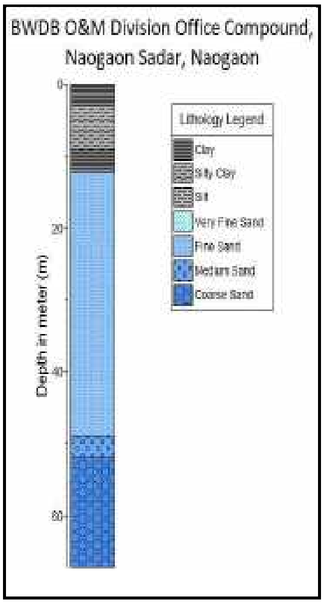
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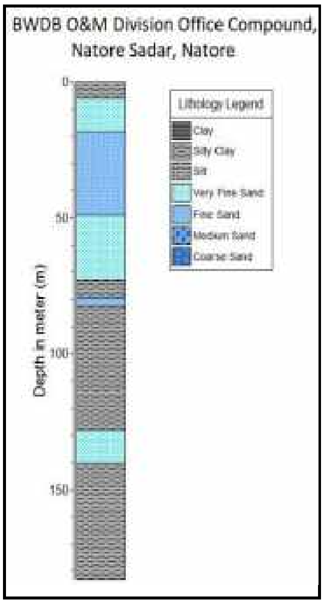
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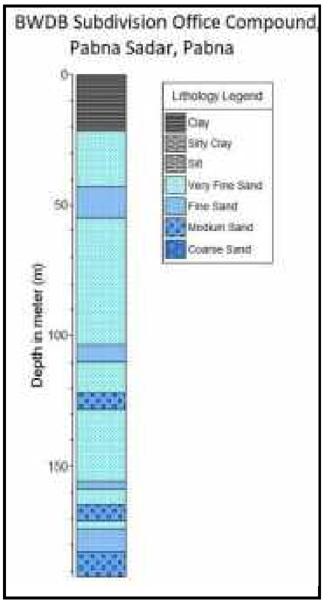
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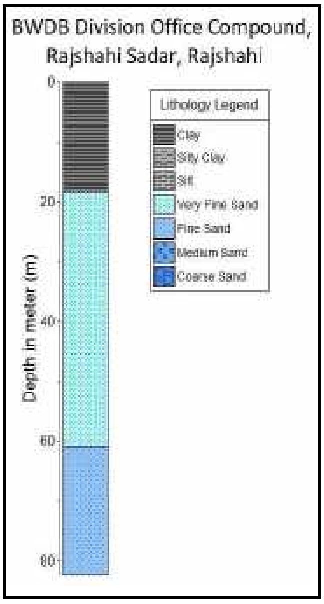
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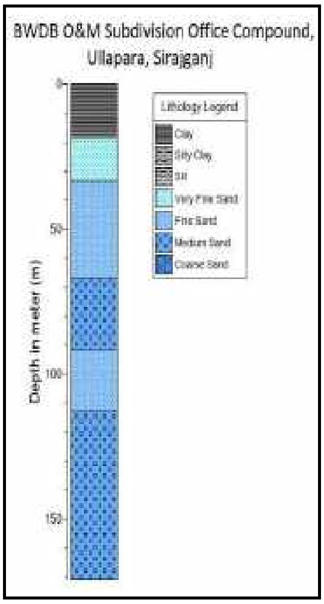
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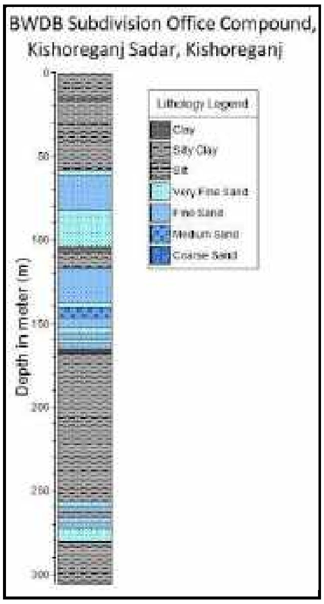
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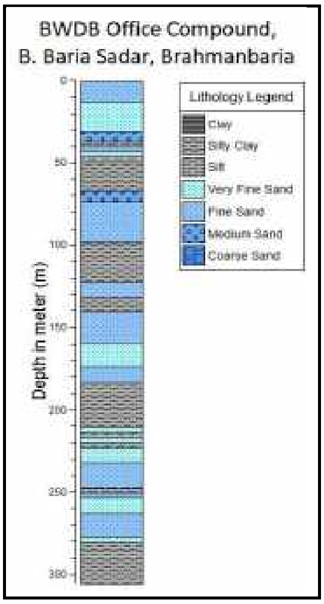
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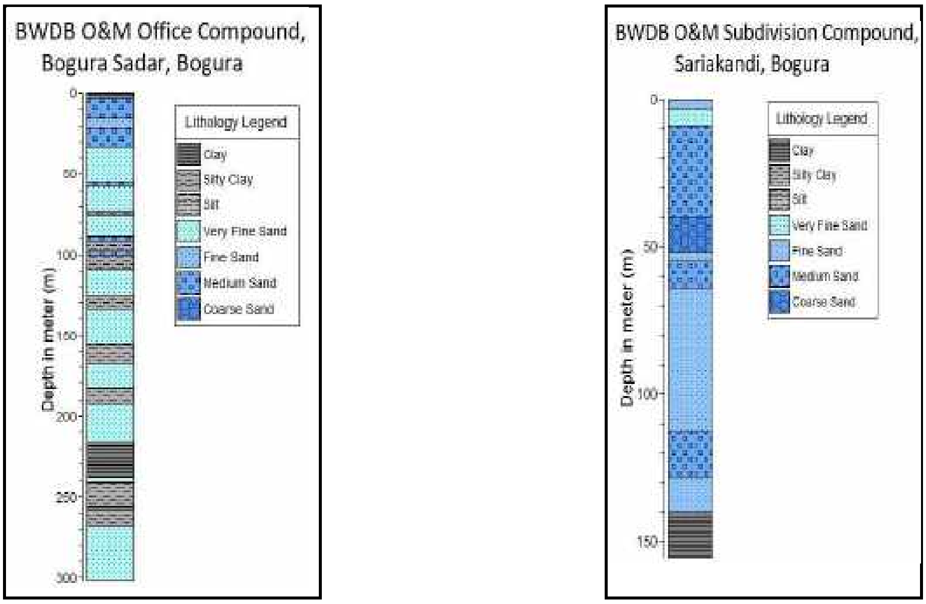
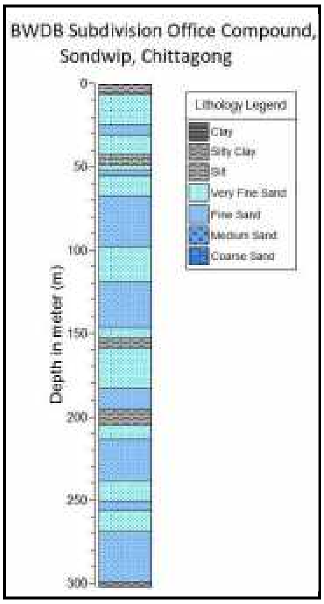
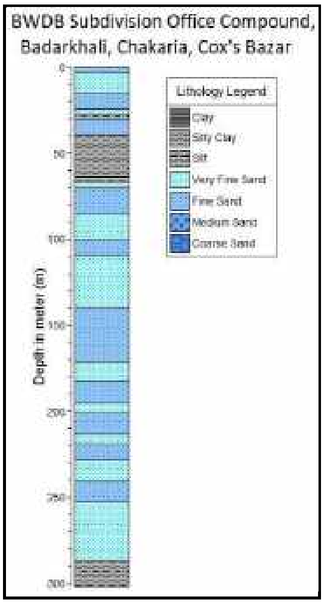


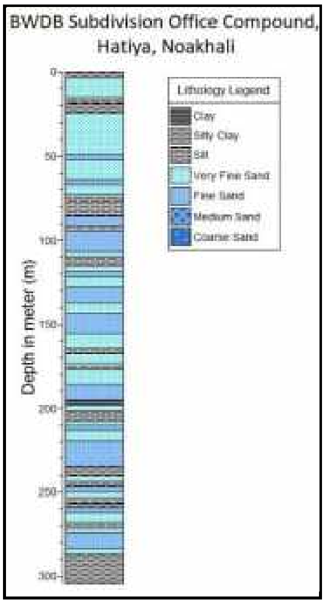
Figure 3-6: Borehole Lithological Logs of Flood Plains.

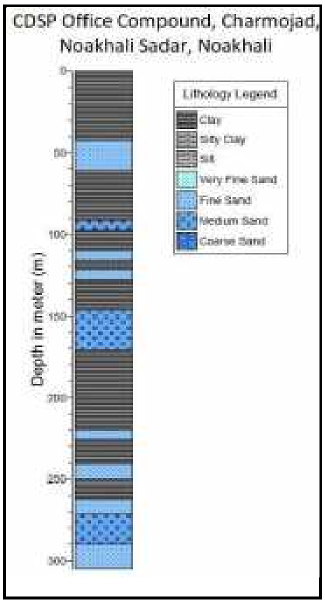
3.5.6 Lithologic Characterization at Delta Plain

The exploratory drilling was conducted up to the depth of 301.83 m at BWDB Subdivision Office Compound, Sandwip, Chattogram under the project of BWCSRP. From the strip log, it can be perceived that there are four aquifers present from 6.1- 42.68 m, 48.78- 152.44 m, 158.54- 195.12 m and 204.27- 298.78 m, separated with thin aquitards. The aquifers consist of very fine sand and fine sand materials. The thickness of the aquitard varies from 6-9 m. The aquitards consist of silt and silty clay material.





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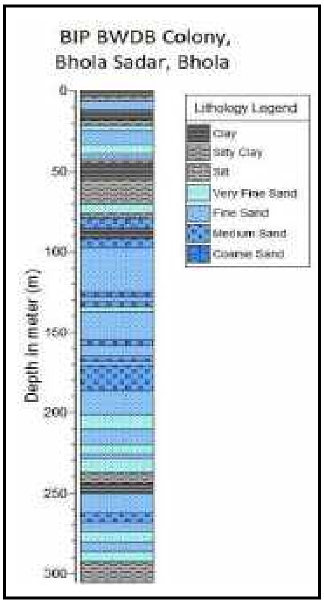
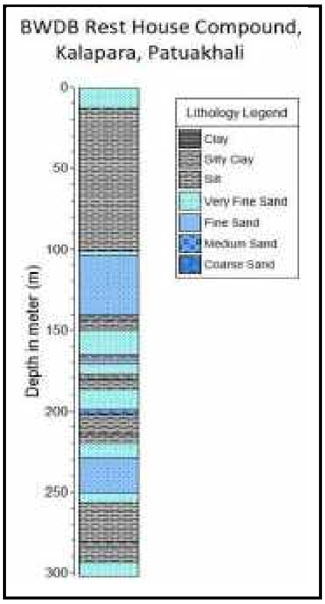
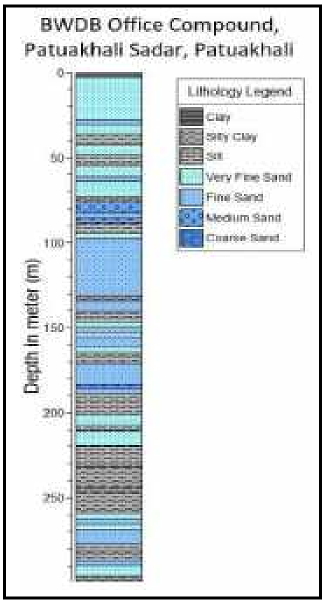

BIP BWDB Colony, Bhola Sadar, Bhola


BWDB Rest House Compound, Kalapara, Patuakhali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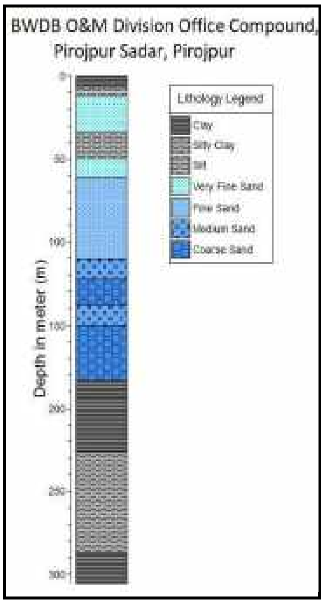
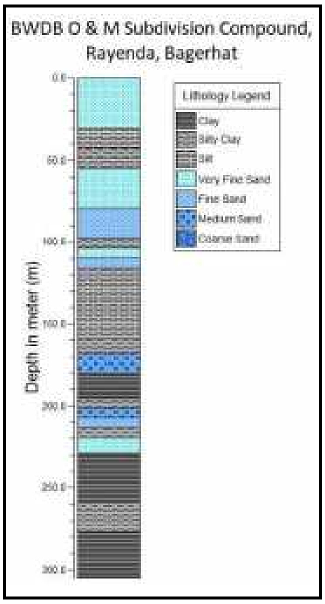

BWDB O&M Division Office Compound, Pirojpur Sadar, Pirojpur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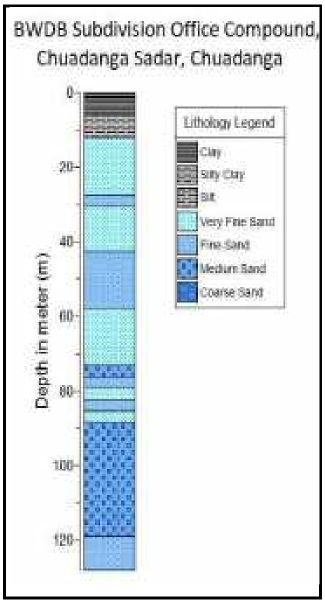
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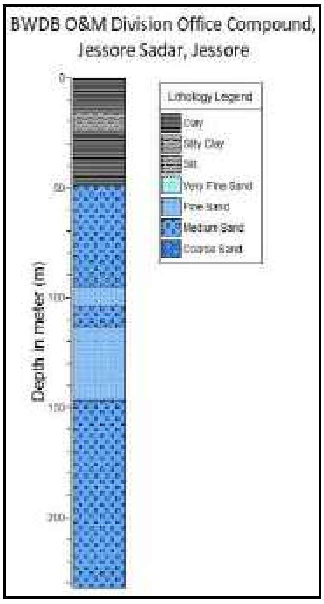
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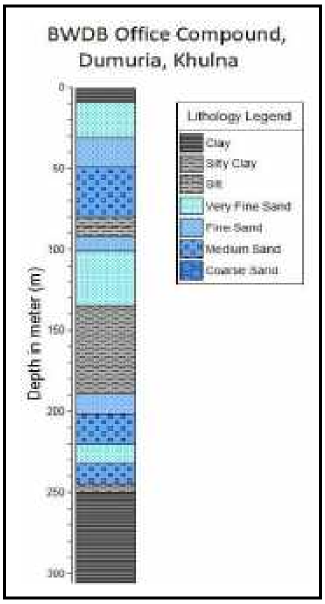
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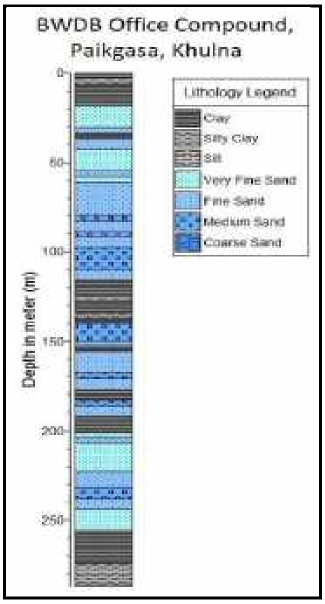
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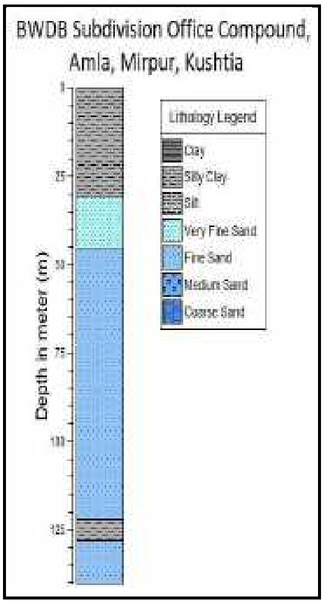
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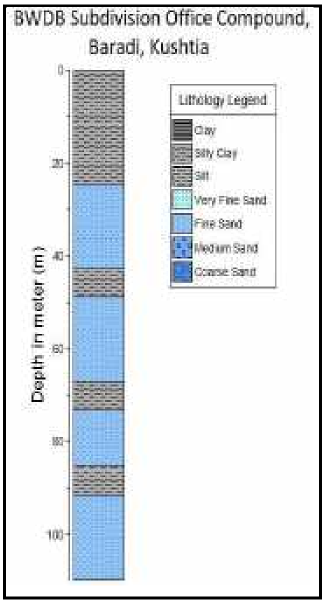
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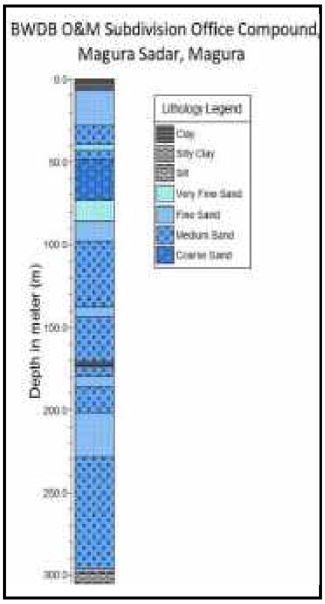
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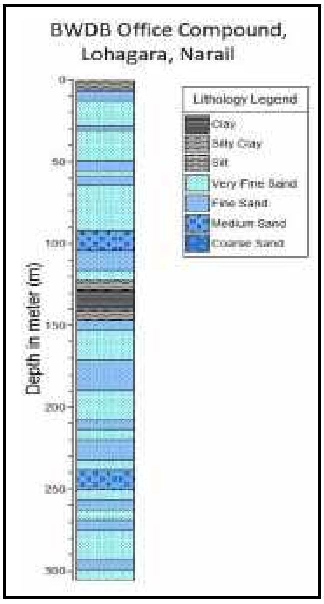
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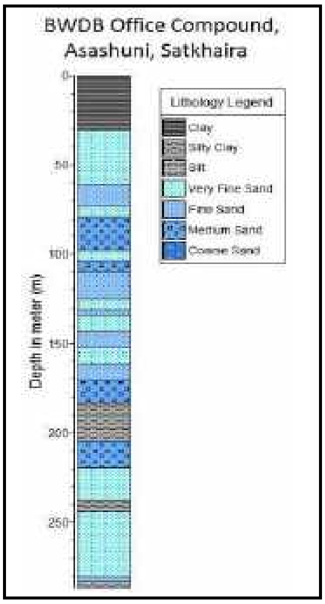
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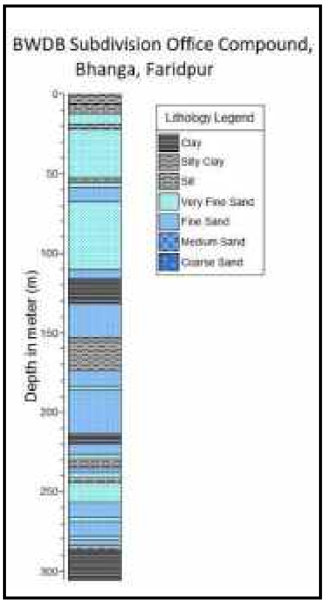
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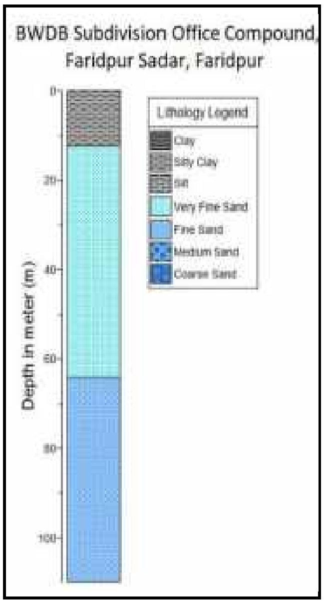
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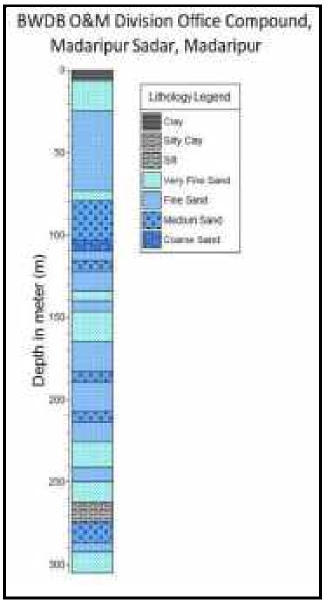
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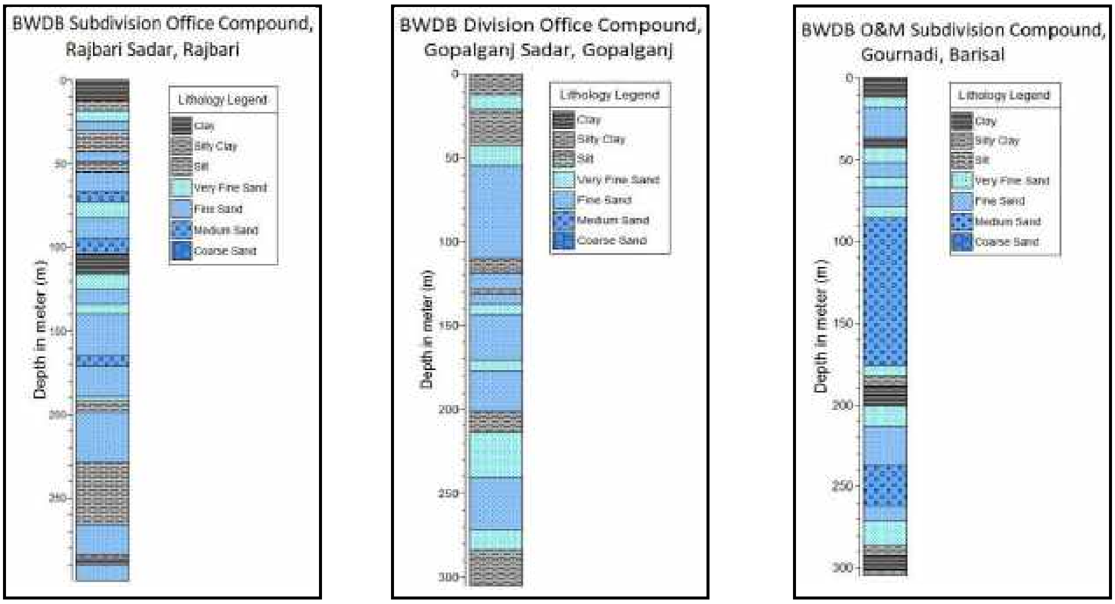

Figure 3-7: Borehole Lithological Logs of Delta Plain Areas.

3.5.7 Lithologic Characterization at Sylhet Depression

The exploratory drilling was conducted up to the depth of 304.88 m at BWDB Rest House Compound, Sylhet Sadar, Sylhet under the project of BWCSRP. From the strip log, it is observed that there is an aquitard layer present from 0-6 m at the top of the area. Below this layer, there are four aquifers present from 6-54 m, 70-95 m, 108-122 m and 140-160 m, separated with silty clay aquitard layers. The aquitard layers thickness varies from 9-18 m. The aquifer sediments consist of very fine sand and fine sand. There is no aquifer encountered below 160 to the drilling depth of 304.88 m, which is composed of silty clay aquitard layer.

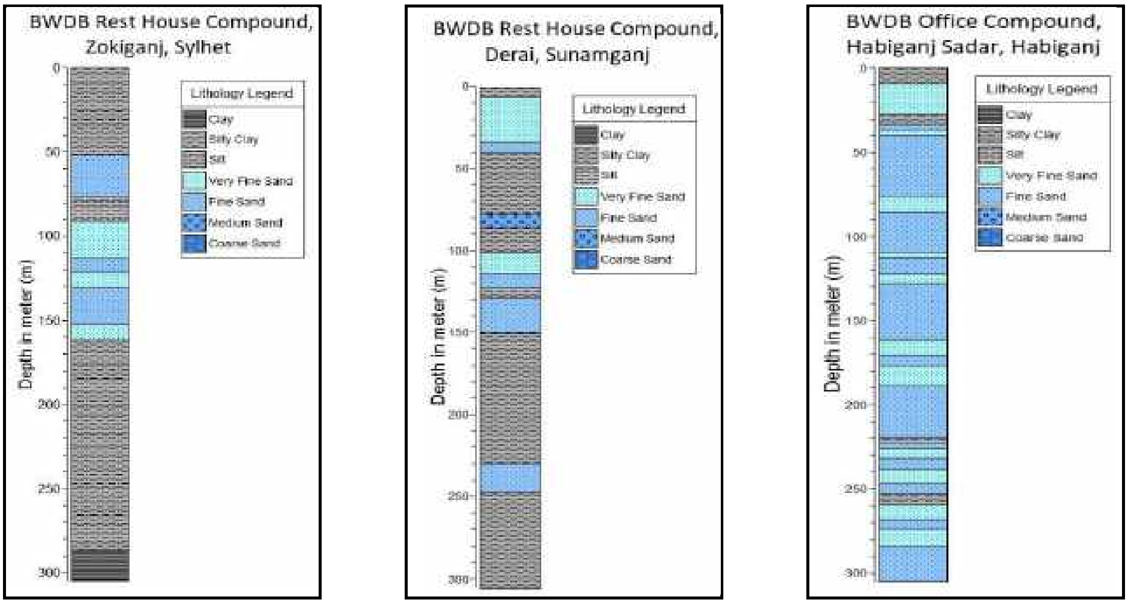

Figure 3-8: Borehole Lithological Logs of Sylhet Depression.

3.6. WATER QUALITY SURVEY AND SAMPLING

A number of field parameters were measured in the field using field kits and handheld field instruments at more than 901 wells 64 districts all over Bangladesh including shallow and deep wells. In all the districts, shallow and deep wells were surveyed.

Figure 3-9: Groundwater Sampling and Measurement of Physical Parameters.

Water samples were also collected from these wells for detailed chemical analysis in the laboratory. For each well, two samples of 500ml acidified and 1000ml of two non-acidified water samples were collected in plastic bottles. Each well was purged for at least 10 minutes before field measurements and sampling. The field parameters measured using handheld meters include- pH, EC, ORP, Salinity, Turbidity, TDS and Temperature. Arsenic was measured in the field using a Field test kit.

3.6.1 Groundwater Level Survey

Depth to groundwater was measured in the field using the level meter at each of the water sampling locations. Like the water sampling, water level was measured in both a shallow and a deep well at every location except when the pair was not available. The depth to water data collected from the field was later converted to groundwater level.

Figure 3-10: Groundwater Level Measurement in Various Locations.

3.7 LABORATORY ANALYSIS

For water quality analysis most of the major ions were analyzed. Some important trace elements were also analyzed to ensure the quality of groundwater all over Bangladesh. For all these analyses different methods were used which are shown in table 3.1.

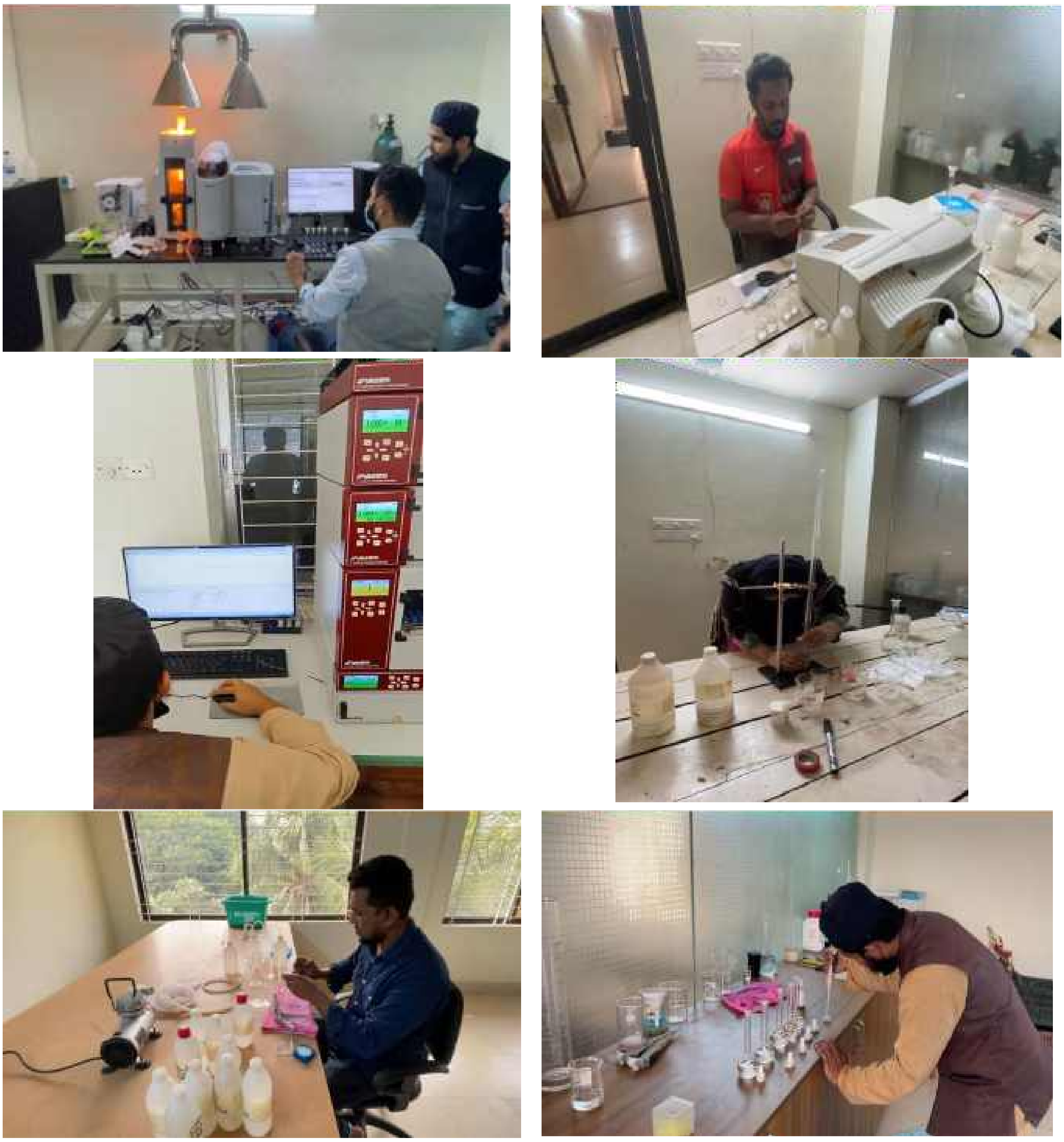

Figure 3-11: Chemical Analysis in Ground Water Hydrology Laboratory of BWDB.

CHAPTER 4: WATER QUALITY

4.1 INTRODUCTION

Water quality is influenced by natural factors and processes and also by the activities of man. Before considering the effects of human intervention and anticipated impacts of climate change, it is also necessary to know about the structure and unusual properties of water as a chemical compound. Quality of both surface water and groundwater is an issue of major concern in the coastal region. Presence of salinity in surface water regime as well as at different depth levels of aquifers and arsenic in shallow groundwater is hindering its use for socio-economic development. It is anticipated that population growth, unplanned urbanization and development of water uses, sea level rise etc. may deteriorate water quality further in future. To monitor future trends of water quality changes, identify causes and devise coping mechanisms, a systematic data collection, monitoring and its evaluation is essential. Keeping this in mind, an intensive water quality data collection program was undertaken all over Bangladesh installing a long-term monitoring well network.

Groundwater samples were collected from 901 observation wells throughout Bangladesh installed at different aquifers down to the depth of 335 m. Data were mostly collected for the dry season of 2019-20 and wet season of 2020 and 2021.

4.2 WATER QUALITY PARAMETERS

Two categories of water quality parameters have been collected, namely physical parameter and chemical parameter. Physical parameters include Temperature, pH, Eh, EC, Salinity, TDS and Arsenic. Chemical parameters that have been analyzed include major anion, cation and trace elements. Values of the water quality parameters were determined in the field using field test kits as well as in the laboratories of BWDB.

Table 4-1: Number of Analyzed Water Samples

Monitoring event	Type of water	Wet season
Cluster Wells (up to 335m)	Groundwater	425
Line Wells (Up to 100m)	Groundwater	260
Single Wells	Groundwater	216
Total		**901**

For ready reference water quality standards for drinking water and irrigation water is shown in Table 4-2.

Table 4-2: Water Quality Standards [56]

Parameters	Units	Bangladesh standards		WHO standards
		Drinking limit	Irrigation limit	Drinking limit
pH		6.5 - 8.5	6.0 - 9.0	6.5 – 8.5
EC	µs/cm	600 - 1000	1200	-
TDS	mg/l	1000	2100	500 - 1000
Calcium (Ca)	mg/l	75	-	75 - 200
Magnesium (Mg)	mg/l	30 – 50	-	50
Sodium (Na)	mg/l	200	-	200
Potassium (K)	mg/l	12	-	-
Bicarbonate (HCO_3)	mg/l	-	200	-
Carbonate (CO_3)	mg/l	100		-
Chloride (Cl)	mg/l	150 - 600	600	200 - 600
Nitrate (NO_3)	mg/l	10	-	50
Phosphate (PO_4)	mg/l	6	10	-
Sulphate (SO_4)	mg/l	400	-	250
Boron(B)	mg/l	1	2	0.5
Iron (Fe)	mg/l	0.3 -1.00	1 -2	0.3
Manganese (Mn)	mg/l	0.1	5	0.1
Arsenic (As)	mg/l	0.05	1	0.01

Source: Water Quality Standards for Drinking Water and Irrigation, Ministry of Environment and Forest, GoB, 1997

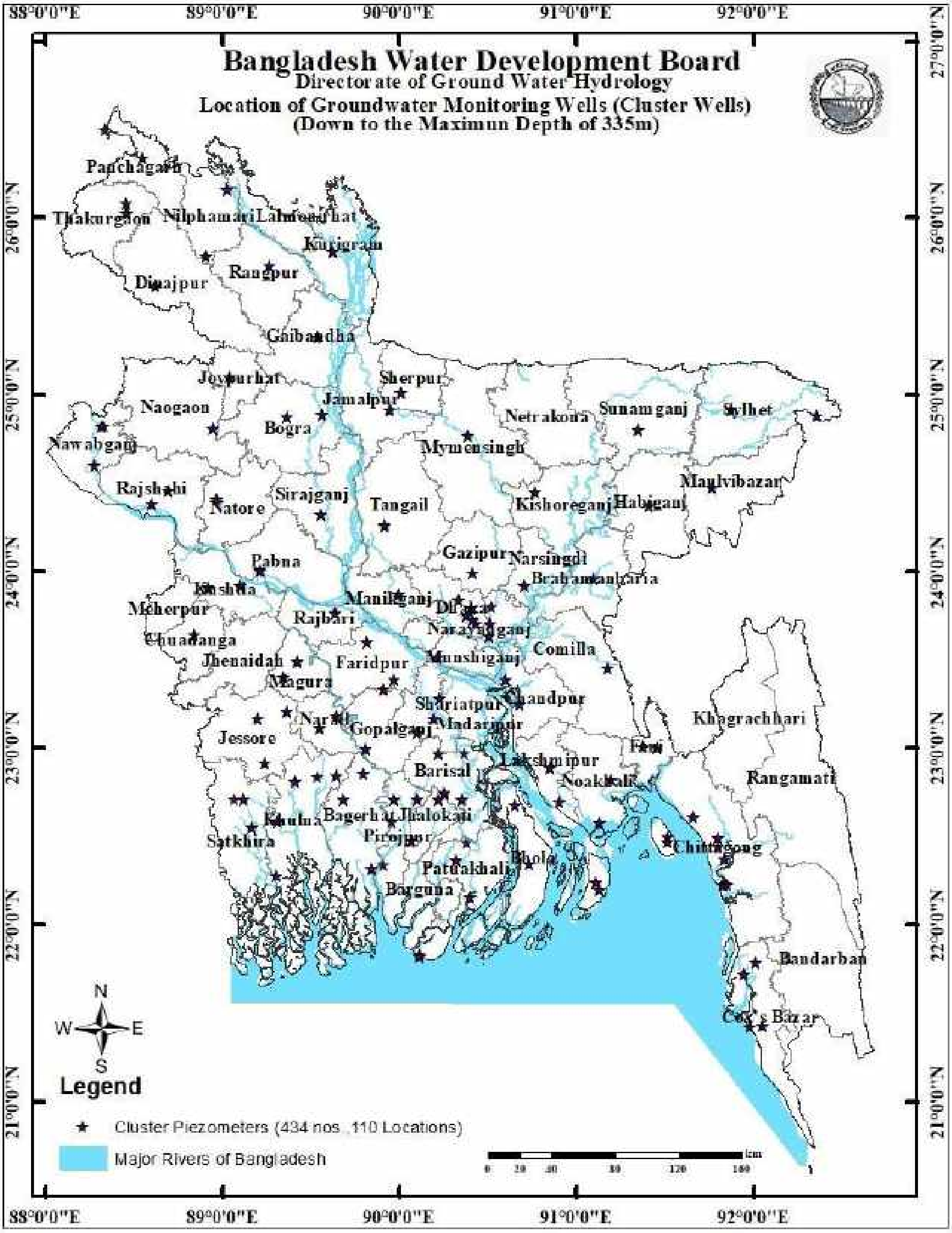

Figure 4-1: Location Map of Nested Wells.

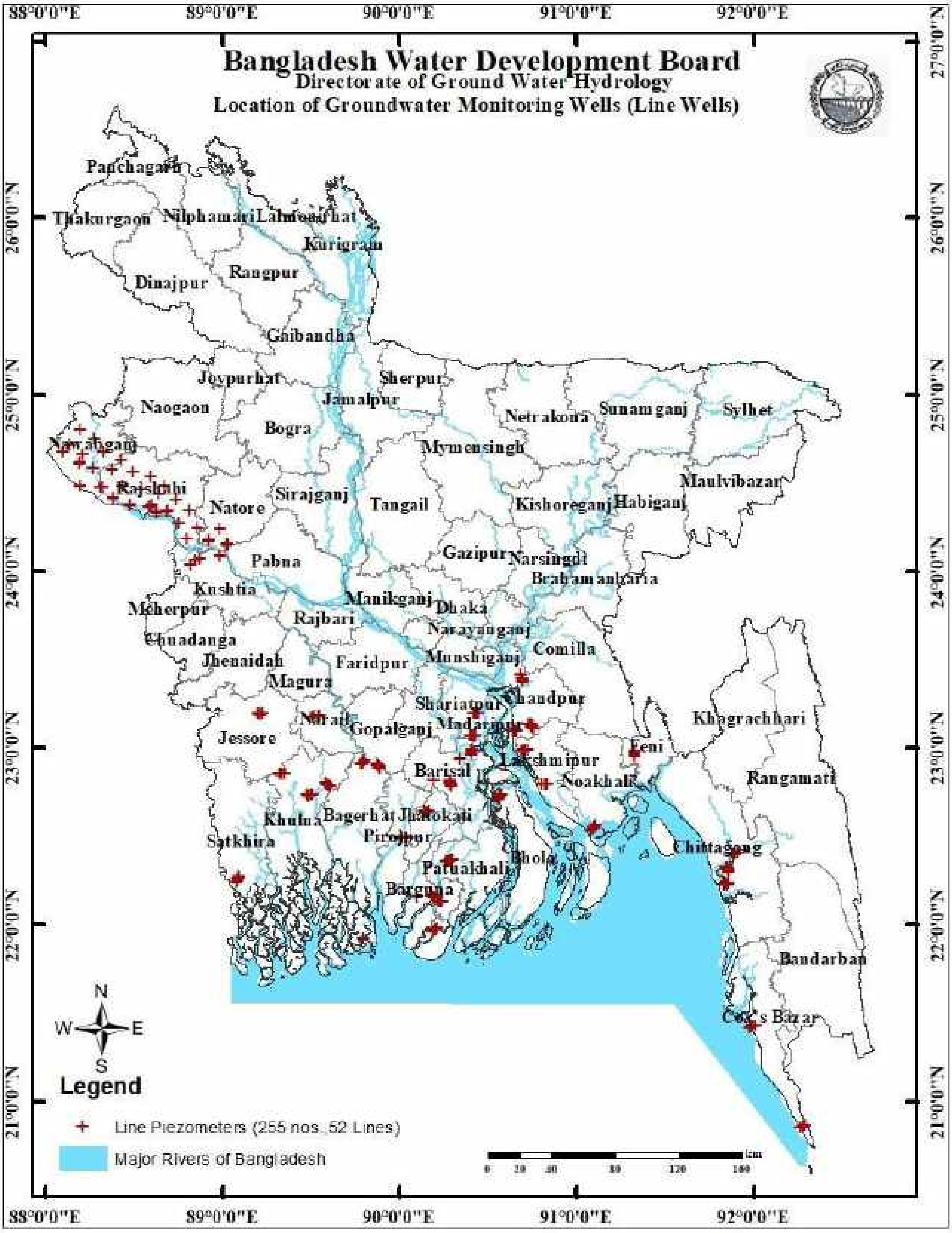

Figure 4-2: Location Map of Line Wells.

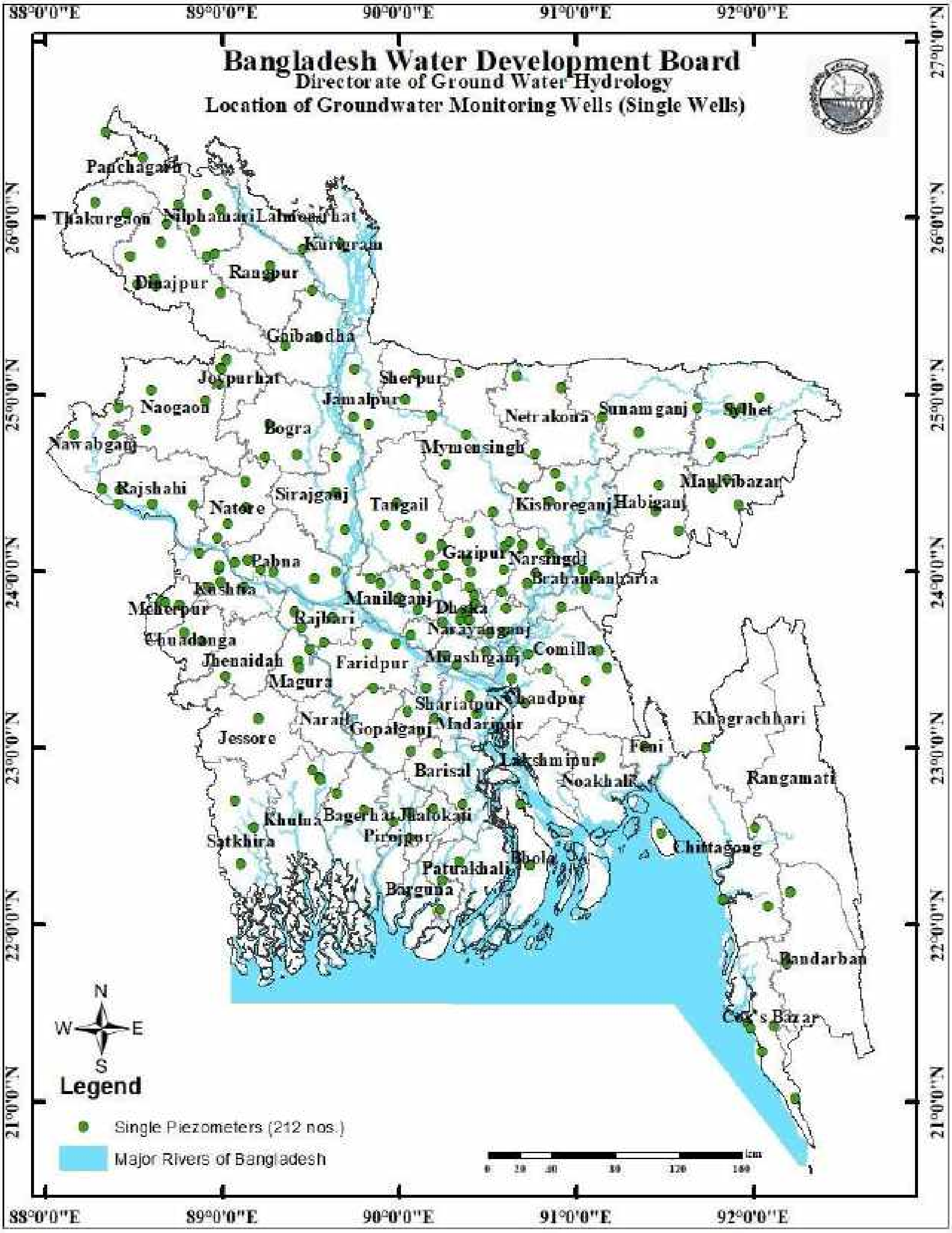

Figure 4-3: Location Map of Single Wells.

CHAPTER 5: RESULT AND DISCUSSION

5.1 RESULT AND DISCUSSION

The groundwater in Bangladesh is generally the Na–Cl type and the Na-Ca-Mg–HCO_3 type. The major ion trends of the Na–Cl type are $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO_3^- > SO_4^{2-}$. Salinization is the most widespread form of groundwater contamination in coastal aquifers, and is represented by the increases of total dissolved solids (TDS), Electric Conductivity (EC) and some specific chemical constituents such as Cl^-, Na^+, Mg^{2+}, and SO_4^{2-}. In order to assess the influence of seawater on a coastal aquifer, it is important to elucidate the source(s) of salinity and to understand the hydraulic and hydro geochemical conditions. However, seawater intrusion is the most common and widespread phenomena in the coastal zone of Bangladesh.

On the other hand, the northern side of Bangladesh is mostly freshwater where the trend is also $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO_3^- > SO_4^2$. But the amount is quite lower than the coastal zone of saline water. Most of the elements are in the range of drinking limit. Water quality test result also shows that groundwater in the northern side is also in a low range in case of water pollution or contamination.

5.2 DATA ANALYSIS

Groundwater refers to all the water occupying the voids, pores and fissures within geological formations, which originated from atmospheric precipitation either directly by rainfall infiltration or indirectly from rivers, lakes or canals. This is a valued freshwater resource and constitutes about two-thirds of the fresh water reserves of the world [63]. In Bangladesh, about 98% of drinking and 80% of dry season irrigation water supplies come from groundwater at shallow depths (< 150 m below ground level) [64]. Approximately 32 km3 of groundwater is withdrawn annually, which is equivalent to ~ 4% of global groundwater withdrawal [65]. Approximately 80% of the extracted groundwater in Bangladesh is used for irrigation [66], which helps this country to cultivate the staple food, rice, in two seasons - Kharif (May–November) and Rabi (December–April) [67].

In Bangladesh, except for the DupiTila sandstone formation of the Plio-Pleistocene age, others are too deep to consider for groundwater extraction except in the hilly region (18 percent of Bangladesh). Most of the groundwater withdrawn for domestic or agricultural purposes in the Barind and Madhupur uplands areas is from the Dupi Tila aquifers. From the available subsurface geological information, it appears that most of the good aquifers occur between 30 to 130 m depth.

This dynamic movement of water through the pore spaces and weathered zones may alter the natural composition of groundwater [68]. Besides, different anthropogenic processes also affect the groundwater composition [69]. Among the anthropogenic processes a variety of point sources e.g., waste disposal sites, industrial pollution, wastewater discharge, on site sanitation and nonpoint sources e.g., agricultural runoff; are predominant [70,71]. Climate change can potentially alter the vulnerability of shallow aquifers by affecting depth-to-water table and recharge [72,73], and human activities such as changes in land use can also affect groundwater vulnerability [74].

The present fresh water-saline water interface is the limit of potable water from the deep aquifer and is fairly well defined. It can be seen that the fresh/saline water interface lies about 50 to 75 km inland in the western most part of the area but swings sharply to the south and lies approximately at the coast over most of the rest of the area [6]. The occurrence of brackish and saline water in the coastal aquifers of Bangladesh does not follow any regular pattern spatially or vertically. All the different depth levels of aquifer units down to the investigated depths of 350 m have been affected by salinity in many areas [6]. More work is needed to define the fresh water-saline water interface and to monitor its seasonal and long-term movements.

In the coastal zone, salinity of the composite and main aquifers is extremely variable and changes abruptly over short distances**.** In most areas, the water is too saline for domestic and irrigation use due to either connate salts or estuarine flooding. In some areas, flushing out of the saline water has resulted in freshwater pockets. The change from potable water to very saline water is sharp and occurs over a relatively short distance [22].

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-1 to Figure 5-56).

5.2.1 Temperature

Temperature is a variable parameter due to the condition of the climate of the area. It also depends on the procedure of measurement. Figure 5-57 shows the variation of temperature in a very shallow aquifer in groundwater of Bangladesh. The maximum temperature value was measured as 30.2 (°C) in Barguna Sadar. The lowest temperature is recorded at 24.7 (°C) in Sirajganj.

Temperature of groundwater shows in Figure 5-57 in shallow aquifers of Bangladesh. Chapai, Naogoan, Rajshahi shows the high temperature zone in ground water in shallow aquifers. Highest temperature is 30 and 29.4 (°C) in this area and the lowest temperature is recorded 25.1 and 25.2 (°C) in Kurigram and Sherpur area.

Figure 5.57 shows temperature in the main aquifer in Bangladesh. Chapai, Thakurgaon shows the high temperature zone in ground water in the main aquifer. Highest temperature is 30.3 and 29.8 (°C) in this area and the lowest temperature is recorded 25.1 and 25 (°C) in Moulvibazar and Sherpur area.

In general, deep wells extend down through an impervious layer to reach an underlying supply. Shallow wells, in contrast, are sunk in easily penetrated strata to a point where they are below the water table. Deep well water usually shows but a slight change in composition over a long period of time. Figure 5.57 shows temperature in deep aquifers of Bangladesh.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-58).

5.2.2 pH

Figure 5.58 shows the variation of pH in groundwater of shallow aquifers in Bangladesh. The maximum pH value was measured 8.84 and 8.81 at Rajshahi, Boalia and Charghat. On the other hand, the lowest EC is recorded 5.72 and 6.3 respectively at Sylhet and Khagrachari.

Figure 5.58 shows the variation of pH in the shallow aquifers in Bangladesh. In most of the aquifers in coastal areas pH is greater than the northern zone of Bangladesh. Highest pH is observed in the middle of Dhaka 8.82. Narayanganj, Manikganj, Kishoreganj also show high range in ph. Then the coastal zone pH is also in the high range of pH 8.25 to 7.90 in Barguna, Patuakhali, Barisal, Bhola. In the northern side of Bangladesh like Sylhet, Kurigram, Moulvibazar are relatively low in pH range. But Chattogram, Cox-Bazar the south-eastern part of Bangladesh pH range is also low.

Among the main aquifers of Bangladesh, the aquifer of Dhaka is recorded to be the highest pH of 8.85. Figure 5.58 shows that seawater intrusion affected the main aquifer of the southern part of Bangladesh. On the other hand, in the northern part, water quality is still in good condition. The lowest value of pH is recorded in the northern part which is 6.79 at Feni.

Figure 5.58 shows that heavy usage of groundwater in Dhaka affected the deep aquifer. So, the people of Dhaka are at high risk for safe drinking water sources. The maximum pH value was measured as 8.74 in Dhaka. On the other hand, the lowest pH is recorded in the wet season in Chandpur Sadar, which is 6.84.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-59).

5.2.3 Dissolved Oxygen (DO)

Dissolved oxygen (DO) is a measure of how much oxygen is dissolved in the water - the amount of oxygen available to living aquatic organisms. This dissolved oxygen is breathed by fish and zooplankton and is needed by them to survive. Figure 5.59 shows the condition of DO in a very shallow aquifer in Bangladesh.

“DO” concentrations can be measured precisely in the field by titration or electrode methods. The best methods of sample recovery are those that use positive pressure displacement devices. A fully adequate sampling procedure will isolate groundwater from the atmosphere and will collect samples at restricted depth intervals at ambient temperature and pressure.

Dissolved oxygen (DO) concentration has a significant effect on groundwater quality by regulating the valence state of trace metals and by constraining the bacterial metabolism of dissolved organic species. For these reasons, the measurement of dissolved oxygen concentration should be considered essential in most water quality investigations. DO measurements have been frequently neglected in ground water monitoring.

The bonded oxygen molecule in water (H2O) is in a compound and does not count toward dissolved sugar when it is stirred. Figure 5.59 shows the condition of DO in deep aquifers in Bangladesh. One can imagine that free oxygen molecules dissolve in water much the way salt or sugar does when it is stirred.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-60).

5.2.4 Electrical Conductivity (EC)

Figure 5-1 shows the variation of EC in groundwater of very shallow aquifers in Bangladesh. The EC in wet season ranges from 40µS/cm to 31600µS/cm and in dry season from 20µS/cm to 32900µS/cm. The maximum EC values were measured in Barguna and Patuakhali. On the other hand, Thakurgaon, Dinajpur, Panchagarh have the lowest EC.

Figure 5-2 shows the variations in EC values measured in groundwater of shallow aquifers of Bangladesh. The measured values of EC during the wet season were found to be between the range of 70-4000 µS/cm. Southern part of Bangladesh has the highest values of EC due to the sea water intrusion, which range from 70 to 42500 µS/cm.

The groundwater pumped out from the main aquifer of Bangladesh gives EC values ranging from 90-31000µS/cm in wet season and 50-40000µS/cm during the dry season. Figure 5-3 shows that sea water intrusion affected the main aquifer of the southern part of Bangladesh. On the other hand, the northern part water quality is still in good condition.

Figure 5-4 shows that sea water intrusion also affected the deep aquifer of south-western part of Bangladesh. So, the people of south-western part of Bangladesh are at high risk for safe drinking water sources. The EC of wet season was found ranging from 120-19000µS/cm. Khulna, Paikgacha, Barguna, Patuakhali, Satkhira and Bagerhat have the highest values of EC. On the other hand, Thakurgaon, Dinajpur, Panchagarh have the lowest values. The EC values were measured ranging from 90-20000µS/cm during the dry season.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-1 to Figure 5-4).

5.2.5 Salinity

Salinity of the very shallow aquifer of Bangladesh is shown in Figure 5.5. Most of the salinity is found in the coastal zone because of the saline water intrusion in the aquifer. High values of salinity were measured in Patuakhali, Barguna zone. Salinity was measured ranging from 0.01-14 ppt during the wet season and 0.01- 14 ppt during dry season.
Figure 5.6 shows the variation of shallow aquifer salinity in groundwater of Bangladesh. The salinity values ranged from 0.01-24ppt during wet season and 0.01-24ppt during dry season as well. Southern part of Bangladesh shows the highest range in Salinity due to the sea water intrusion. The salinity in the dry season was recorded ranging from 0.01- 26ppt.
In the main aquifer of Bangladesh, the highest Salinity of 18.3 ppt in wet season is recorded at Amtali upazila under Barguna district and 24.4ppt in dry season. Figure 5.7 shows that sea water intrusion affected the main aquifer of the southern part of Bangladesh. On the other hand, the northern part water quality is still in good condition. Salinity ranges between 0.04-0.94ppt in wet season and in dry season which is 0.06- 0.76ppt.
Figure 5-8 shows that deep aquifer water condition is good in most of the area of Bangladesh. Range of salinity in the deep aquifer was recorded 0.01-10.6ppt and 0.01-11.3ppt respectively in wet and dry season of Bangladesh. In the dry season due to water intrusion Barguna and Patuakhali districts were affected by saline water in deep the aquifer.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-5 to Figure 5-8).

5.2.6 Total Dissolved Solids (TDS)

TDS of very shallow aquifers is shown in Figure 5.9 in Bangladesh. Most of the high values of TDS is measured in the coastal zone because of the saline water intrusion in the aquifer, i.e., Patuakhali, Barguna zone. Range of TDS in the wet season was 14(mg/l) to 20000 tand in the dry season which was 20(mg/l) to 21300(mg/l).

Figure 5.10 shows the variation of shallow aquifer TDS in groundwater of Bangladesh. Range of TDS in shallow aquifer was recorded 44(mg/l) to 24061(mg/l) and 47(mg/l) to 27340(mg/l) respectively in the wet and dry season of Bangladesh. The maximum TDS value of wet season was measured as 24061 (mg/l) at Barguna Patharghata and in dry season which is 27340(mg/l) at the same place.

In the main aquifer of Bangladesh TDS range of wet season was recorded 11(mg/l) to 19030(mg/l). Figure 5.11 shows that sea water intrusion affected the main aquifer of the southern part of Bangladesh. On the other hand, the northern part water quality is still in good condition. TDS range of dry season was recorded 26(mg/l) to 25800(mg/l).

Figure 5.12 shows that sea water intrusion also affected the deep aquifer of south-western part of Bangladesh. So, the people of south-western part of Bangladesh are at high risk for safe drinking water sources. Patuakhali, Satkhira, Bagerhat gave the highest range in TDS values. On the other hand, Thakurgaon, Dinajpur, Panchagarh showed the lowest range in TDS values. Range of TDS in deep aquifer was recorded 34(mg/l) to 11072(mg/l) and 58(mg/l) to 12860(mg/l) respectively in wet and dry season of Bangladesh.

Groundwater quality maps of different parameters are presented as Annexure (Figure 5-9 to Figure 5-12).

5.2.7 Sodium (Na)

Sodium is a highly soluble chemical element with the symbol “Na.” Sodium is often naturally found in groundwater. In water, sodium has no smell but it can be tasted by most people at concentrations of 200 milligrams per liter (mg/L) or more. Figure 5.13 shows the contamination of Sodium in the very shallow aquifer of Bangladesh.

Sodium is a naturally occurring element that is widely distributed throughout the Earth’s rocks and soils, most often found in combination with chloride in the form of salt (sodium chloride). Figure 5.14 shows the affected area. The presence of sodium in groundwater can result from a number of sources including the weathering of minerals in the soil, salt-bearing geological formations, deposition of salt spray, the use of salt for road de-icing, and in coastal areas, intrusion of salty ocean water into fresh groundwater sources.

Most of our coastal belt is contaminated by sodium ions. Because of saltwater intrusion in groundwater, Barguna, Patuakhali, Khulna, Satkhira are affected the most. Figure 5.15 shows the affected area. Range of Sodium in main aquifer was recorded ranging from 0.31(mg/l) to 4550(mg/l) and 6.2(mg/l) to 5140(mg/l) respectively in the wet and dry season of Bangladesh. Elevated sodium levels can sometimes be reduced by reconstruction of your well, or in other cases, by the use of a water treatment device, and it is recommended that advice from a qualified groundwater professional be sought prior to deciding what solution best meets your particular situation. The most common water treatment devices for reducing the sodium content of drinking water are reverse osmosis or distillation treatment systems.

Groundwater quality maps of different parameters are presented as Annexure (Figure 5-13 to Figure 5-16).

5.2.8 Magnesium (Mg)

Magnesium (Mg^{2+}) Magnesium in groundwater derived from the decomposition of dolomite, ferromagnesian minerals like olivine, pyroxene, amphiboles and dark colored micas. In the metamorphic rocks, magnesium occurs in the structure of chlorite, montmorillonite and serpentine. The reaction involving solution of magnesium is influenced by the amount of CO_2 in the groundwater in dissolved condition.

Dissolved from practically all solids and rocks, but especially from limestone, dolomite, and gypsum, calcium (Ca) and magnesium (Mg) are found in large quantities in some brines. Magnesium is present in large quantities in sea water. It causes most of the hardness and scale-forming properties of water. Water low in calcium and magnesium is desired in electroplating, tanning, dyeing, and in textile manufacturing. Calcium and magnesium are the principal cause of the formation of scale in boilers, water heaters, and pipes, and to the objectionable curd in the presence of soap. These mineral constituents and hardness greatly affect the value of water for public and industrial uses.

Calcium and magnesium are of great importance to human wellbeing and inadequate intake of either nutrient can impair health. The main objective of this book is to present a selection of studies on calcium and magnesium in groundwater and to highlight their importance for human health.

Magnesium is a dietary mineral for any organism but insects. It is a central atom of the chlorophyll molecule, and is therefore a requirement for plant photosynthesis. Magnesium cannot only be found in seawater, but also in rivers and rain water, causing it to naturally spread throughout the environment.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-17 to Figure 5-20).

5.2.9 Calcium (Ca)

The normal concentration of calcium in groundwater ranges from 10 to 100mg/l. The basic sources of calcium are carbonate rocks, i.e., limestone and dolomites, which are dissolved by carbonic acid in groundwater. The chemical breakdown of calcic-plagioclase feldspars and pyroxenes may be responsible for calcium in the groundwater. Calcium can also originate as lime in agricultural fertilizers.

Calcium daily intake is grossly inadequate in both water and foods but staple foods supplement the low values of magnesium in drinking water of the study area. Although, direct correlation, could not be established between, the consumption of these minerals, in water and prevalence of diseases. Probably, inadequate consumption of the recommended levels of calcium in foods and water could contribute to prevalence of calcium diseases in the area in addition to other environmental or social factors.

Calcium and magnesium are found in groundwater that has come in contact with certain rocks and minerals, especially limestone and gypsum. When these materials are dissolved, they release calcium and magnesium. Hard water is considered bad for your plumbing, but people with heart or circulatory problems may want to consult their physician about drinking softened water, because the softening process removes calcium and magnesium, and adds sodium to the water.

The most common problem associated with groundwater may be hardness, generally associated with an abundance of calcium and/or magnesium dissolved in the water. Hard water has not been shown to cause health problems, but can be a nuisance as it may cause soap curds and deposits to form on pipes and other plumbing fixtures. Over time this can reduce the diameter of the pipes.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-21 to Figure 5-24).

5.2.10 Potassium (K)

Studies of variations in major ions help to identify the chemical processes and interaction between soil and water that are responsible for the changes in groundwater quality with respect to space and time. He reported on the importance of groundwater recharge on seasonal variation in the major-ion concentration of groundwater. Potassium concentration into groundwater all groundwater samples coming under permissible limits.

Potassium occurs in various minerals; from which it may be dissolved through weathering processes. Examples are feldspars (orthoclase and microcline), which are however not very significant for potassium compounds production, and chlorine minerals carnallite and sylvite, which are most favorable for production purposes. Some clay minerals contain potassium. It ends up in seawater through natural processes, where it mainly settles in sediments.

Potassium plays a central role in plant growth, and it often limits it. Potassium from dead plant and animal material is often bound to clay minerals in soils, before it dissolves in water. Consequently, it is readily taken up by plants again. Ploughing may disturb this natural process. Consequently, potassium fertilizer is often added to agricultural soils.
Potassium is a dietary requirement for us, and we take up about 1-6 g per day at a requirement of 2-3.5 g per day. The total potassium amount in the human body lies somewhere between 110 and 140 g and mainly depends upon muscle mass. The muscles contain most potassium after red blood cells and brain tissue. Potassium shortages are relatively rare, but may lead to depression, muscle weakness, heart rhythm disorder and confusion. Potassium loss may be a consequence of chronic diarrhea or kidney disease, because the physical potassium balance is regulated by the kidneys. When kidneys operate insufficiently, potassium intake must be limited to prevent greater losses.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-25 to Figure 5-28).

5.2.11 Chloride (Cl)

Chloride is a naturally occurring element that is common in most natural waters and is most often found as a component of salt (sodium chloride) or in some cases in combination with potassium or calcium. The presence of chloride in groundwater can result from a number of sources including the weathering of soils, salt-bearing geological formations, deposition of salt spray, salt used for road de-icing, contributions from wastewaters and in coastal areas, intrusion of salty ocean water into fresh groundwater sources.
Chloride is considered to be an essential nutrient for human health and the main source of chloride is from foods, with drinking water making up only a small portion of normal dietary intake. Chloride in drinking water is not harmful, and most concerns are related to the frequent association of high chloride levels with elevated sodium levels. There is no health-based drinking water guideline for chloride however the Guidelines for Canadian Drinking Water Quality recommend an aesthetic objective for chloride levels of 250 mg/L, based on the potential for undesirable tastes at concentrations above this level, and the increased risk of corrosion of pipes.
High chloride concentrations in freshwater can harm aquatic organisms by interfering with osmoregulation, the biological process by which they maintain the proper concentration of salt and other solutes in their bodily fluids. Difficulty with osmoregulation can hinder survival, growth, and reproduction.
Elevated chloride levels can sometimes be reduced by reconstruction of your well, or in other cases, by the use of a water treatment device, and it is recommended that advice from a qualified groundwater professional be sought prior to deciding what solution best meets your particular situation. The most common water treatment devices for reducing the chloride content of drinking water are reverse osmosis, anion exchange or distillation treatment systems.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-29 to Figure 5-32).

5.2.12 Bicarbonate (HCO3)

Bicarbonate (HCO−3) The possible sources of bicarbonate include the presence of organic matter in the aquifer that is oxidized to produce carbon dioxide, which promotes dissolution of minerals. The fossil carbon of the calcite and dolomite in the aquifer would contribute half of the bicarbonate ions. This weathering enriches the groundwater in calcium, magnesium and bicarbonate ions. Bicarbonate ions may be resulted from the weathering of silicate minerals. The origin of sodium-bicarbonate groundwater in siliciclastic aquifers in general has often been attributed to cation exchange. According to this model, microbial oxidation of organic carbon produces carbonic acid which dissolves calcite, producing dissolved calcium and bicarbonate. The calcium is exchanged for sodium adsorbed on clays, and the net result is sodium-bicarbonate groundwater.

Groundwater contains minerals carried in solution, the type and concentration of which depends upon several factors such as soluble products of rock weathering and decomposition in addition to water– rock interactions by dissolution and dilution process. As a result of chemical and biochemical interaction between groundwater and contaminants from agricultural and industrial activities along with geological materials through which it flows it contains a wide variety of dissolved inorganic chemical constituents in various concentrations. Spatial variations in water chemistry and thermodynamic considerations, supports the hypothesis that the process in the Southern Hills aquifer system is driven by dissolution-precipitation reactions primarily involving silicate minerals, not calcite dissolution and cation exchange. There is a progression of geochemical reactions down the groundwater flow path from north to south which results in the evolution of meteoric recharge waters to high pH, sodium-bicarbonate groundwater.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-33 to Figure 5-36).

5.2.13 Iron (Fe)

Iron dissolved in groundwater is in the reduced iron II form. This form is soluble and normally does not cause any problems by itself. Iron II is oxidized to iron III on contact with oxygen in the air or by the action of iron related bacteria. Iron III forms insoluble hydroxides in water. These are rusty red and cause staining and blockage of screens, pumps, pipes, reticulation systems etc. If the iron hydroxide deposits are produced by iron bacteria, then they are also sticky and the problems of stain and blockage are many times worse.

Biological iron removal is a means of removing iron from groundwater within water filters. Microbiologists have known for many years that certain bacteria are capable of oxidizing and immobilizing iron. The bacteria responsible for the process appear to be natural inhabitants of the well environment.

The presence of iron in ground water is a direct result of its natural existence in underground rock formations and precipitation water that infiltrates through these formations. As the water moves through the rocks some of the iron dissolves and accumulates in aquifers which serve as a source for groundwater. Since the earth's underground rock formations contain about 5% iron it is common to find iron in many geographical areas around the globe.

The most common sources of iron and manganese in groundwater are naturally occurring, for example from weathering of iron and manganese bearing minerals and rocks. Industrial effluent, acid-mine drainage, sewage and landfill leachate may also contribute iron and manganese to local groundwater.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-37 to Figure 5-40).

5.2.14 Manganese (Mn)

Water with a high concentration of iron or manganese may cause the staining of plumbing fixtures or laundry. Manganese solids may form deposits within pipes and break off as black particles that give water an unpleasant appearance and taste. Similarly, iron can collect and block pipes or fixtures and produce color, taste and rust flakes in water. Both substances can increase the growth of unwanted bacteria that form a slimy coating in water pipes.

The occurrence of manganese in groundwater causes colored water and pipe rusting in water treatment systems. Consumption of manganese-contaminated water promotes neurotoxicity in humans and animals. Manganese-oxidizing bacteria were isolated from contaminated areas in Thailand for removing manganese from water.

Traditional manganese removal is performed in water treatment facilities by transforming soluble manganese to an insoluble form through oxidation, then separating the insoluble manganese via sedimentation and/or filtration processes. However, in many cases, chemical oxidation processes have not been adequate for removing manganese to drinking water standards.

To treat manganese contamination in water, manganese-oxidizing bacteria could be inoculated to accelerate the treatment efficiency. In practice, the previously isolated cultures may not survive well or perform effectively in a different environment. Therefore, using an indigenous culture isolated from the contaminated site could be more promising for manganese oxidation for water treatment. The isolated culture should be investigated for its removal performance and mechanism to better understand its potential and limitations. Thus far, there has been no published work reporting bacterial isolation and its removal kinetics for manganese treatment.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-41 to Figure 5-44).

5.2.15 Aluminium (Al)

Aluminum forms during mineral weathering of feldspars, such as orthoclase, anorthite, albite, micas and bauxite, and subsequently ends up in clay minerals. A number of gemstones contain aluminum, examples are ruby and sapphire. Currently, only iron and steel are produced in larger amounts than aluminum. Additionally, aluminum is largely recycled because this is very distinctly possible.

Aluminum may negatively affect terrestrial and aquatic life in different ways. Regular aluminum concentrations in groundwater are about 0.4 ppm, because it is present in soils as water insoluble hydroxide. At pH values below 4.5 solubility rapidly increases, causing aluminum concentrations to rise above 5 ppm. This may also occur at very high pH values.

Aluminum is a metal widely distributed in nature. It may be present in water from natural sources or as a result of human activities. The metal is used for many purposes: in the production of construction materials, vehicles, aircraft, electronics, pharmaceuticals and personal care products; as food additives; and as components of food packaging materials. Aluminum salts are commonly added as coagulants during water treatment to remove turbidity, organic matter and microorganisms. Aluminum is also an impurity found in other water treatment chemicals and can leach into drinking water from cement mortar pipes or linings.

Aluminum is not an essential element. Studies in humans have found possible associations between aluminum ingestion and diseases of the nervous system. However, these studies have a number of design limitations and do not provide strong evidence that aluminum can cause these diseases. Studies in animals have consistently observed adverse effects on the nervous system following ingestion of high levels of aluminum, which supports effects seen in human studies.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-45 to Figure 5-48).

5.2.16 Iodine (I)

Elevated iodine concentrations in shallow groundwater commonly occur in discharge areas where there is a high rate of solute evaporation; elevated iodine concentrations in deep groundwater are likely attributed to microbial decomposition of organic matter under anaerobic conditions. Processes of iodine enrichment led to correlations between high iodine and high fluorine contents in shallow groundwater, and between high iodine and high arsenic concentrations in deep groundwater. Moreover, redox processes and active water recycling are important factors for groundwater iodine enrichment.

More than two billion people worldwide have suffered thyroid disorders from either iodine deficiency or excess. By creating the national map of groundwater iodine throughout China, we reveal the spatial responses of diverse health risks to iodine in continental groundwater. Greater non-carcinogenic risks relevant to lower iodine are more likely to occur in the areas of higher altitude, while those associated with high groundwater iodine are concentrated in the areas suffering from transgressions enhanced by land over-use and intensive anthropogenic overexploitation.

The potential roles of groundwater iodine species are also explored: iodide might be associated with subclinical hypothyroidism particularly in higher iodine regions, whereas iodate impacts on thyroid risks in presence of universal salt iodization exhibit high uncertainties in lower iodine regions. This implies that accurate iodine supply depending on spatial heterogeneity and dietary iodine structure optimization are highly needed to mitigate thyroid risks in iodine-deficient and -excess areas globally.

Iodine speciation is of great significance to the biogeochemical cycle and health risk. In the hydro-biogeochemical cycle, iodine predominantly appears in oxidation state and reduction state, i.e., iodate ($IO3^-$) and organo-iodine as well as iodide (I^-). Reduction iodine (I^-), with high mobility and bioavailability, is the major species under anoxic and reducing groundwater environments, especially in groundwater with high-iodine content.

Groundwater quality maps of different parameters are presented as Annexure B (Figure 5-49 to Figure 5-52).

5.2.17 Arsenic (As)

Arsenic also can be released into groundwater as a result of human activities, such as mining, and from its various uses in industry, in animal feed, as a wood preservative, and as a pesticide. In drinking-water supplies, arsenic poses a problem because it is toxic at low levels and is a known carcinogen. Figure 5.53 shows the condition of Arsenic (As) in the very shallow aquifer in Bangladesh.

Most of the Arsenic contamination is caused in the south western part in Bangladesh. Satkhira, Bagerhat, Khulna are the most affected areas. Highest Arsenic values during wet season are measured as 212(μg/l) and 247(μg/l) which is in Shariatpur district.

Arsenic also can be released into groundwater as a result of human activities, such as mining, and from its various uses in industry, in animal feed, as a wood preservative, and as a pesticide. Figure 5.55 shows the contamination of Arsenic in the main aquifer of Bangladesh.

Arsenic contamination of groundwater is a form of groundwater pollution which is often due to naturally occurring high concentrations of arsenic in deeper levels of groundwater. It is a high-profile problem due to the use of deep tube wells for water supply in the Ganges Delta, causing serious arsenic poisoning to large numbers of people.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-53 to Figure 5-56).

5.2.18 Nitrate (NO_3)

Nitrates can get into groundwater from many sources, including fertilizers, manure on the land, and liquid waste discharged from septic tanks. Natural bacteria in soil converts various forms of nitrogen into nitrate. Rain and irrigation water can carry nitrate down through the soil into groundwater.

Nitrates generally moves relatively slowly in soil and groundwater: there is a lag time of approximately 20 years between the pollution activity and the detection of the pollutant in groundwater. For this reason, it is predicted that current polluting activities will continue to affect nitrate concentrations for several decades. However, if the pressure in the aquifer is high, transport can be very rapid within the saturation zone more:

In nature, inorganic nitrogen exists in the form of nitrates, nitrites and ammonia nitrogen. Among them, nitrite and ammonia nitrogen are unstable, their concentration is low and easily converted to nitrate. Studies in recent years have shown that high nitrate levels in drinking water during the first trimester of pregnancy are associated with birth defects in newborns, methemoglobinemia is directly related to high nitrate levels in drinking water.

Nitrate (NO_3^-) is a well-known environmental pollutant that not only arises naturally, but also is released by a number of anthropogenic exercises. These anthropogenic activities include the manufacture and use of nitrate fertilizers, fossil fuel combustion and releases of both domestic and industrial sewage systems and modification in nitrogen-fixing crops in natural vegetation. In most natural waters, nitrate forms a critical portion of the ionic charge.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-60).

5.2.19 Phosphate (PO_4)

The small quantity of phosphorus present in natural waters does not promote the growth of plants. However, a rise in the concentration of phosphorus results in the proliferation of algae, which leads to the eutrophication of the water body. In the mid-20th century, the anthropogenic contamination of water bodies with phosphate has resulted in widespread eutrophication via fertilizers, wastewater, and washing detergents, among other things.

Phosphorus is a highly reactive element that is essential for life and forms a variety of compounds in terrestrial and aquatic ecosystems. In water, phosphorus may be present as the orthophosphate ion (PO_4^{3-}) and is also present in all life forms as an essential component of cellular material. In natural ecosystems, phosphorus is derived from the erosion of rocks and is conserved for plant growth as it is returned to the soil through animal waste and the decomposition of plant and animal tissue; but in agricultural systems, a portion of the phosphorus is removed with each harvest, especially since phosphorus is concentrated in the seeds and fruit.

Phosphorus is largely retained in soil by a process called adsorption. Soils have a limited capacity to store phosphorus, and once the capacity of soil to adsorb phosphorus is exceeded, the excess will dissolve and move more freely with water either directly to a stream or downward to an aquifer. Surface-water runoff from rainstorms or excess irrigation is the primary way that phosphorus or soil containing phosphorus is transported to streams in most watersheds. There is a growing awareness that long-term over-application of manure and chemical fertilizer contributes to phosphorus movement into the groundwater system, resulting in a significant groundwater source of phosphorus to streams and lakes, as well as potential contamination of the groundwater resources.

Phosphorus is considered to be the main limiting nutrient in most freshwater ecosystems. Controlling phosphorus inputs is thus considered the key to reducing eutrophication and managing ecological quality. Very little attention has been paid to evaluating transfers via groundwater due to the long-held belief that adsorption and metal complex formation retain the majority of potentially mobile phosphorus. In each country, ecologically-important phosphorus thresholds are exceeded in a significant number of groundwater samples. The relative contributions of potential sources for these elevated concentrations are currently unclear but there is evidence to suggest that they are at least partly anthropogenic.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-61).

5.2.20 Sulphate (SO_4)

Most abundant form of Sulphur in the geosphere has been sulphate. Sulphate, with Sulphur in the plus six oxidation state is very stable. Sources of sulphate in groundwater include mineral dissolution, atmospheric deposition and other anthropogenic sources (mining, fertilizer, etc.). Gypsum is an important contributor to the high levels of sulphate in many aquifers of the world. Sulphate is not as much as toxic, but it can cause catharsis, dehydration and diarrhea, and when ingested in higher amounts through dietary absorption, the levels of methaemoglobin and sulphaemoglobin are changed in the human and animal body.

Sulfate is ubiquitous in groundwater, with both natural and anthropogenic sources. Sulfate reduction reactions play a significant role in mediating redox conditions and biogeochemical processes for subsurface systems. They also serve as the basis for innovative in-situ methods for groundwater remediation. An overview of sulfate reduction in subsurface environments is provided, along with a brief discussion of characterization methods and applications for addressing acid mine drainage.

Sulfate is a chemical commonly found in air, soil and water. Since it is soluble (easily dissolved) in water, sulfate is found at high concentrations in many aquifers and in surface water. Combustion of fossil fuels releases large quantities of sulfur to the atmosphere. Sulfur in the atmosphere is oxidized to sulfate and eventually deposited with precipitation or through dry deposition. Because sulfate occurs as a dissolved ion, it is mobile in groundwater.

People who are not used to drinking water with high sulfate can get diarrhea and dehydration from drinking the water. Infants are often more sensitive to sulfate than adults. To be safe, only use water with a sulfate level lower than 500 milligrams per liter (mg/L) to make infant formula. Older children and adults may get used to high sulfate levels after a few days.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-62).

5.2.21 Copper (Cu)

Eating or drinking too much copper can cause vomiting, diarrhea, stomach cramps, nausea, liver damage, and kidney disease. People with Wilson's disease and some infants (babies under one-year-old) are extra sensitive to copper. Their bodies are not able to get rid of extra copper easily.

Copper can get into drinking water if the water moving through the plumbing system is corrosive. Corrosive water can dissolve copper in plumbing parts. Pinhole leaks, pitting in your pipes, or blue green stains on plumbing fixtures may be signs that you have corrosive water. If you see signs of corrosive water, lead may also be in your drinking water. Water with a lot of dissolved copper in it can make drinking water taste or smell bad or give it a blue color.

Seawater intrusion, a common geological process along the coastal zones, changes the groundwater properties, which are potentially associated with the groundwater copper (Cu) levels. However, there are no studies on the details of groundwater Cu levels affected by seawater intrusion. The groundwater in the seawater intrusion in coastal areas of Bangladesh. Town was sampled to detect the effect of seawater intrusion on groundwater Cu levels.

In most developing countries, drinking water is still a serious challenge. Many water purification methods exist, but they are costly and out of reach for many people. Copper is an ancient metal that has been used for several thousands of years. Because of its antibacterial properties, ancient cultures held this metal in high regard. Copper vessels are still in use today for storing drinking water due to its ability to purify water. Therefore, the objective of this study was to evaluate the copper concentration in drinking water after storing it in copper containers/bottles over different time periods with respect to copper safety levels.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-63).

5.2.22 Carbonate (CO_3)

Most of the carbonate-rock aquifers consist of limestone, but dolomite and marble locally are sources of water. The water-yielding properties of carbonate rocks are highly variable; some yield almost no water and are considered to be confining units, whereas others are among the most productive aquifers known.

Most carbonate rocks form from calcareous deposits that accumulate in marine environments ranging from tidal flats to reefs to deep ocean basins. The deposits are derived from calcareous algae or the skeletal remains of marine organisms that range from foraminifera to molluscs. Minor amounts of carbonate rocks are deposited in fresh to saline lakes, as spring deposits, geothermal deposits, or dripstone in caves. The original texture and porosity of carbonate deposits are highly variable because of the wide range of environments in which the deposits form. The primary porosity of the deposits can range from 1 to more than 50 percent. Compaction, cementation, and dolomitization are diagenetic processes which act on the carbonate deposits to change their porosity and permeability.

In karst aquifers, surface and subsurface drainage are commonly integrated from sinkholes to springs via conduit networks. Groundwater velocities can approach those of surface streams and interbasin groundwater flow can occur beneath topographic divides. Consequently, solute tracers are often used to determine connectivity between recharge and discharge points in karst aquifers. Because of susceptibility to contamination and the ecological significance of cave and spring ecosystems, monitoring of flow and water quality in carbonate aquifers is particularly important.

In most water, nearly all the hardness is due to calcium and magnesium carbonates. All of the metallic cations other than the alkali metals deposit soap curd on bathtubs. Hard water forms scales in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate or "temporary" hardness because it can be removed by boiling. Any hardness in excess of this is called noncarbonate or "permanent" hardness. Noncarbonate hardness is caused by the combination of calcium and magnesium with sulfate, chloride, and nitrate. Scale caused by carbonate hardness usually is porous and easily removed, but that caused by noncarbonate hardness is hard and difficult to remove.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-64).

5.2.23 Chromium (Cr)

Chromium is a metallic chemical that originates as a contaminant in the environment from the discharges of dye and paint pigments, wood preservatives, chrome-plating liquid wastes, and leaching from hazardous waste sites. The greatest use of chromium is in metal alloys such as stainless steel; protective coatings on metal; magnetic tapes; and pigments for paints, cement, paper, rubber, composition floor covering, etc. The two largest sources of chromium emission in the atmosphere are from the chemical manufacturing and combustion of natural gas, oil and coal.

Chromium is a metal found in natural deposits of ores containing other elements, mostly as chrome-iron ore. It is also widely present in soil and plants. Under most conditions, natural chromium in the environment occurs as Cr^3. Under oxidizing conditions, alkaline pH range, presence of MnO_2, and minerals containing chromium, part of it may occur as hexavalent chromium dissolved in groundwater.

Chromium is a potentially toxic metal occurring in water and groundwater as a result of natural and anthropogenic sources. Microbial interaction with mafic and ultramafic rocks together with geogenic processes release Cr (VI) in the natural environment by chromite oxidation. Moreover, Cr (VI) pollution is largely related to several Cr (VI) industrial applications in the field of energy production, manufacturing of metals and chemicals, and subsequent waste and wastewater management.

Public concerns with chromium are primarily related to hexavalent compounds owing to their toxic effects on humans, animals, plants, and microorganisms. The risks for human health are dependent on dose, exposure level, and duration. A lasting and continuative exposure to chromium even at low concentration, that is, in the case of occupational exposure, can damage the skin, eyes, blood, respiratory, and immune system. On a cellular level, the genotoxic effect of chromium leads to oxidative stress, DNA damages, and other harms that can result in tumour development.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-65).

5.2.24 Bromine (Br)

Bromine (Br) is one of the halogen elements found in trace amounts in all groundwater. Almost all naturally occurring bromine found in groundwater is in the form of a simple negative monovalent ion, bromide (Br−).

Brominated acetic acids are formed during the disinfection of water that contains bromide ions and organic matter. Bromide ions occur naturally in surface water and groundwater and exhibit seasonal fluctuations in levels. Bromide ion levels can increase as a result of either saltwater intrusion resulting from drought conditions or pollution and enriched in the lagoon environment. Brominated acetates are generally present in surface water and groundwater distribution systems at mean concentrations below 5 µg/l.

Bromine is found naturally in the earth's crust and in seawater in various chemical forms. Bromine can also be found as an alternative to chlorine in swimming pools. Products containing bromine are used in agriculture and sanitation and as fire retardants (chemicals that help prevent things from catching fire).

The primary natural source of bromide in surface water is believed to originate from sea water. Atmospheric moisture, which derives its halogen content from sea spray, is the means by which the halogens enter the surface waters from rainfall. In addition to natural sources, bromide is introduced to the environment through a variety of anthropogenic means. The most significant source of bromide is from the combustion of leaded gasoline.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-66).

5.2.25 Boron (B)

The use of boron in some cleaning agents is beginning to decrease due to environmental concerns. However, boron compounds are among the most widely used whitening agents today. Borate compounds are used in the manufacturing of many different commercial products including: insulation and textile-grade fiberglass, borosilicate glass, fire retardants, enamels, ceramic glazes, laundry bleach, agricultural fertilizers, and herbicides.

Major anthropogenic sources of boron to groundwater include: industrial wastewater discharges, municipal wastewater discharges, and agricultural activities. Boron is also released to the atmosphere via industrial air emissions.

Boron is a naturally occurring element found in rocks, soil, and water. Boron does not exist as a pure element. Boron has a high affinity for forming very stable bonds with electronegative atoms (atoms that donate electrons), and as a result often exists in compounds bound to oxygen atoms. Boron containing minerals are common in nature as sodium and calcium borates, borosilicate minerals, and boric acid.

In animal studies, exposure to high levels of boron caused decreased fetal weight and improper fetal development, as well as disruption to the male reproductive system. MDH’s guidance value of 500 ppb is designed to be protective of formula-fed infants, who may ingest more boron from food and water, on a per body weight basis, than older children or adults.

Groundwater quality maps of different parameters are presented as Annexure C (Figure 5-67).

5.3 DETERMINING THE WATER TYPE

Groundwater quality has become a major concern in Bangladesh [75, 76]. There are concerns of potential contamination of deep groundwater due to entrance of Arsenic and salinity from shallow depths [77], presence of higher concentration of Fe and Mn than other heavy metals [78] and groundwater depletion. The abstraction of groundwater is increasing day by day due to extra demand, and the groundwater level of Dhaka City area is declining by 2–3 m per year [79]. The impact of over abstraction has been well documented by many authors [80]. Moreover, large-scale abstractions even change in the geological formation of the aquifer [81]. Depletion of groundwater is also linked with the vulnerability of an aquifer to chemical contamination [82]. For example, groundwater depletion is one of the causes for arsenic contamination [82].

The Piper-trilinear plot shows the classification of water samples from various lithological environments of various depth in physio-graphically of Bangladesh. It also demonstrates the chemical character of the water samples using the dominant cation and anion to tell the dissimilarities and similarities of the groundwater samples.

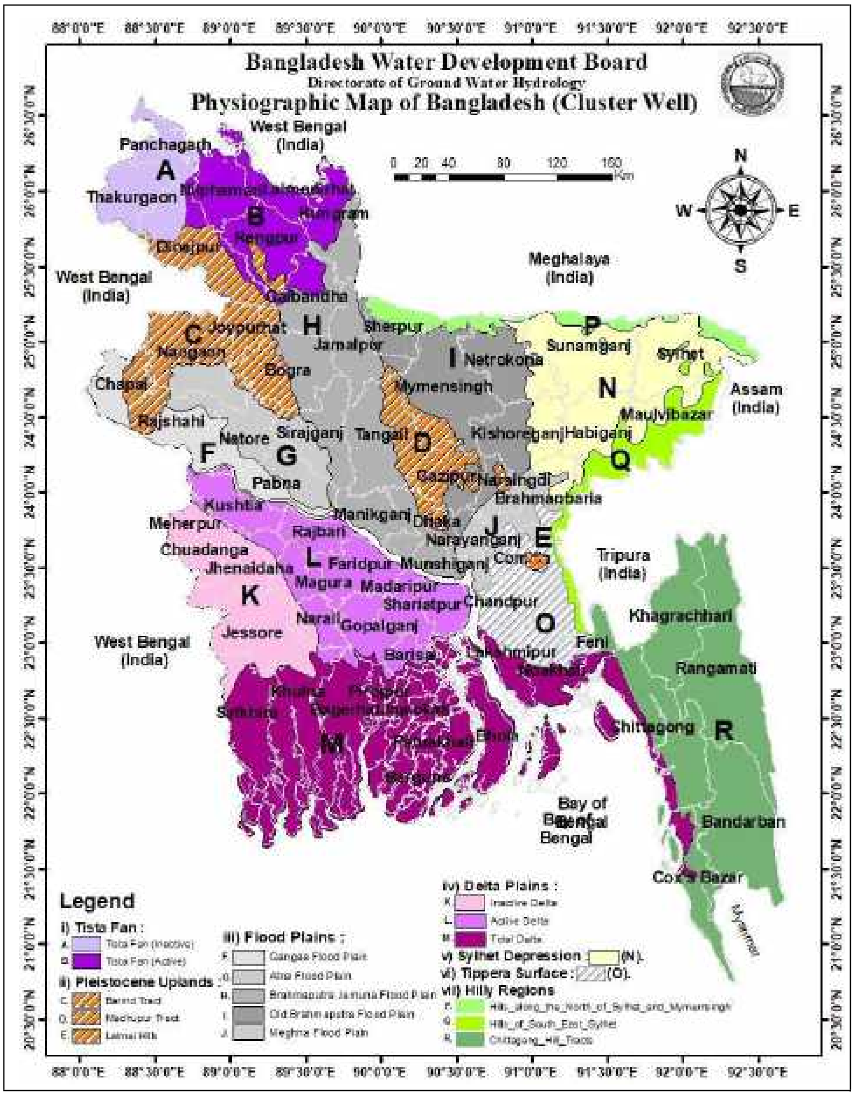

Figure 5-1: Physiographic Map of Bangladesh.

Groundwater analysis results are plotted in a piper diagram and are presented as Annexure D (Figure 5-69 to Figure 5-85).

5.3.1 Water Type in Tista Fan (Active)

According to the piper diagram (Fig: 5-69), The Active Delta water samples in both seasons are predominant in chloride and bicarbonate type and it can be calcium chloride and magnesium bicarbonate type of water. Some of the samples are mixed type of water where the alkaline earth of the water exceeds the alkalies.

5.3.2 Water Type in Tista Fan (Inactive)

According to the piper diagram (Fig: 5-70), the water samples from the Tista Fan (Inactive) in both wet and dry season are predominantly magnesium bicarbonate to calcium and bicarbonate type in nature. The water is more mixed in dry season. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.3 Water Type in Barind Tract

The piper diagram (Fig: 5-71) shows that the water samples from the Barind Tract are Mg-Ca-HCO_3 type to Mixed type during wet season and predominantly mixed type during dry season. The water samples are predominantly HCO3 type in wet season and Cl type in dry season. In both seasons, alkaline earth exceeds the alkalies.

5.3.4 Water Type in Madhupur Tract

Figure 5-72 suggest that the water samples are Mg-HCO3 to mixed type in nature during wet season. The water samples are mixed type during the dry season. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.5 Water Type in Ganges Flood Plain

The water samples from Ganges Floodplain are overall Mg -HCO3 type in nature (Fig 5-73). The waters exhibit predominance of Ca and HCO3. In both seasons, the samples show the trend where the alkaline earth exceeds the alkalies.

5.3.6 Water Type in Atrai Flood Plain

The water samples from the Atrai Floodplain are HCO_3 type to Mixed type during wet season and mixed type during dry season as exhibited in the piper diagram (Fig: 5-74). In both seasons, alkaline earth exceeds the alkalies.

5.3.7 Water Type in Brahmaputra Jamuna Flood Plain

The Piper trilinear diagram of water samples collected from the Brahmaputra Jamuna Flood Plain exhibits predominantly magnesium bicarbonate type to mixed type water and the water is predominantly HCO3 type in wet season and HCO3 to Cl type in dry season.

5.3.8 Water Type in Old Brahmaputra Flood Plain

According to the piper diagram (Fig: 5-76), the water samples from the Old Brahmaputra Flood Plain in both wet and dry season are predominantly magnesium bicarbonate to calcium and bicarbonate type in nature. The water is more mixed type in dry season. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.8 Water Type in Old Brahmaputra Flood Plain

According to the piper diagram (Fig: 5-76), the water samples from the Old Brahmaputra Flood Plain in both wet and dry season are predominantly magnesium bicarbonate to calcium and bicarbonate type in nature. The water is more mixed type in dry season. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.10 Water Type in Inactive Delta

In Figure 5-78, the piper diagrams demonstrate magnesium bicarbonate to calcium chloride type water. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.11 Water Type in Active Delta

According to the piper diagram (Fig: 5-79), The water samples from the Active Delta region in dry and wet season vary from being predominantly Ca-Cl to Mixed type to $Mg\text{-}CO_3$ type. The sample distribution in the piper diagram suggests that the alkaline earth exceeds the alkalies.

5.3.12 Water Type in Tidal Delta

Figure 5-80 suggests that the water samples collected from the Tidal Delta are predominantly calcium chloride type to magnesium bicarbonate type in nature. During wet season, the cations are Mg to Ca type and the anions are HCO3 to Cl type in nature whereas it is Mg to mixed type and predominantly Cl type during the dry season. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.13 Water Type in Sylhet Depression

From figure 5-65, it is observed that the water samples from the wet season are predominantly magnesium bicarbonate with Mg-Ca-HCO3-Cl type in nature and the water samples collected during the dry season show mixed type of water. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.14 Water Type in Tippera Surface

From figure 5-82, it is observed that the water samples collected from the Tiperra Surface exhibit predominantly Mg-HCO3 to mixed type to Ca-Cl type water in wet season whereas it is more mixed type during the dry season. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.15 Water Type in Hills along the North of Sylhet and Mymensingh

The water samples of the Hills of North of Sylhet and Mymensingh Mg-HCO3 type during wet season and Mg-Cl type during the dry season. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.16 Water Type in Hills of South East Sylhet

From the figure 5-84 it is observed that the water samples collected during the wet season show magnesium bicarbonate. Whereas the samples collected during dry season are mixed type in nature. During both seasons, the alkaline earth of the water exceeds the alkalies.

5.3.17 Water Type in Chattogram Hill Tracts

Water samples from Chattogram Hill Tract (Fig 5-85) are Mg-HCO3 to Cl type in wet season and mixed type in dry season. In both seasons, the alkaline earth exceeds the alkalies.

CHAPTER 6: SUMMARY

6.1 SUMMARY

During 2020-2021, both dry and wet season samples were collected from 901 automated wells installed down to the maximum depth of about 335 m throughout the country under BWCSRP, Component B project. Mainly analytical results with few maps and figures are presented in this report. Further interpretation and analysis of findings can be done as per requirement and purposes by different stakeholders and users including professionals, researchers and policy makers. This report can be referred to as data bank on analyzed water quality parameters.

The groundwater quality analysis conducted under this study provides valuable insights into the overall quality of the groundwater of Bangladesh. The analysis aimed to assess various physical and chemical parameters to determine the suitability of the groundwater for different purposes such as drinking, irrigation, and industrial use. Through the analysis of these parameters, the report sheds light on the overall groundwater quality in Bangladesh. The findings indicate the level of contamination, the presence of essential elements, and potential health risks associated with water consumption or agricultural use. The assessment extends down to the depth of 335 meters, providing a comprehensive understanding of groundwater quality at various depth levels.

The Active Delta water samples in both seasons are predominant in chloride and bicarbonate type and mostly calcium chloride and magnesium bicarbonate type of water. The water samples from the Tista Fan (Inactive) in both wet and dry season are predominantly magnesium bicarbonate to calcium and bicarbonate type in nature. The water is more mixed type in dry season. The water samples from the Barind Tract are magnesium - calcium - bicarbonate type to mixed type during wet season and predominantly mixed type during dry season. The water samples are predominantly bicarbonate type in wet season and chloride type in dry season. The water samples are magnesium - bicarbonate to mixed type in nature during wet season. The water samples are mixed type during dry season. The water samples from Ganges Floodplain are generally magnesium - bicarbonate type in nature. The waters exhibit predominance of calcium and bicarbonate. The water samples from the Atrai Floodplain are bicarbonate type to mixed type during wet season and mixed type during dry season as exhibited in the piper diagram. The Brahmaputra Jamuna Flood Plain exhibits predominantly magnesium bicarbonate type to mixed type water and the water is predominantly bicarbonate type in wet season and bicarbonate to chloride type in dry season. The water samples from the Old Brahmaputra Flood Plain in both wet and dry season are predominantly magnesium bicarbonate to calcium and bicarbonate type in nature. The water is more mixed type in dry season. The water samples from the Old Brahmaputra Flood Plain in both wet and dry season are predominantly magnesium bicarbonate to calcium and bicarbonate type in nature. The water is more mixed type in dry season. The piper diagrams demonstrate magnesium bicarbonate to calcium chloride type water. The water samples from the Active Delta region in dry and wet season vary from being predominantly calcium - chloride to mixed type to magnesium - carbonate type. The sample distribution in the piper diagram suggests that the alkaline earth exceeds the alkalis. The water samples collected from Tidal Delta are predominantly calcium chloride type to magnesium bicarbonate type in nature. During wet season, the cations are magnesium to calcium type and the anions are bicarbonate to chloride type in nature whereas it is magnesium to mixed type and predominantly chloride type during the dry season. It is observed that the water samples from the wet season are predominantly magnesium bicarbonate with magnesium - calcium - bicarbonate - chloride type in nature and the water samples collected during the dry season show mixed type of water. The water samples collected from the Tiperra Surface exhibit predominantly magnesium - bicarbonate to mixed type to calcium - chloride type water in wet season whereas it is more mixed type during the dry season. The water samples from the Hilly areas of North of Sylhet and Mymensingh are magnesium - bicarbonate type during wet season and magnesium - chloride type during the dry season. The water samples collected during the wet season show magnesium bicarbonate. Whereas the samples collected during dry season are mixed type in nature. Water samples from Chattogram Hill Tract are magnesium - bicarbonate to chloride type in wet season and mixed type in dry season. In all samples collected from the entire country at different depths levels for both seasons the alkaline earth exceeds the alkalis.

Groundwater temperatures are relatively stable and range from around 23 to 32 degrees Celsius in different parts of the country. The maximum temperature value was measured as 31.60 at Rajshahi. On the other hand, the lowest temperature is recorded at 22.83 at Pirojpur. The maximum pH value was measured as 8.84 and 8.81 in Rajshahi district at Boalia and Charghat in the shallow aquifer. On the other hand, the lowest EC is as recorded 5.72µS/cm and 6.3µS/cm respectively at Sylhet and Khagrachari. In the main aquifer in Dhaka highest pH of 8.9 is recorded. The sea water intrusion affected the main aquifer of the southern part of Bangladesh. On the other hand, in the northern part water quality is generally in good condition. The maximum pH value was measured as 8.9 at Dhaka. On the other hand, the lowest pH is recorded in wet season as 4.93 at Lakshmipur.

The EC in wet season was measured between 40 to 31600 µS/cm and in dry season which was 20 to 32900µS/cm. The maximum EC value was measured as Barguna and Patuakhali. On the other hand, groundwater of Sylhet, Moulvibazar, Panchagarh show the lowest values respectively 40.10, 58.3, 59 µS/cm. The range of wet season was measured 70 to 40000µS/cm. Southern part of Bangladesh exhibits the highest range in EC due to the sea water intrusion in the upper aquifer. In dry season the EC was measured about 70 to 42500 µS/cm.

Salinity range of wet season was found 0.01 to 14 ppt and in dry season which was 0.01 to 19 ppt in the main aquifer. Amtali upazila under Barguna district has the highest Salinity of 18.3 ppt in wet season and 24.4ppt in dry season. The sea water intrusion affected the main aquifer of the southern part of Bangladesh. Salinity range of wet season was 0.1 to 24.4ppt and in dry season it was 0.1 to 18.3ppt. On the other hand, in the northern part groundwater quality is still in good condition.

The Arsenic contamination is primarily found in shallow groundwater, which were commonly used for drinking water through hand tube wells. The Arsenic contamination is severe in the shallow aquifers of south western and eastern part of Bangladesh mainly under the flood plains and deltaic areas. Satkhira, Bagerhat, Jhalokathi, Khulna Shariatpur, Chandpur Comilla are the most affected areas. Under this study, during wet season, high Arsenic concentration was detected in Jhalokathi, Chandpur, Shariatpur districts and during dry season, in Kushtia, Cumilla and Shariatpur districts.

Most of the coastal belt, groundwater is dominated by sodium ions mainly due to the encroachment of sea water. Barguna, Patuakhali, Khulna, Satkhira are affected most by salinity. Range of Sodium in the Main aquifer was recorded from 0.31 to 4550 mg/l and 6.2 to 5140 mg/l during wet and dry seasons respectively. The coastal belt is also dominated by Chloride, Calcium, Magnesium and Potassium in groundwater because of the salt water intrusion.

The maximum value of Bicarbonate was measured as 1268 and 1500 mg/l in Pirojpur groundwater during wet and dry season respectively. The concentrations of iron and manganese are high in a few intermediate depths and deep wells. In dry season maximum iron was measured as 22.14 mg/l in Sylhet and maximum iron concentration was measured as 15 mg/l in Bagerhat, during wet season. During dry season maximum aluminum was measured as 10.53 mg/l in Narayanganj and during wet season maximum aluminum was measured as 3.10 mg/l in Bhola.

However, certain parameters at few locations and depths exhibited higher values that require proper attention. The analysis revealed elevated levels of Nitrate, Phosphate, Bromine and Boron in some groundwater samples. It is recommended to implement mitigation measures and monitoring systems to address these issues and prevent further deterioration of groundwater quality.

Additionally, the analysis identified the presence of certain heavy metals, such as Arsenic, Aluminum, Manganese and Iron concentrations exceeding the permissible limits. These metals are known to have detrimental effects on human health, even at low concentrations. Hence, it is crucial to investigate and identify the sources of these contaminants, implement appropriate remediation strategies, and closely monitor their levels in the groundwater to safeguard public health.

Furthermore, the analysis highlighted the importance of regular monitoring and periodic testing of the groundwater quality to ensure ongoing assessment and its suitability for various uses. As environmental conditions and human activities evolve, the groundwater quality can be subjected to change. Therefore, continued monitoring efforts are necessary to detect emerging contaminants, assess their impacts, and implement timely interventions.

The groundwater analysis presented in this report provides a comprehensive understanding of the current state of groundwater quality in the multi-layered aquifer system in Bangladesh. It emphasizes the need for proactive measures to address identified issues and ensure the long-term sustainability and safety of groundwater resources. By implementing appropriate management strategies and engaging in collaborative efforts among stakeholders, it is possible to protect and preserve the quality of groundwater for the benefit of present and future generations.

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Annexure A

3.4 PROCEDURS OF THE TEST METHODS

3.4.1 Iron Test Procedure

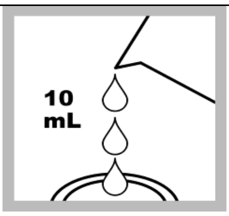
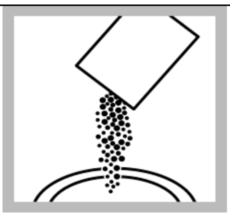
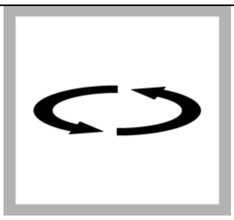
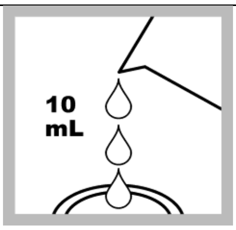
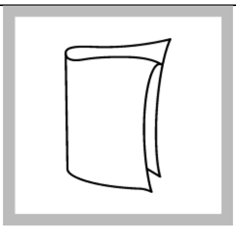
Items to collect

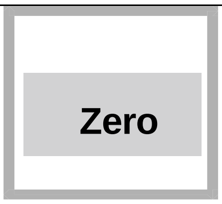
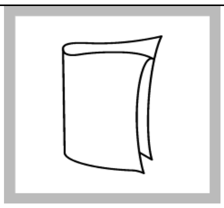
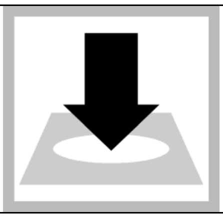
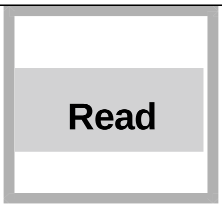
Description	Quantity
FerroVer® Iron Reagent Powder Pillows, 10-mL[1]	1
Sample cells	2

Sample collection and storage

- Collect samples in clean glass or plastic bottles that have been cleaned with 6 N (1:1) hydrochloric acid and rinsed with deionized water.
- To measure only dissolved iron, filter the sample immediately after collection andbefore acidification.
- To preserve samples for later analysis, adjust the sample pH to less than 2 with concentrated nitric acid (approximately 2 mL per liter). No acid addition is necessary ifthe sample is tested immediately.
- Keep the preserved samples at room temperature for a maximum of 6 months.
- Before analysis, adjust the pH to 3–5 with 5 N sodium hydroxide solution.
- Correct the test result for the dilution caused by the volume additions.

Powder pillow procedure

			
1. Start program 265 Iron,FerroVer.	**2.** Prepare the sample: Filla sample cell with 10 mL of sample.	**3.** Add the contents of one FerroVer Iron Reagent Powder Pillow to the sample cell.	**4.** Swirl the sample cell to mix. Undissolved powder will not affect accuracy.
			
5. Start the instrument timer. A 3-minute reaction time starts. An orange color will show if iron is present. Let samples that contain rust react for 5 minutes or more.	**6.** Prepare the blank: Fill a second sample cell with 10 mL of sample.	**7.** Clean the blank sample cell.	**8.** When the timer expires, insert the blank into the cell holder.

			
9. Push ZERO. The display shows 0.00 mg/L Fe.	**10.** Clean the prepared sample cell.	**11.** Push READ. Results show in mg/L Fe.	**12.** Push READ. Results show in mg/L Fe.

Standard solution method

Use the standard solution method to validate the test procedure, the reagents and theinstrument.

Items to collect:

- Iron standard solution, 100 mg/L
- 100-mL volumetric flask, Class A
- 2-mL volumetric pipet, Class A and pipet filler
- Deionized water

Prepare a 2.00-mg/L iron standard solution as follows:

a. Use a pipet to add 2 mL of the 100-mg/L iron standard solution into thevolumetric flask.
b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.

2. Use the test procedure to measure the concentration of the prepared standardsolution.
3. Compare the expected result to the actual result.

Note: The factory calibration can be adjusted slightly with the standard adjust option so that theinstrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are slight variations in the reagents or instruments.

Summary of method

FerroVer Iron Reagent converts all soluble iron and most insoluble forms of iron in thesample to soluble ferrous iron. The ferrous iron reacts with the 1-10 phenanthroline indicator in the reagent to form an orange color in proportion to the iron concentration. The measurement wavelength is 510 nm for spectrophotometers or 520 nm for colorimeters.

3.4.2 Copper Test Procedure

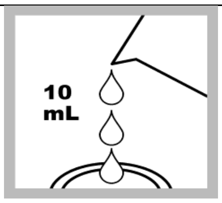
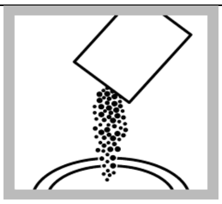
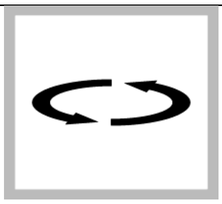
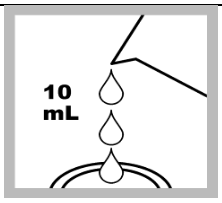
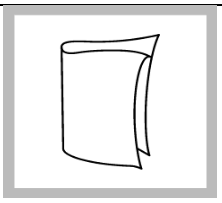
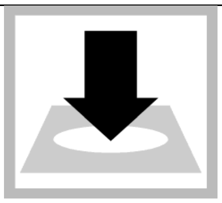
Items to collect

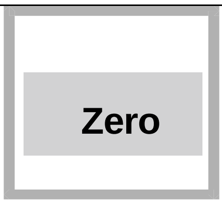
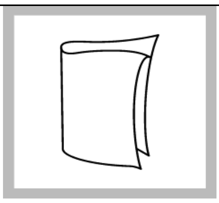
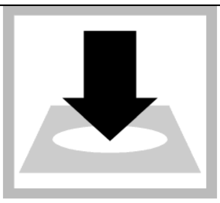
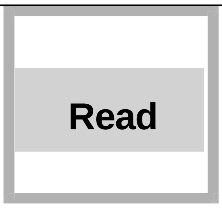
Description	Quantity
CuVer® 1 Copper Reagent Powder Pillow, 10-mL	1
Sample cells	2

Sample collection and storage

- Collect samples in clean glass or plastic bottles that have been cleaned with 6 N (1:1) hydrochloric acid and rinsed with deionized water.
- To preserve samples for later analysis, adjust the sample pH to less than 2 with concentrated nitric acid (about 2 mL per liter). No acid addition is necessary if the sample is tested immediately.
- If only dissolved copper is to be determined, filter the sample before the acid addition.
- Keep the preserved samples at room temperature for a maximum of 6 months.
- Before analysis, adjust the pH to 4–6 with 8.0 N potassium hydroxide standardsolution (do not exceed pH 6, as copper may precipitate).
- Correct the test result for the dilution caused by the volume additions.

Powder pillow procedure

			
1. Start program 135 Copper.	**2.** Prepare the sample: Filla sample cell with 10 mL of sample.	**3.** Add the contents of one CuVer 1 Copper Reagent powder pillow.	**4.** Swirl to mix.
			
5. Start the instrument timer. A 2-minute reactiontime starts. The sample shows a purplecolor when copper in the sample mixes with the reagent powder. Undissolved powder does not affect accuracy.	**6.** Prepare the blank: Fill a second sample cell with 10 mL of sample.	**7.** Clean the blank samplecell.	**8.** Insert the blank into thecell holder.

			
9. Push ZERO. The display shows 0.00 mg/L Cu.	**10.** Clean the prepared sample cell.	**11.** Within 30 minutes afterthe timer expires, insert the prepared sample into the cell holder.	**12.** Push READ. Results show in mg/L Cu.

Standard solution method

Use the standard solution method to validate the test procedure, the reagents and theinstrument.

Items to collect:

- Copper Standard Solution, 100-mg/L
- 100-mL volumetric flask, Class A
- 4-mL volumetric pipet, Class A and pipet filler
- Deionized water

1. Prepare a 4.00-mg/L copper standard solution as follows:
    a. Use a pipet to add 4.00 mL of 100-mg/L copper standard solution into thevolumetric flask.
    b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use the test procedure to measure the concentration of the prepared standardsolution.
3. Compare the expected result to the actual result.

Note: The factory calibration can be adjusted slightly with the standard adjust option so that theinstrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are small variations in the reagents or instruments.

Summary of method

Copper in the sample reacts with a salt of bicinchoninic acid contained in CuVer 1 or CuVer 2 Copper Reagent to form a purple-colored complex in proportion to the copperconcentration. The measurement wavelength is 560 nm.

3.4.3 Manganese Test Procedure

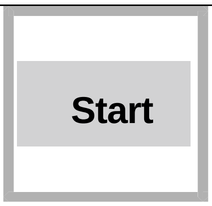
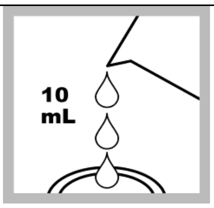
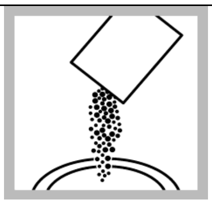
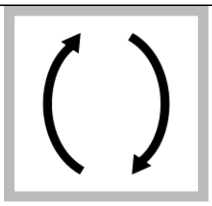
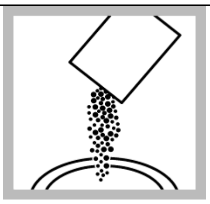
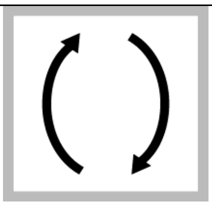
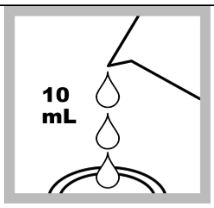
Items to collect

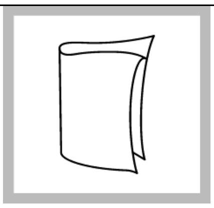
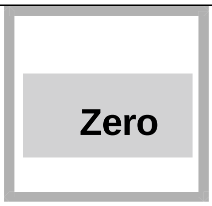
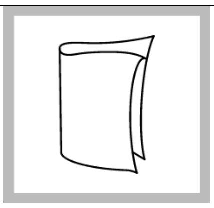
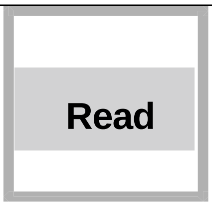
Description	**Quantity**
High Range Manganese Reagent Set, 10-mL	1
Sample cells	2

Sample collection and storage

- Collect samples in acid-washed plastic bottles. Do not use glass containers toprevent possible adsorption of manganese to glass.
- If only dissolved manganese is to be determined, filter the sample before acidaddition.
- To preserve samples for later analysis, adjust the sample pH to less than 2 with concentrated nitric acid (approximately 2 mL per liter). No acid addition is necessary if the sample is tested immediately.
- Keep the preserved samples at room temperature for a maximum of 6 months.
- Before analysis, adjust the pH to 4–5 with 5 N sodium hydroxide standard solution.Do not exceed pH 5 to prevent precipitation of the manganese.
- Correct the test result for the dilution caused by the volume additions.

Powder pillow procedure

			
1. Start program 295 Manganese, HR.	**2.** Prepare the sample: Filla sample cell with 10 mL of sample.	**3.** Add the contents of one Buffer Powder Pilow, CitrateType for Manganese.	**4.** Put the stopper on the sample cell. Invert the sample cell to mix.
			
5. Add the contents of one Sodium Periodate Powder Pillow to the sample cell.	**6.** Put the stopper on the sample cell. Invert to mix. A violet color will show if manganese is present in thesample.	**7.** Start the instrument timer. A 2-minute reactiontime starts.	**8.** Prepare the blank: Fill a second sample cell with 10 mL of sample.

			
9. When the timer expires, clean the blank sample cell.	**10.** Insert the blank into thecell holder.	**11.** Push ZERO. The display shows 0.0 mg/L Mn.	**12.** Clean the prepared sample cell.
			
13. Within 8 minutes after the timer expires, insert the prepared sample into the cell holder.	**14.** Push READ. Results show in mg/L Mn.		

Standard solution method

Use the standard solution method to validate the test procedure, the reagents and theinstrument.

Items to collect:

- Manganese Standard Solution, 1000 mg/L
- 1-L volumetric flask, Class A
- 10-mL volumetric pipet, Class A and pipet filler safety bulb
- Deionized water

1. Prepare a 10.0 mg/L manganese standard solution as follows:
    a. Use a pipet to add 10.00 mL of 1000 mg/L manganese standard solution into the volumetric flask.
    b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use the test procedure to measure the concentration of the prepared standardsolution.
3. Compare the expected result to the actual result.

Note: The factory calibration can be adjusted slightly with the standard adjust option so that theinstrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are slight variations in the reagents or instruments.

Summary of method

Manganese in the sample is oxidized to the purple permanganate state by sodium periodate, after buffering the sample with citrate. The purple color is directly proportional to the manganese concentration. The measurement wavelength is 525 nm for spectrophotometers or 520 nm for colorimeters.

3.4.4 Nitrate Test Procedure

Items to collect

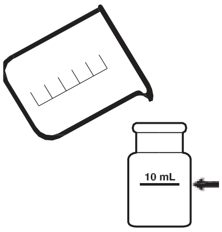
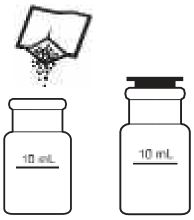
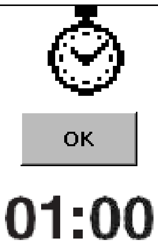
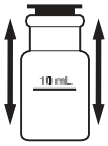
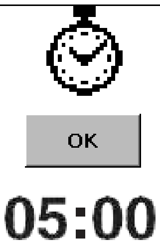
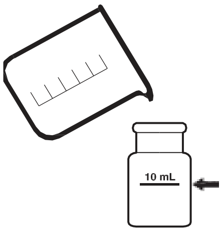
Description	Quantity
NitraVer® 5 Nitrate Reagent Powder Pillow	1
Sample Cells, 1-inch square, 10-mL, with stopper	2

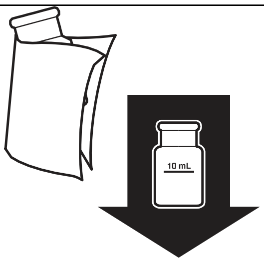
Sample Collection, Storage, and Preservation

More reliable results are obtained when samples are analyzed as soon as possible after collection. If prompt analysis is impossible, store samples in clean plastic or glass bottles for up to 24 hours at 4 °C. To preserve samples for longer periods, add 2 mL of Concentrated Sulfuric Acid (H2SO4) * per liter and store at 4 °C.

Before analysis, warm the sample to room temperature and adjust the pH to 7 with 5.0 N Sodium Hydroxide Standard Solution*. Do not use mercury compounds as preservatives. Correct the test result for volume additions by dividing the total volume (acid + base + sample) by the original sample volume and multiplying the test result by this factor.

Powder pillow procedure

			
1. Press STORED PROGRAMS	**2.** Select the test.	**3.** Fill a square sample cell with 10 mL of sample.	**4.** Prepared Sample: Add the contents of one NitraVer 5 Nitrate Reagent Powder Pillow. Stopper.
			
5. Press TIMER>OK. A one-minute reaction period will begin.	**6.** Shake the cell vigorously until the timer expires. .	**7.** When the timer expires, press TIMER>OK again. A five-minute reaction period will begin. An amber color will develop if nitrate is present.	**8.** Blank Preparation: When the timer expires, fill a second square sample cell with 10 mL of sample.

	Zero		Read
9. Wipe the blank and insert it into the cell holder with the fill line facing right.	**10.** Press ZERO. The display will show: 0.0 mg/L NO3—N	**11.** Within one minute after the timer expires, wipe the prepared sample and insert it into the cell holder with the fill line facing right.	**12.** Press READ. Results are in mg/L NO3—N.

Accuracy Check

Standard Additions Method (Sample Spike)

After reading test results, leave the sample cell (unspiked sample) in the instrument. Verify the chemical form.

Press OPTIONS>MORE. Press STANDARD ADDITIONS. A summary of the standard addition’s procedure will appear.

Press OK to accept the default values for standard concentration, sample volume, and spike volumes. Press EDIT to change these values. After values are accepted, the unspiked sample reading will appear in the top row. See the user manual for more information.

Snap the neck off a Nitrate Nitrogen Voluette® Ampule Standard, 250-mg/L NO3—N.

Prepare three sample spikes. Fill three sample cells* with 10 mL of sample. Use the TenSette® Pipet to add 0.1 mL, 0.2 mL, and 0.3 mL of standard, respectively, to each sample and mix thoroughly.

Analyze each sample spike as described in the procedure above, starting with the 0.1 mL sample spike. Accept each standard additions reading by pressing READ. Each addition should reflect approximately 100% recovery.

Note: For AccuVac® Ampuls, fill three mixing cylinders* with 50 mL of sample and spike with 0.4 mL, 0.8 mL, and 1.2 mL of standard. Transfer 40 mL from each of the three mixing cylinders to three 50-mL beakers*. Analyze each standard addition sample as described in the procedure above. Accept each standard additions reading by pressing READ. Each addition should reflect approximately 100% recovery.

After completing the sequence, press GRAPH to view the best-fit line through the standard additions data points, accounting for the matrix interferences. Press IDEAL LINE to view the relationship between the sample spikes and the “Ideal Line” of 100% recovery.

Standard Solution Method

To test accuracy, use a 10.0-mg/L Nitrate Nitrogen Standard Solution in place of the sample and perform the procedure as described above.

To adjust the calibration curve using the reading obtained with the standard solution, press

OPTIONS>MORE on the current program menu. Press STANDARD ADJUST.

Press ON. Press ADJUST to accept the displayed concentration (the value depends on the selected chemical forms). If an alternate concentration is used, press the number in the box to enter the actual concentration, then press OK. Press ADJUST.

Summary of Method

Cadmium metal reduces nitrates in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution. Test results are measured as 500 nm.

3.4.5 Phosphate Test Procedure

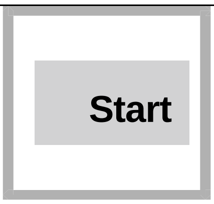
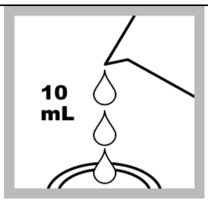
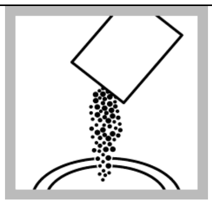
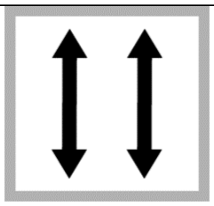
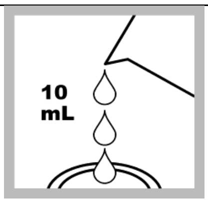
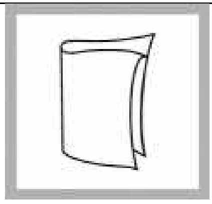
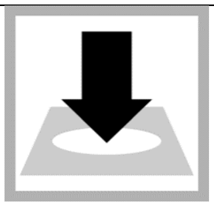
Items to collect

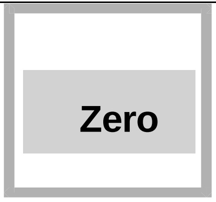
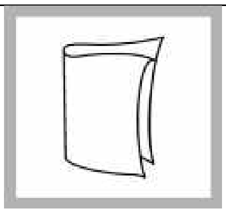
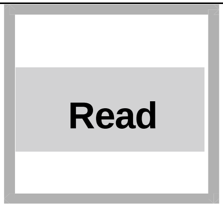
Description	Quantity
PhosVer® 3 Phosphate Reagent powder pillow, 10-mL	1
Sample cells	2

Sample collection and storage

- Collect samples in clean glass or plastic bottles that have been cleaned with 6 N (1:1) hydrochloric acid and rinsed with deionized water.
- Do not use a detergent that contains phosphate to clean the sample bottles. The phosphate in the detergent will contaminate the sample.
- Analyze the samples as soon as possible for best results.
- If immediate analysis is not possible, immediately filter and keep the samples at or below 6 °C (43 °F) for a maximum of 48 hours.
- Let the sample temperature increase to room temperature before analysis.

Powder pillow procedure

			
1. Start program 490 P React. PP.,	**2.** Prepare the sample: Filla sample cell with 10 mL of sample.	**3.** Add the contents of one PhosVer 3 Phosphate Reagent Powder Pillow to the cell. A blue color develops if phosphorus is inthe sample.	**4.** Immediately close the sample cell. Shake vigorously for 20–30 seconds.
			

5. Start the instrument timer. A 2-minute reactiontime starts. If the sample was digestedusing the Acid Persulfate digestion, a 10-minute reaction period is necessary.	**6.** Prepare the blank: Fill a second sample cell with 10 mL of sample.	**7.** When the timer expires, clean the blank sample cell.	**8.** Insert the blank into thecell holder.
			
9. Push ZERO. The display shows 0.00 mg/L PO^{3-}.	**10.** Clean the prepared sample cell.	**11.** Insert the prepared sample into the cell holder.	**12.** Push READ. Results show in mg/L PO^{3-}.

Standard solution method

Use the standard solution method to validate the test procedure, the reagents and the instrument.

Items to collect:

- 50 mg/L phosphate standard solution
- 100-mL volumetric flask, Class A
- 4-mL volumetric pipet, Class A and pipet filler safety bulb
- Deionized water

1. Prepare a 2.00-mg/L phosphate standard solution as follows:
   a. Use a pipet to add 4.00 mL of a 50-mg/L phosphate standard solution into the volumetric flask. *(Alternately, use one of the available mixed parameter standards. These standards contain 2.0 mg/L phosphate.)*
   b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use the test procedure to measure the concentration of the prepared standard solution.
3. Compare the expected result to the actual result.

Note: The factory calibration can be adjusted slightly with the standard adjust option so that the instrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are small variations in the reagents or instruments.

Summary of method

Orthophosphate reacts with molybdate in an acid medium to produce a mixed phosphate/molybdate complex. Ascorbic acid then reduces the complex, which gives an intense molybdenum blue color. The measurement wavelength is 880 nm for spectrophotometers (DR 1900: 710 nm) or 610 nm for colorimeters.

3.4.6 Sulfate Test Procedure

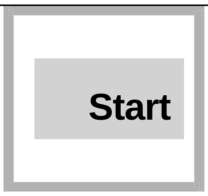
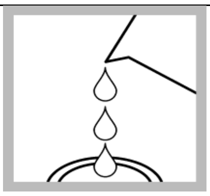
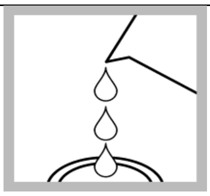
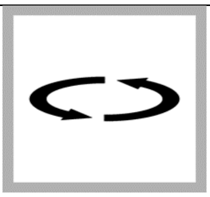
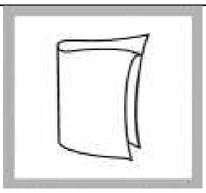
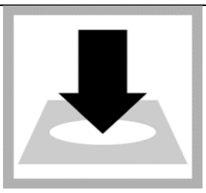
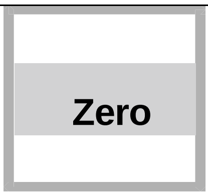
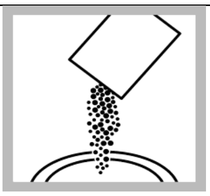
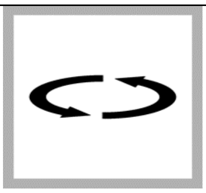
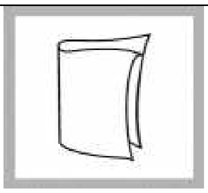
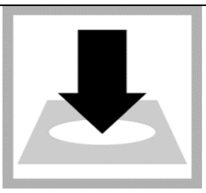
Items to collect

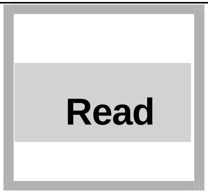
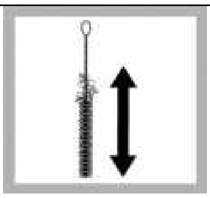
Description	**Quantity**
SulfaVer® 4 Reagent Powder Pillows, 10-mL	1
Sample cells	2

Sample collection and storage

- Collect samples in clean glass or plastic bottles.
- To preserve samples for later analysis, keep the samples at or below 6 °C (43 °F) forup to 28 days.
- Let the sample temperature increase to room temperature before analysis.

Powder pillow procedure

			
1. Start program 680 Sulfate.	**2.**Add the sample volumethat is specified for the test range to a sample cell: 2–70 mg/L: 10 mL 20–700 mg/L: 1.0 mL 200–7,000 mg/L: 0.1 mL Use a TenSette Pipet or glass pipet to measure 0.1 mL or 1.0 mL.	**3.** If the sample volume is less than 10-mL add deionized water to the 10-mL line. For the dilution factor, refer to Set the dilution factor on page 3.	**4.** Swirl to mix.
			
5. Clean the blank sample cell.	**6.** Insert the blank into thecell holder.	**7.** Push ZERO. The display shows 0 mg/L SO 2–.	**8.** Add the contents of one SulfaVer 4 Reagent Powder Pillow to the sample cell. The sample will get cloudy if sulfate is present in the sample.
			

9. Swirl the sample cell to mix. Undissolved powder will not affect accuracy.	**10.** Start the instrument timer. A 5-minute reactiontime starts. Do not move the sample cell during the reaction period.	**11.** Clean the prepared sample cell.	**12.** Within 5 minutes after the timer expires, insert the prepared sample into the cell holder.
			
13. Push READ. Results show in mg/L SO 2–.	**14.** Clean the sample cell immediately after each test with soap, water and a brush.		

Standard solution method

Use the standard solution method to validate the test procedure, the reagents and theinstrument.

Items to collect:

- Sulfate standard solution, 1000 mg/L
- 100-mL volumetric flask, Class A
- 5-mL volumetric pipet, Class A and pipet filler safety bulb
- Deionized water

1. Prepare a 50 mg/L sulfate standard solution as follows:
   a. Use a pipet to add 5.0 mL of 1000 mg/L sulfate standard solution into thevolumetric flask.
   b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use the test procedure to measure the concentration of the prepared standardsolution.
3. Compare the expected result to the actual result.

Note: The factory calibration can be adjusted slightly with the standard adjust option so that theinstrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are small variations in the reagents or instruments.

Summary of method

Sulfate ions in the sample react with barium in the SulfaVer 4 and form a precipitate of barium sulfate. The amount of turbidity formed is proportional to the sulfate concentration. The measurement wavelength is 450 nm for spectrophotometers or 520 nm for colorimeters.

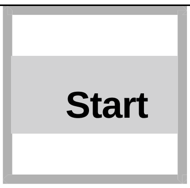
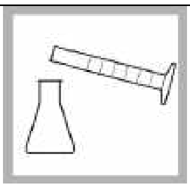
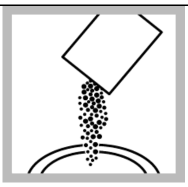
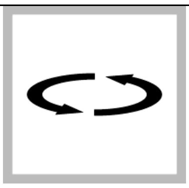
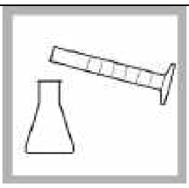
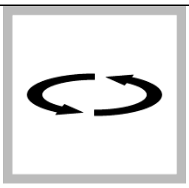
3.4.7 Boron Test Procedure

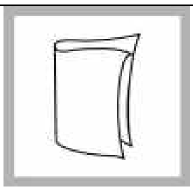
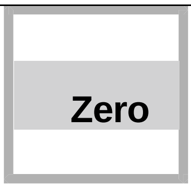
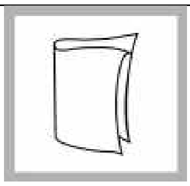
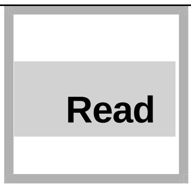
Items to collect

Description	Quantity
BoroVer 3 Boron Reagent Powder Pillow	1
Sulfuric Acid, concentrated, ACS	75 mL
Water, deionized	2 mL
Cylinder, graduated, 100-mL	1
Cylinder, graduated, 50-mL	1
Flask, Erlenmeyer, 250-mL	1
Flask, Erlenmeyer, 125-mL	2
Pipet, volumetric, Class A, 2.0-mL	2
Pipet filler, safety bulb	1
Sample cells	2

Sample collection
Collect samples in clean polyethylene or polypropylene bottles.

Powder pillow procedure

			
1. Start program 40 Boron.	**2.** Use a 100-mL graduated cylinder to measure 75 mL of concentrated sulfuric acid. Pour the acid into a 250-mL Erlenmeyer flask.	**3.** In a well-ventilated areaor fume hood, add the contents of one BoroVer 3 Reagent Powder Pillow to the flask.	**4.** Swirl to mix. Wait for up to 5 minutes forthe powder to completely dissolve.
			
5. Prepare the blank: Usea pipet to add 2.0 mL of deionized water into a 125-mL Erlenmeyer flask.	**6.** Prepare the sample: Use a pipet to add 2.0 mL of sample into a second 125-mL Erlenmeyer flask.	**7.** Use a 50-mL graduated cylinder to measure 35 mL of the solution prepared in step 3 to each Erlenmeyerflask.	**8.** Swirl to mix.

			
9. Start the instrument timer. A 25-minute reactiontime starts.	**10.** When the timer expires,pour at least 10 mL from each flask into separate sample cells.	**11.** Clean the blank samplecell.	**12.** Insert the blank into thecell holder.
			
13. Push ZERO. The display shows 0.0 mg/L B	**14.** Clean the prepared sample cell.	**15.** Insert the prepared sample into the cell holder.	**16.** Push READ. Results show in mg/L B.

Reagent preparation

More than 75 mL of the BoroVer 3/Sulfuric Acid Solution can be prepared for use inmultiple analyses.

Preparation notes

- Gaseous hydrochloric acid (HCl) forms when the powder pillow is added to sulfuric acid. Always mix under a fume hood.
- The solution is stable for a maximum of 48 hours when kept in plastic containers.
- To prevent boron contamination from the glassware, do not keep the solution in borosilicate glassware (Pyrex® or Kimax®) for more than 1 hour.
- The BoroVer 3/Sulfuric Acid Solution is highly acidic. Refer to the current MSDS/SDS for safe handling and disposal instructions.

1. Determine the amount of sulfuric acid and powder pillows that are necessary for the number of samples to be analyzed. Use 75 mL of sulfuric acid for each analysis. Use one BoroVer 3 Reagent Powder Pillow for each 75 mL of sulfuric acid.
2. Under a fume hood, measure the concentrated sulfuric acid with a graduatedcylinder.
3. Pour the acid into a Erlenmeyer flask.
4. Stir the acid and add the contents of one BoroVer 3 Reagent Powder Pillow to the flask. Swirl to mix. Wait for the powder to completely dissolve. Continue to add onepowder pillow at a time. Stir to dissolve after each powder pillow is added.
5. Pour this solution into plastic containers and use within 48 hours.

Standard solution method

Use the standard solution method to validate the test procedure, the reagents and theinstrument. Items to collect:

- 1000-mg/L Boron Standard Solution

- 200-mL volumetric flask, Class A
- 2.00-mL volumetric pipet, Class A and pipet filler
- Deionized water

1. Prepare a 10-mg/L boron standard solution as follows:
   a. Use a pipet to add 2.00 mL of a 1000-mg/L boron standard solution into the volumetric flask.
   b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use the test procedure to measure the concentration of the prepared standardsolution.
3. Compare the expected result to the actual result.

Note: The factory calibration can be adjusted slightly with the standard adjust option so that theinstrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are slight variations in the reagents or instruments.

Summary of Method

Boron reacts with carminic acid in a sulfuric acid solution to produce a reddish to bluishcolor. The amount of color is directly proportional to the boron concentration. The measurement wavelength is 605 nm.

3.4.8 Bromide Test Procedure

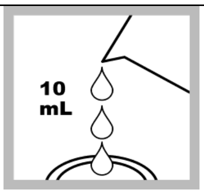
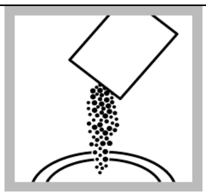
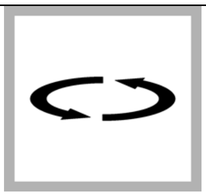
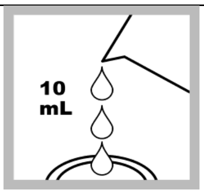
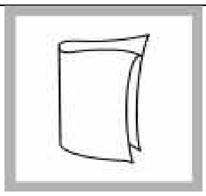
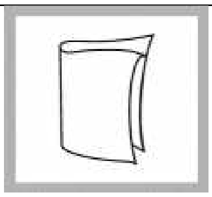
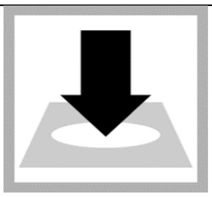
Items to collect

Description	Quantity
DPD Total Chlorine Reagent Powder Pillow, 10-mL	1
Sample cells	2

Sample collection

- Analyze samples for bromine immediately after collection.
- Bromine is a strong oxidizing agent and is unstable in natural waters. Bromine reacts quickly with various inorganic compounds and more slowly with organic compounds. Many factors, including reactant concentrations, sunlight, pH, temperature and salinity influence the decomposition of bromine in water.
- Collect samples in clean glass bottles. Do not use plastic containers because thesecan have a large bromine demand.
- Pretreat glass sample containers to remove bromine demand. Soak the containers ina weak bleach solution (1 mL commercial bleach to 1 liter of deionized water) for at least 1 hour. Rinse fully with deionized or distilled water. If sample containers are rinsed fully with deionized or distilled water after use, only occasional pretreatment isnecessary.
- Make sure to get a representative sample. If the sample is taken from a spigot or faucet, let the water flow for at least 5 minutes. Let the container overflow with the sample several times and then put the cap on the sample container so that there isno headspace (air) above the sample.

Powder pillow procedure

Start			
1. Start program 50 Bromine.	**2.** Fill a sample cell with10 mL of sample.	**3.** Prepare the sample: Add the contents of one powder pillow to the samplecell.	**4.** Swirl the sample cell forto mix. A pink color shows if bromine is in the sample.
			
5. Start the instrument timer. A 3-minute reactiontime starts. The instrument can be set to zero with the blank during the reaction timer.	**6.** Prepare the blank: Fill a second sample cell with 10 mL of sample.	**7.** Clean the blank samplecell.	**8.** Insert the blank into the cell holder.
Zero			Read
9. Push ZERO. The display shows 0.00 mg/L Br_2.	**10.** Clean the prepared sample cell.	**11.** Within 3 minutes after the timer expires, insert the prepared sample into the cell holder.	**12.** Push READ. Results show in mg/L Br_2.

Summary of method

Bromine residuals reacts with DPD (N,N-diethyl-p-phenylenediamine) to form a pink color which is proportional to the total bromine concentration. The measurement wavelength is530 nm for spectrophotometers or 520 nm for colorimeters.

3.4.9 Iodine Test Procedure

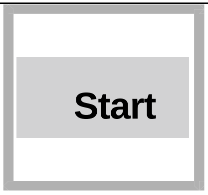
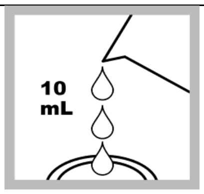
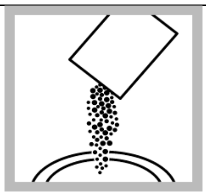
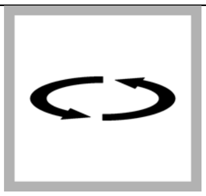
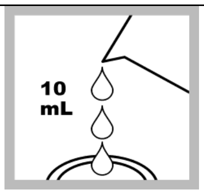
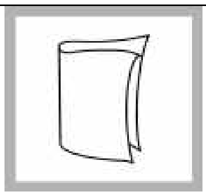
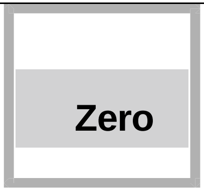
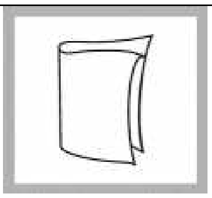
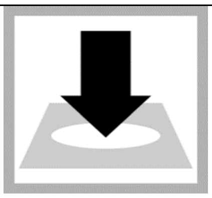
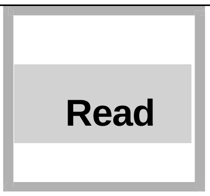
Items to collect

Description	Quantity
DPD Total Chlorine Reagent Powder Pillow, 10-mL	1
Sample cells	2

Sample collection

- Analyze the samples immediately. The samples cannot be preserved for lateranalysis.
- Collect samples in clean glass bottles.
- Make sure to get a representative sample. If the sample is taken from a spigot or faucet, let the water flow for at least 5 minutes. Then let the container overflow withthe sample several times. Put the cap on the sample container so that there is no headspace (air) above the sample. If a sample cell is used, rinse the cell several times with the sample, then carefully fill to the 10-mL mark.
- Be careful to prevent agitation. Do not expose the water to sunlight during sample collection.

Powder pillow procedure

			
1. Start program 50 Bromine.	**2.** Fill a sample cell with10 mL of sample.	**3.** Prepare the sample: Add the contents of one powder pillow to the samplecell.	**4.** Swirl the sample cell forto mix. A pink color shows if bromine is in the sample.
			
5. Start the instrument timer. A 3-minute reactiontime starts. The instrument can be set to zero with the blank during the reaction timer.	**6.** Prepare the blank: Fill a second sample cell with 10 mL of sample.	**7.** Clean the blank samplecell.	**8.** Insert the blank into the cell holder.
			

9. Push ZERO. The display shows 0.00 mg/L Br_2.	**10.** Clean the prepared sample cell.	**11.** Within 3 minutes after the timer expires, insert the prepared sample into the cell holder.	**12.** Push READ. Results show in mg/L Br_2.

Summary of Method

Iodine reacts with DPD (N, N-diethyl-p-phenylenediamine) to form a pink color, the intensity of which is proportional to the total iodine concentration. The measurementwavelength is 530 nm.

3.4.10 Aluminium Test Procedure

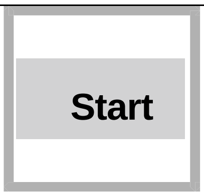
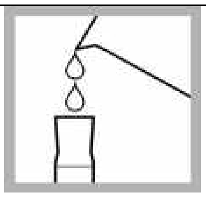
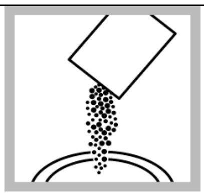
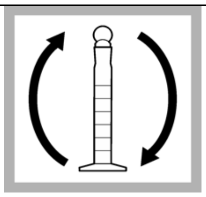
Items to collect

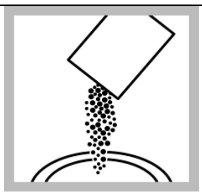
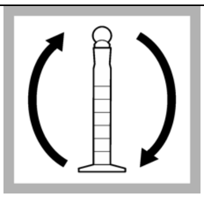
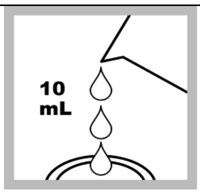
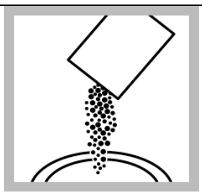
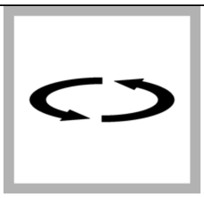
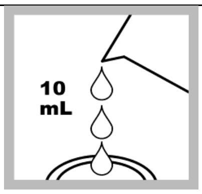
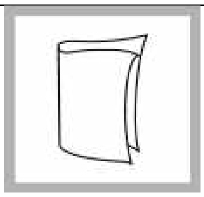
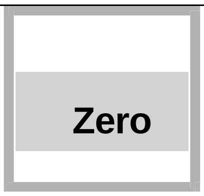
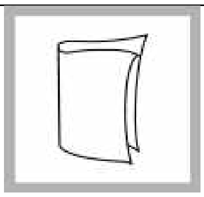
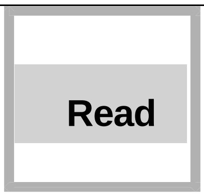
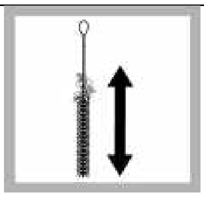
Description	**Quantity**
AluVer 3[1] Aluminum Reagent Powder Pillow	1
Ascorbic Acid Powder Pillow	1
Bleaching 3 Reagent Powder Pillow	1
Mixing cylinder, graduated, 50 mL, with glass stopper	1
Sample cells	2

Sample collection and storage

- Collect samples in clean glass or plastic bottles that have been cleaned with 6 N (1:1) hydrochloric acid and rinsed with deionized water.
- To preserve samples for later analysis, adjust the sample pH to less than 2 with concentrated nitric acid (approximately 2 mL per liter). No acid addition is necessary if the sample is tested immediately.
- Keep the preserved samples at room temperature for a maximum of 6 months.
- Before analysis, adjust the pH to 3.5–4.5 with 5 N sodium hydroxide solution.
- Correct the test result for the dilution caused by the volume additions.

Powder pillow procedure

			
1. Start program 10 Aluminum Alumin.	**2.** Fill a mixing cylinder to the 50-mL mark with sample.	**3.** Add the contents of one Ascorbic Acid Powder Pillow.	**4.** Put the stopper on the mixing cylinder. Invert the mixing cylinder several times to dissolve the powder.

			
5. Add one AluVer 3 Aluminum reagent powderpillow. An orange to orange-red color shows if aluminum ispresent.	**6.** Start the instrument timer. A 1-minute reactiontime starts.	**7.** Invert the cylinder repeatedly during the reaction time. Undissolved powder will cause inconsistent results.	**8.** Prepare the blank: Pour 10 mL of the reacted sample into a sample cell.
			
9. Add one Bleaching 3 Reagent powder pillow to the blank.	**10.** Start the instrument timer. A 30-second reactiontime starts.	**11.** Swirl the sample cell vigorously. The solution will show a light to medium orange.	**12.** Start the instrument timer. A 15-minute reactiontime starts.
			
13. Prepare the sample: Pour 10 mL of solution fromthe cylinder into a second sample cell.	**14.** When the timer expires,clean the blank sample cell.	**15.** Insert the blank into thecell holder.	**16.** Push ZERO. The display shows 0.00 or 0.000 mg/L Al^{3+}.
			
17. Clean the prepared sample cell.	**18.** Within 5 minutes after the timer expires, insert the prepared sample into the cell holder.	**19.** Push READ. Results show in mg/L Al^{3+}.	**20.** Immediately clean the graduated cylinder and sample cells with soapy water and a brush. Rinse with deionized water.

Standard solution method

Use the standard solution method to validate the test procedure, the reagents and theinstrument.

Items to collect:

- 100-mg/L aluminum standard solution
- 250-mL volumetric flask, Class A
- 1.00-mL volumetric pipet, Class A and pipet filler safety bulb
- Deionized water

1. Prepare a 0.4 mg/L aluminum standard solution as follows:
   a. Use a pipet to add 1.00 mL of 100-mg/L aluminum standard solution into the volumetric flask. (Alternate preparation: Use a pipet to add 0.8 mL of a 50-mg/L aluminum standard solution into a 100-mL volumetric flask.)
   b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use the test procedure to measure the concentration of the prepared standardsolution.
3. Compare the expected result to the actual result.

Note: The factory calibration can be adjusted slightly with the standard adjust option so that theinstrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are small variations in the reagents or instruments.

Summary of method

Aluminon indicator combines with aluminum in the sample to form a red-orange color. The intensity of color is proportional to the aluminum concentration. Ascorbic acid is added before the AluVer 3 reagent to remove iron interference. To establish a reagent blank, the sample is divided after the addition of the AluVer 3. Bleaching 3 Reagent is then added to one-half of the divided sample to bleach out the color of the aluminum aluminon complex. The AluVer 3 Aluminum Reagent, packaged in powder form, showsexceptional stability and is applicable for fresh water applications. The measurement wavelength is 522 nm for spectrophotometers or 520 nm for colorimeters.

3.4.11 Chloride Test Procedure

Introduction

This method determines the chloride ion concentration of a solution by titration with silver nitrate. As the silver nitrate solution is slowly added, a precipitate of silver chloride forms.

$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

The end point of the titration occurs when all the chloride ions are precipitated. Then additional silver ions react with the chromate ions of the indicator, potassium chromate, to form a red-brown precipitate of silver chromate.

$$2\,Ag^+(aq) + CrO_4^{2-}(aq) \longrightarrow Ag_2CrO_4(s)$$

This method can be used to determine the chloride ion concentration of water samples from many sources such as seawater, stream water, river water and estuary water. Seawater is used as the example here.

The pH of the sample solutions should be between
6.5 and 10. (Refer to the additional notes (3) for the explanation). If the solutions are acidic, the gravimetric method or Volhard's method should be used.

Equipment Needed

Burette and stand, 10- and 20-mL pipettes, 100 mL volumetric flask, 250 mL conical flasks, 10 mL and 100 mL measuring cylinders.

Solutions Needed

Silver nitrate solution: (0.1 mol L−1) If possible, dry 5 g of AgNO3 for 2 hours at 100°C and allow to cool. Accurately weigh about 4.25 g of solid AgNO3 and dissolve it in 250 mL of distilled water in a conical flask. Store the solution in a brown bottle.

Potassium chromate indicator solution: (approxiately0.25 molL-1) Dissolve 1 g of K2CrO4 in 20 mL distilled water.

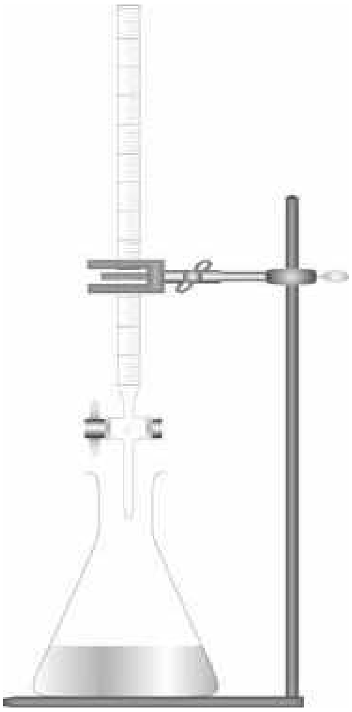


Figure 3-12: Chloride Analysis with Titration.

Method

Sample Preparation

If the seawater contains traces of solid matter such as sand or seaweed, it must be filtered before use.

Titration

1. Dilute seawater by pipetting a 20 mL sample into a 100 mL volumetric flask and making it up to the mark with distilled water.
2. Pipette a 10 mL aliquot of diluted seawater into a conical flask and add about 50 mL distilled water and 1 mL of chromate indicator.
3. Titrate the sample with 0.1 mol L−1 silver nitrate solution. Although the silver chloride that forms is a white precipitate, the chromate indicator initially
4. gives the cloudy solution a faint lemon-yellow colour (figure 1).

Figure 3-13: After Adding Indicator the Chromate Indicator Colour.

5. The endpoint of the titration is identified as the first appearance of a red-brown colour of silver chromate (figure 2).

Figure 3-14: Colour Changing Stages with the Addition of Silver Nitrate.

6. have precipitated. The slightest excess of Ag+ precipitates with the chromate indicator giving a slight red-brown colouration. Right flask: If addition of Ag+ is continued past the endpoint, further silver chromate precipitate is formed and a stronger red-brown colour results. NB: The titration should be stopped when the first trace of red-brown colour is observed. Using an
7. incompletely titrated reference flask for comparison is a helpful way to identify the first appearance of red-brown colouration.
8. Repeat the titration with further aliquots of diluted seawater until concordant results (titres agreeing within 0.1 mL) are obtained.

Result Calculations

1. Determine the average volume of silver nitrate used from your concordant titres.
2. Calculate the moles of silver nitrate reacting.
3. Use the following reaction equation to determine the moles of chloride ions reacting.
    i. $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$
4. Calculate the concentration of chloride ions in the diluted seawater.
5. Calculate the concentration of chloride ions in the original undiluted seawater.
6. Calculate the concentration of sodium chloride in the seawater in $molL^{-1}$, gL^{-1} and g/100 mL (%).

3.4.12 Carbonate and Bicarbonate Test Procedure

Introduction

Alkalinity is primarily a way of measuring the acid neutralizing capacity of water.
In other words, its ability to maintain a relatively constant pH.
The possibility to maintain constant pH is due to the hydroxyl, carbonate and bicarbonate ions present in water.
The ability of natural water to act as a buffer is controlled in part by the amount of calcium and carbonate ions in solution.
Carbonate ion and calcium ion both come from calcium carbonate or limestone.
So, water that comes in contact with limestone will contain high levels of both Ca++ and C_3O 2- ions and have elevated hardness and alkalinity.

Materials Required

Apparatus Requierd

1. Burette with Burette stand and porcelain title
2. Pipettes with elongated tips
3. Pipette bulb
4. Conical flask (Erlenmeyer Flask)
5. 250 mL Measuring cylinders
6. Standard flask
7. Wash Bottle
8. Beakers

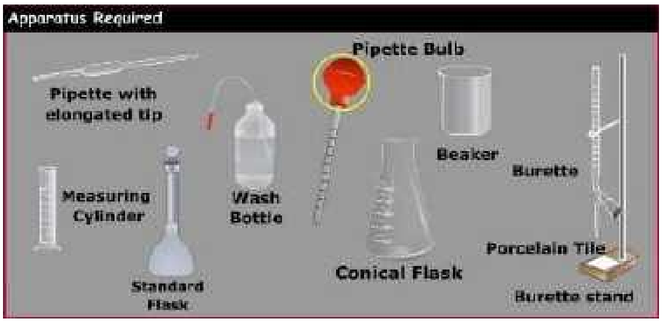


Figure 3-15: Apparatus Required for Carbonate and Bicarbonate Titration.

Chemicals Required

9. Standard sulphuric acid
10. Phenolphthalein
11. Mixed Indicator
12. Bromocresol Green
13. Methyl Red
14. Ethyl alcohol
15. Distilled Water

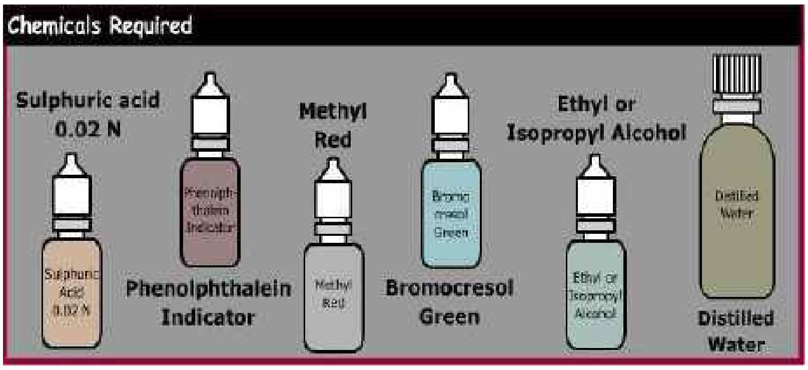


Figure 3-16: Chemicals Required for Carbonate and Bicarbonate Titration.

Procedure

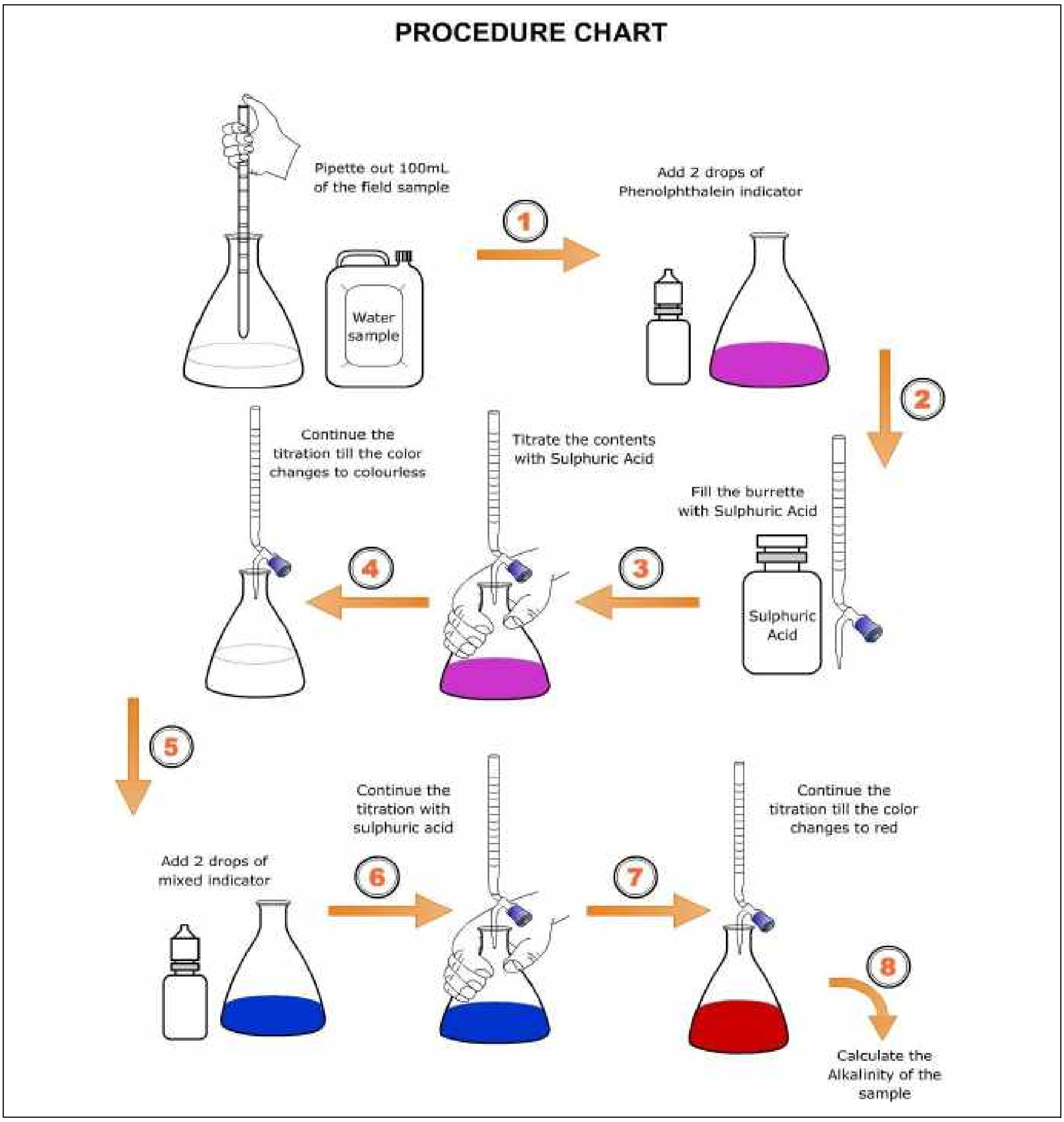


Figure 3-17: Product Chart of Carbonate and Bicarbonate Titration.

Preparation of Reagents

For testing the given sample, first the reagents are required to be prepared.

Sulphuric Acid Solution (0.02N):

- Take approximately 500 mL of distilled water in a 1000 mL standard flask.
- Pipette 20 mL of concentrated 0.1 Normality Sulphuric acid and add slowly along the sides of the standard flask.
- Then make up the volume up to 1000 mL mark. Now the strength of this solution is 0.02 N.

Phenolphthalein Indicator Preparation:

- Weigh 1g of phenolphthalein and add to 100 mL of 95% ethyl alcohol or to 100 mL of distilled water. Use the readymade Phenolphthalein indicator available in the market.

Mixed Indicator Preparation:

- Dissolve 100 mg Bromocresol green and 20 mg of methyl red in 100 mL of 95% ethyl alcohol or use 100 mL of distilled water. Mixed indicator also readily available in the market. So, it can be used as indicator in this experiment.

Testing of Water Sample

- Rinse the burette with 0.02N Sulphuric acid and discard the solution.
- Fill the burette with 0.02N sulphuric acid and adjust it to zero.
- Fix the burette in the stand.
- Using a measuring cylinder exactly measure 100 mL of sample and pour it into a 250 mL of conical flask.
- Add few drops of phenolphthalein indicator to the contents of conical flask. The colour of the solution will turn to pink. This colour change is due to alkalinity of hydroxyl ions in the water sample.
- Titrate it against 0.02N sulphuric acid till the pink color disappears. This indicates that all the hydroxyl ions are removed from the water sample. Note down the titter value (V1). The value of titration is 0.5mL. This value is used in calculating the phenolphthalein alkalinity.
- To the same solution in the conical flask add few drops of mixed indicator. The colour of the solution turns to blue. This colour change is due to CO_3^{2-} & HCO_3^{-} ions in water sample.
- Continue the titration from the point where stopped for the phenolphthalein alkalinity. Titrate till the solution becomes red. The entire volume (V2) of sulphuric acid is noted down and it is accountable in calculating the total alkalinity.
- The value of titration is 8.3mL.
- Repeat the titration for concordant values.

3.4.13 Atomic Absorption Spectrometers (AAS) Test Procedure

Introduction

- Thermo Scientific iCE 3500
- Dual atomizer AA spectrometer
- Flame atomization in left hand sample compartment
- Furnace atomization in the right-hand sample compartment
- Vapour atomization in either sample compartment
- Zeeman or non-Zeeman furnace options
- Wide range photomultiplier
- Furnace vision system as standard

Optics specifications

- iCE 3500
- Double beam, Stockdale optics
- Self-referencing Zeeman system
- Echelle monochromator and prism
- Nominal 0.1 (available below 400 nm), 0.2, 0.5, and 1.0 nm spectral bandwidths
- Reciprocal linear dispersion 0.5 nm/mm at 200 nm

Wavelength range

Wide range photomultiplier 180 - 900 nm Standard photomultiplier 185 - 760 nm

Absorbance range

-0.150A to 3.000A (including background signal)

Background correction

Quadline (continuum source) is standard on all spectrometers. Background signals below 2A are corrected for with less than
2 % error. Total signal up to 3A.

Light source

Single or multi-element hollow cathode lamps Uncoded or data coded hollow cathode lamps 6 independent power supplies Each power supply provides 0 to 20 mA

Flame systems

All flame systems are supported by the enhanced Universal Finned 50 mm Titanium Burner to accommodate all flame types. This burner can provide exceptionally low carbon build up, high solids handling, and flame stability. For extra sensitivity with air/acetylene elements there is a 100 mm titanium burner available. The burner height is automatically optimized and there are controls for the rotational and transverse positions of the burner. A high-tension electric spark provides automatic flame ignition.

The automatic gas control system uses programmable array state logic and binary flow switching technology for reliability. Changeover of oxidant gas, and fuel and oxidant flow rates are software controlled and interlocked to prevent operation with incorrect burners and gas flows.

Gas lines are fitted with flame arrestors and pressure sensors which will provide automatic safe shut down if the pressure in the line falls below safe limits. If the power fails the system will shut down safely.

The ‘kitchen’ area is totally enclosed, draught proof and has a safety door containing a heat and UV absorbing window.

An inert fluoroplastic spray chamber contains an inert adjustable impact bead, flow spoiler, low memory hydrophilic disc and built in over pressure relief. All flame types can be used with the standard spray chamber configuration and burner supplied. The inert nebulizer has a Pt/Ir capillary and PTFE venturi as standard and this is optimized in the factory.

Gas Control

Automatic binary switching fuel flow control

Safety

Automatic flame ignition
Software controlled, automatic oxidant changeover
Software controlled, automatic fuel gas boost on oxidant changeover
Automatic flame shut down
Fuel line flashback arrestor
Fuel line pressure regulator
Fuel and oxidant line pressure sensors
Flame present sensor
Burner type sensor
Power failure protection
Empty drain protection
Spray chamber over pressure protection

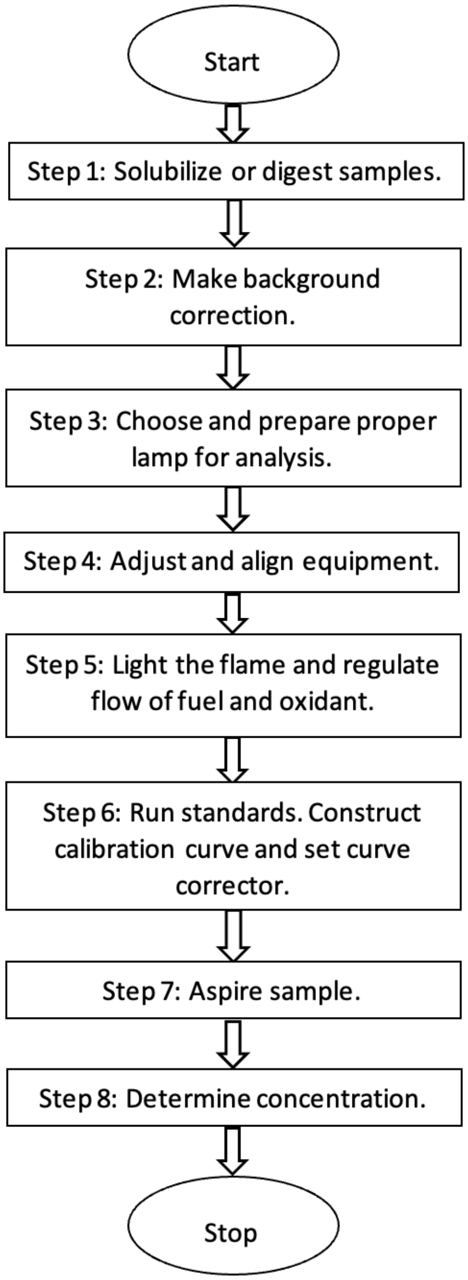


Figure 3-18: Product Chart of Atomic Absorption Spectrometers (AAS).

Step 1: Solubilize or Digest Sample

Aqueous samples can be generally introduced for analysis directly and without any prior treatment. The only major problem associated with work with solutions is their collection and storage. Concerning atomic spectroscopic analysis itself, no particular precautions have to be taken. If measured concentrations satisfy the principal criteria of the spectroscopic method used (sensitivity, dynamic range) and possible interferences are under control, the analysis of solutions may be performed automatically with all modern atomic spectroscopic systems.

Step 2: Make Background Correction

Background absorption is an interference in atomic absorption for which the method of additions will not compensate. There are two causes of background absorption: light scattering by particles in the flame and absorption of light by undissociated molecular forms of matrix materials in the flame.

To compensate for this problem, the background absorption must be measured and subtracted from the total measured absorption to determine the true atomic absorption component. Fortunately, background absorption can be distinguished from the absorption due to the element of interest. The element can absorb only the narrow line emitted by the source lamp; background absorption is less specific and extends over a broad wavelength band.

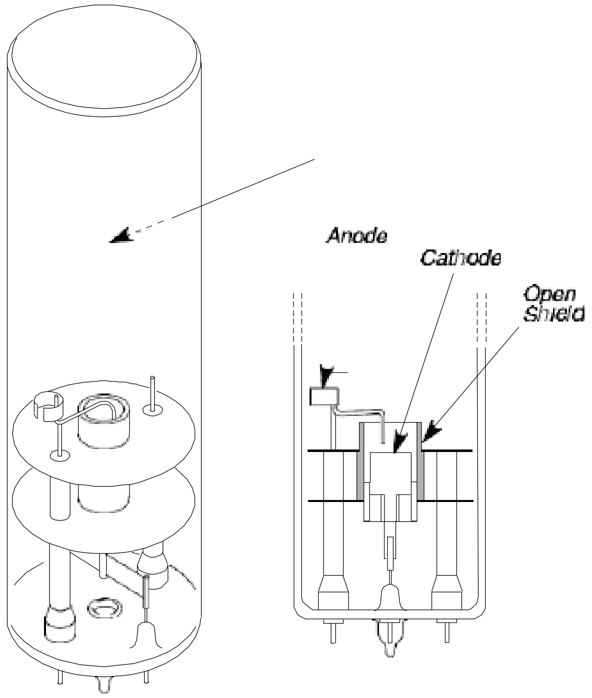


Figure 3-19: Diagram of a Hollow Cathode Lamp.

Step 3: Choose and Prepare Proper Lamp for Analysis

The cathode is a hollowed-out cylinder constructed entirely or in part of the metal whose spectrum is to be produced. The anode and cathode are sealed in a glass cylinder filled with neon or argon. The glass cylinder has a quartz or UV glass window for optimum transmittance of the emitted radiation. The optimum fill gas is selected that gives the best lamp intensity while taking into consideration spectral interferences from either neon or argon. A red glow is observed in lamps filled with neon, while argon filled lamps have a blue glow.

Hollow cathode lamps are available for more than 60 elements. The hollow cathode emission process is illustrated in **Figure:3-8**.

Step 4: Adjust and Align Equipment

Burner Adjustment

Adjustment of the burner head relative to the light path of the instrument is necessary to obtain maximum sensitivity. The burner height may be adjusted by first lowering the burner (with the flame off) until the burner head is well below the light beam and then zeroing the readout. Slowly raise the burner until the head just intersects the beam (indicated by a positive reading on the readout). The burner should then be slowly lowered until the readout returns to zero (indicating the burner is just below the light beam).

Nebulizer Adjustment

Set up the instrument for the determination of copper, magnesium, or other elements which have an absorbing wavelength above 250 nm and whose sensitivity is not dependent on the fuel/oxidant ratio. Do not select an element requiring a nitrous oxide-acetylene flame. Aspirate a standard solution of the element being determined and turn the knurled end cap of the nebulizer counterclockwise until air bubbles into the solution. If the flame becomes leaner during this operation, slight adjustment of the fuel flow may be necessary. While observing the absorbance reading, slowly turn the knurled end cap of the nebulizer clockwise. The absorbance reading may go through several peaks as the end cap is turned. Return the end cap to the peak which gives maximum absorbance (normally the first peak). After adjustment turn the locking ring counterclockwise until it rests against the nebulizer end cap to prevent accidental misadjustment. Nebulizers do not normally require readjustment unless a different solvent is used.

Step 5: Light the Flame and Regulate Flow of Fuel and Oxidant

Gas Flow Adjustment

For many elements, the fuel/oxidant ratio must be adjusted for maximum sensitivity. Aspirate a standard solution and adjust the Fuel, checking zero after each flow change and readjusting as necessary.

Step 6: Run Standards, construct calibration curve and set curve corrector

Instrument Calibration

Curve Correction

Quantitative measurements in atomic absorption are based on Beer’s Law, which states that concentration is proportional to absorbance (C = kA). It is well known, however, that for most elements, particularly at high concentrations, the relationship between concentration and absorbance deviates from Beer’s Law and is not linear. Figure 9 shows the relationship between concentration and absorbance for nickel.

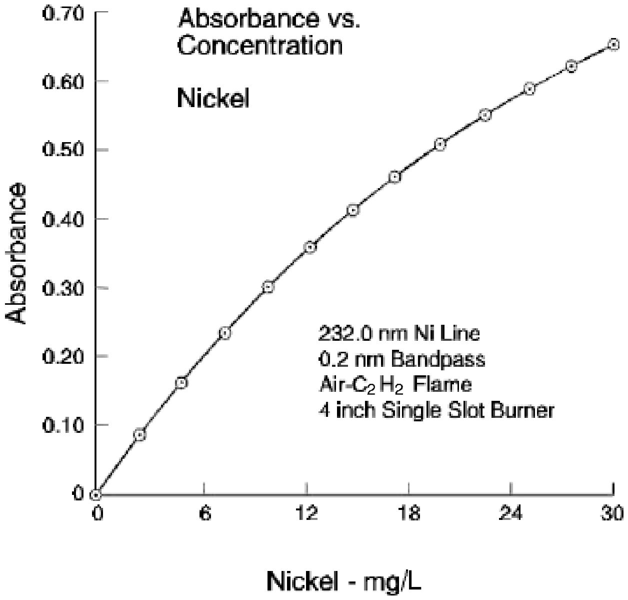


Figure 3-20: Absorbance vs. Concentration for Nickel

There are several reasons for this, including stray light, non-homogeneities of temperature and space in the absorbing cell, line broadening, and in some cases, absorption at nearby lines.

In the past, it was necessary to plot an absorbance vs. concentration curve for several standards to get an accurate reading of elemental content when samples were out of the linear range. One could also dilute the samples to be analyzed so that they would fall in the linear range.

Step 7: Aspire Sample

The sample is then exposed to a source of radiation, which typically originates from a light source. This light source has been set to defined wavelengths, and the metal atoms in the sample absorb these wavelengths (or not). When absorption occurs, the result is a light spectrum that has reduced light intensity in one or more of its areas. This reduced intensity is characteristic of a given element and helps to identify it, as well as to determine its concentration.

Step 8: Determine concentration

Afterwards, the analyte is excited by different light sources and emits a mixture of wavelengths. Following dispersion of these wavelengths (including the characteristic wavelength of the analyte), the AAS instrument detector measures wavelength intensity. Because element concentration is a function of its wavelength intensity, the concentration of the target element can be determined. Also, by establishing a reference system from standards of known concentration, unknown samples can be analyzed quantitatively.

Annexure B

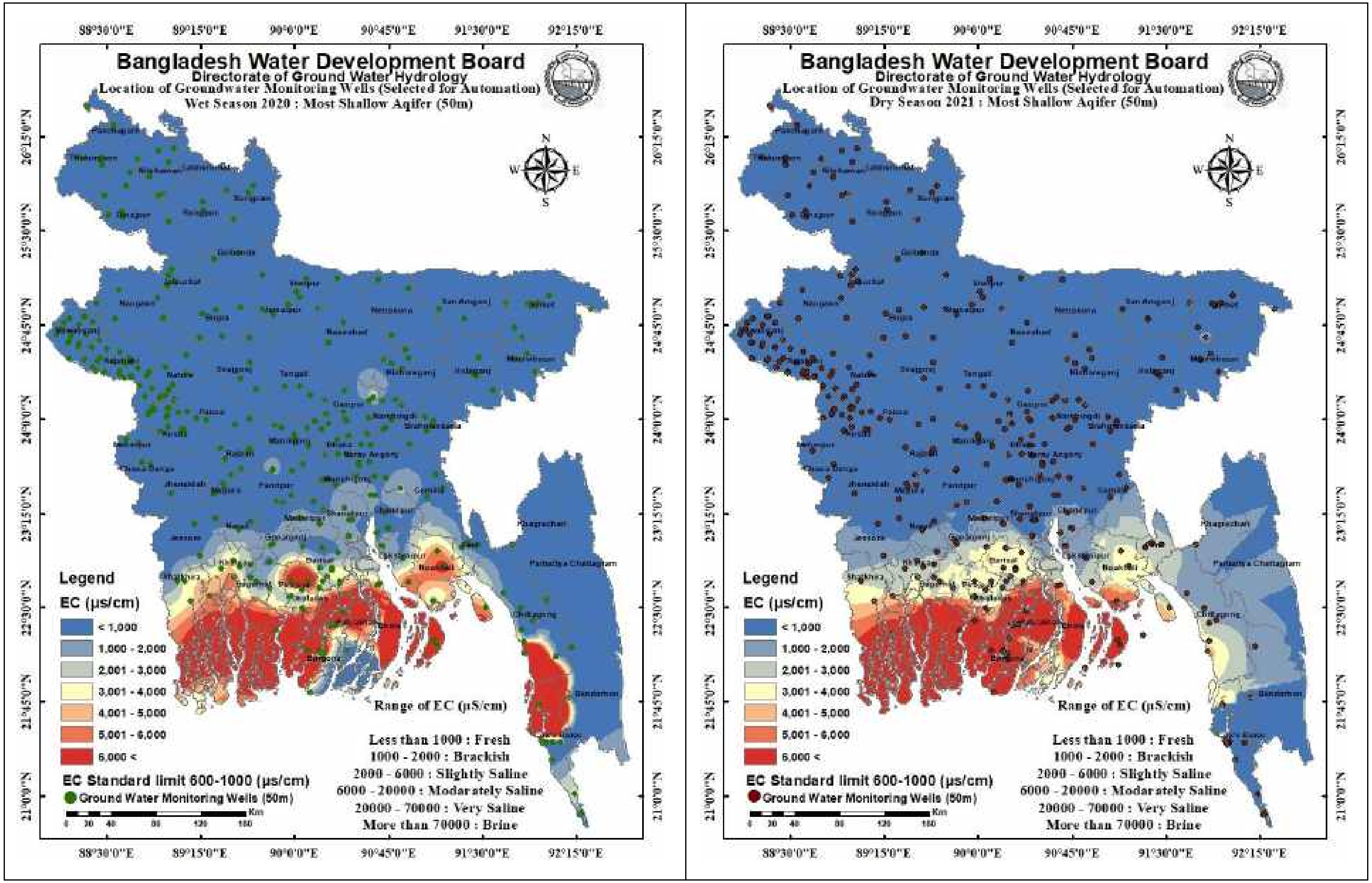


Figure 5-1: Groundwater EC at Very Shallow Aquifer (50m).

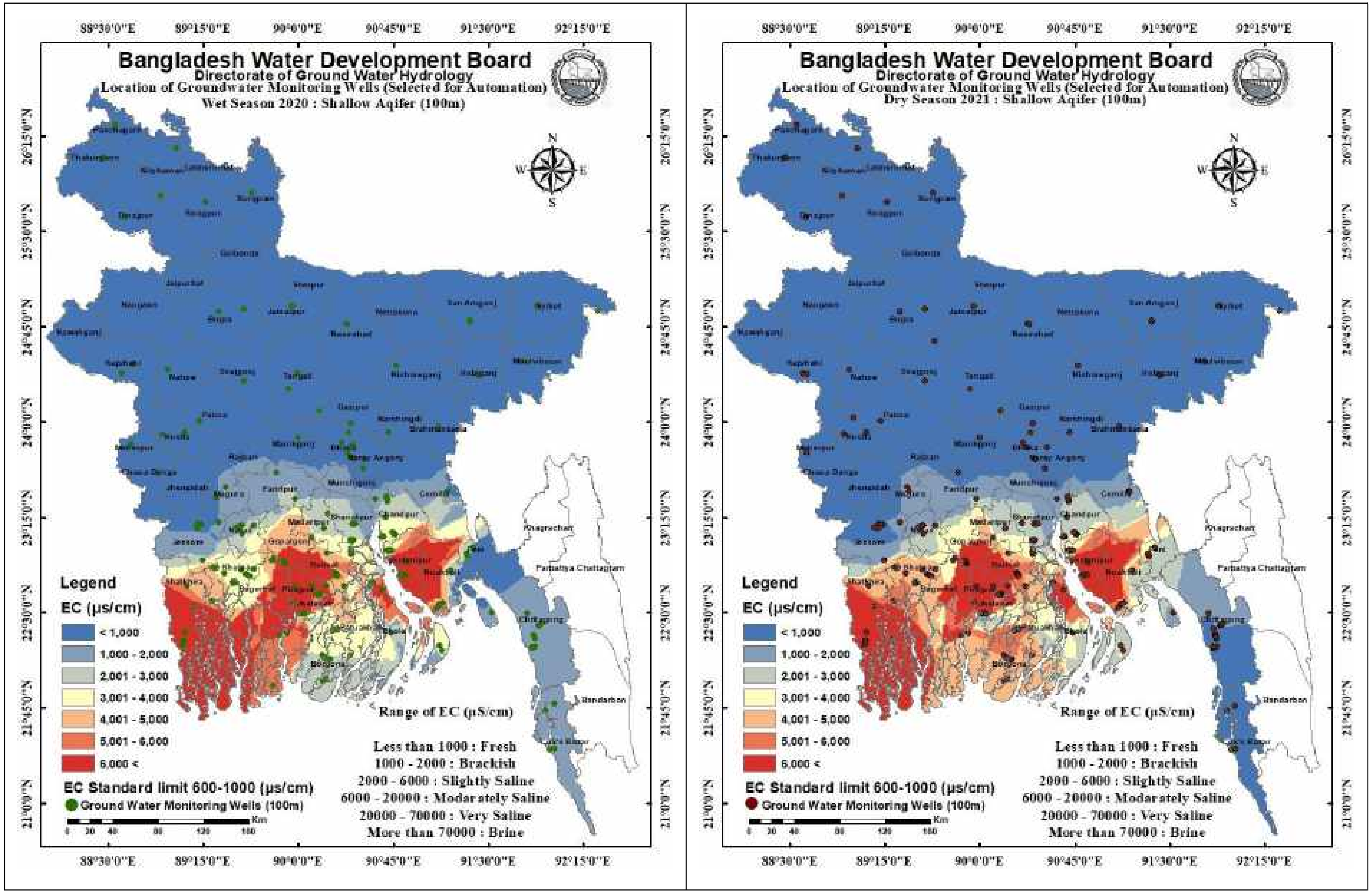


Figure 5-2: Groundwater EC at Shallow Aquifer (100m).

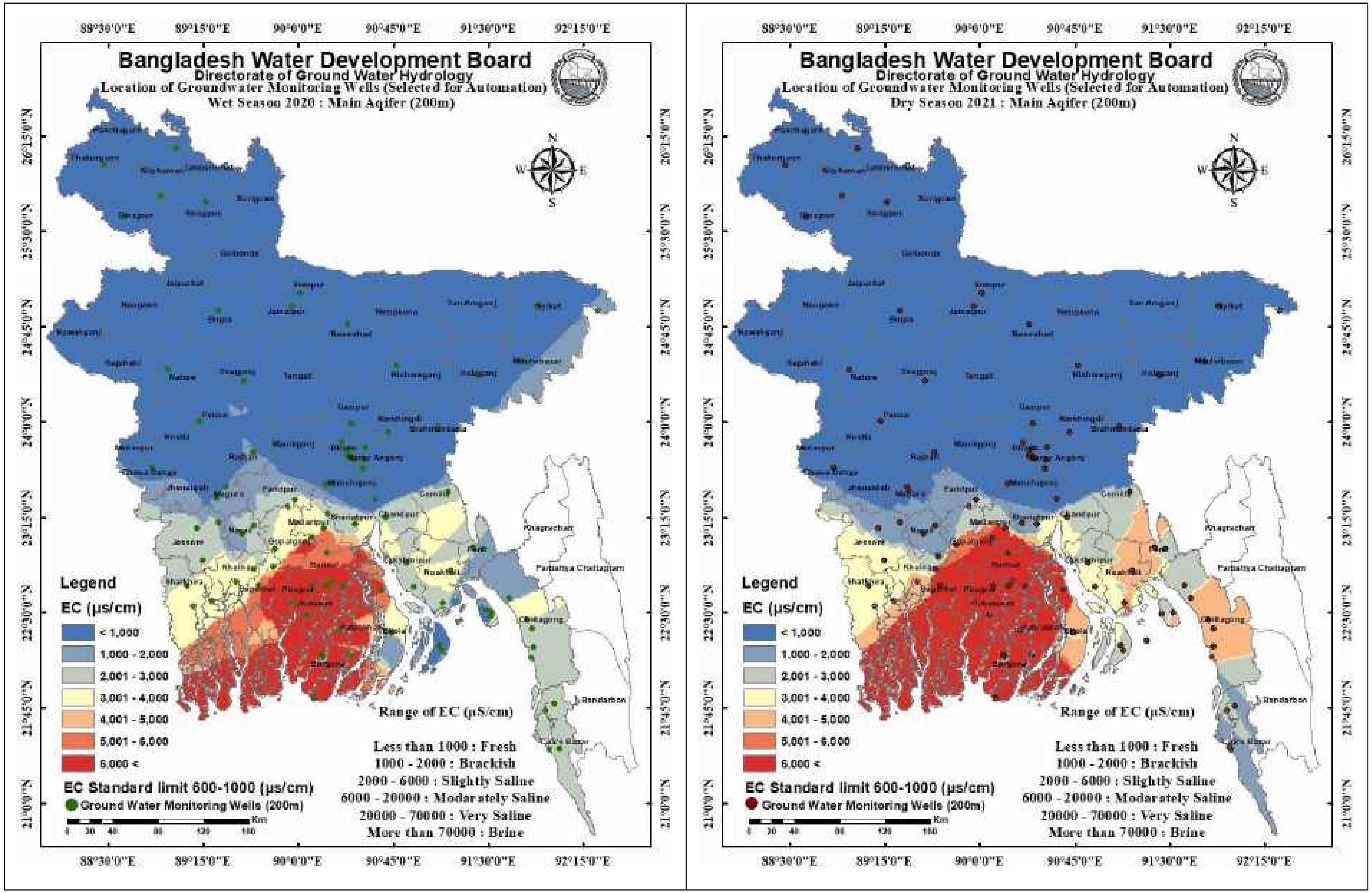


Figure 5-3: Groundwater EC at Main Aquifer (200m).

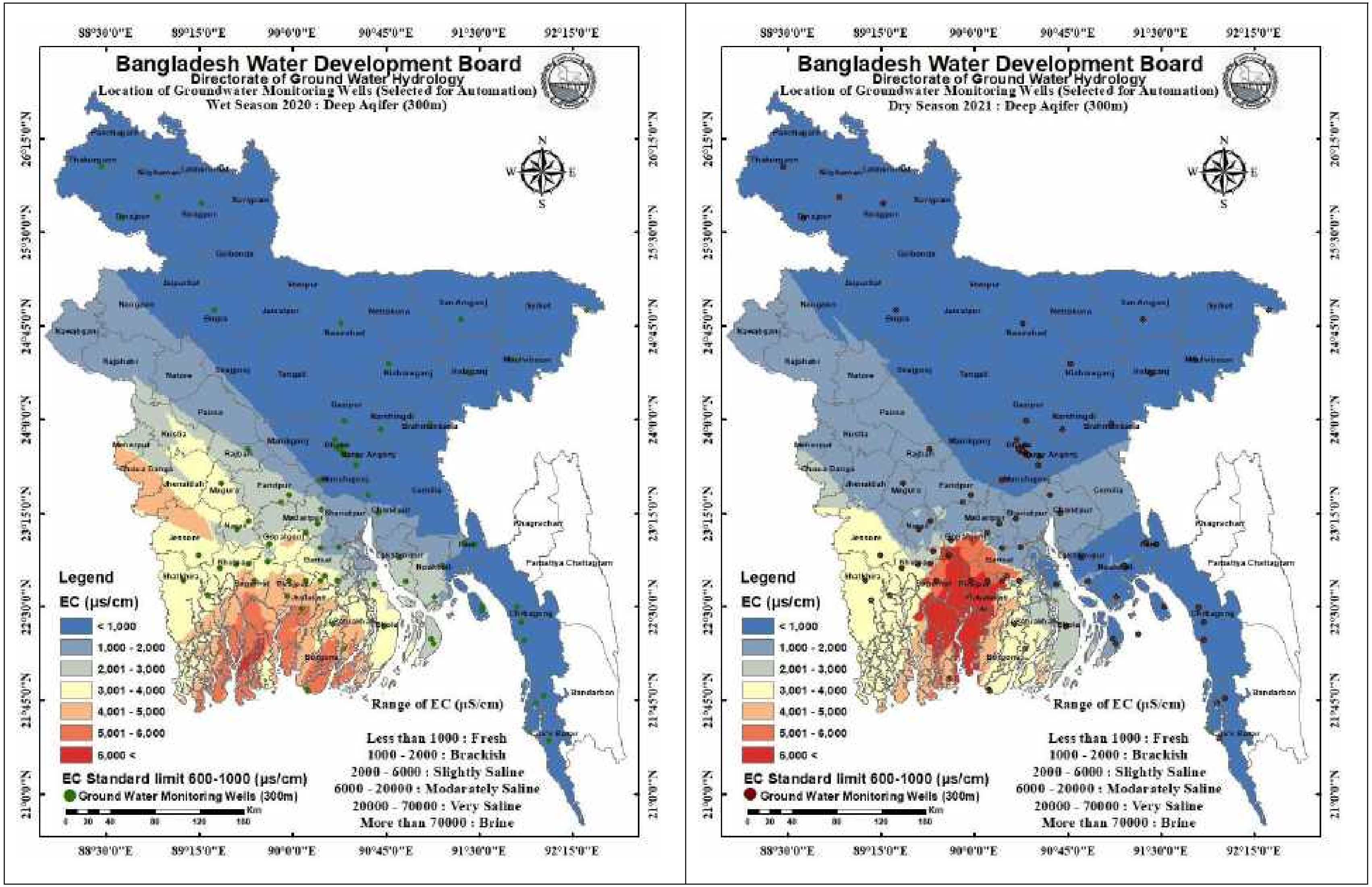


Figure 5-4: Groundwater EC at Deep Aquifer (300m).

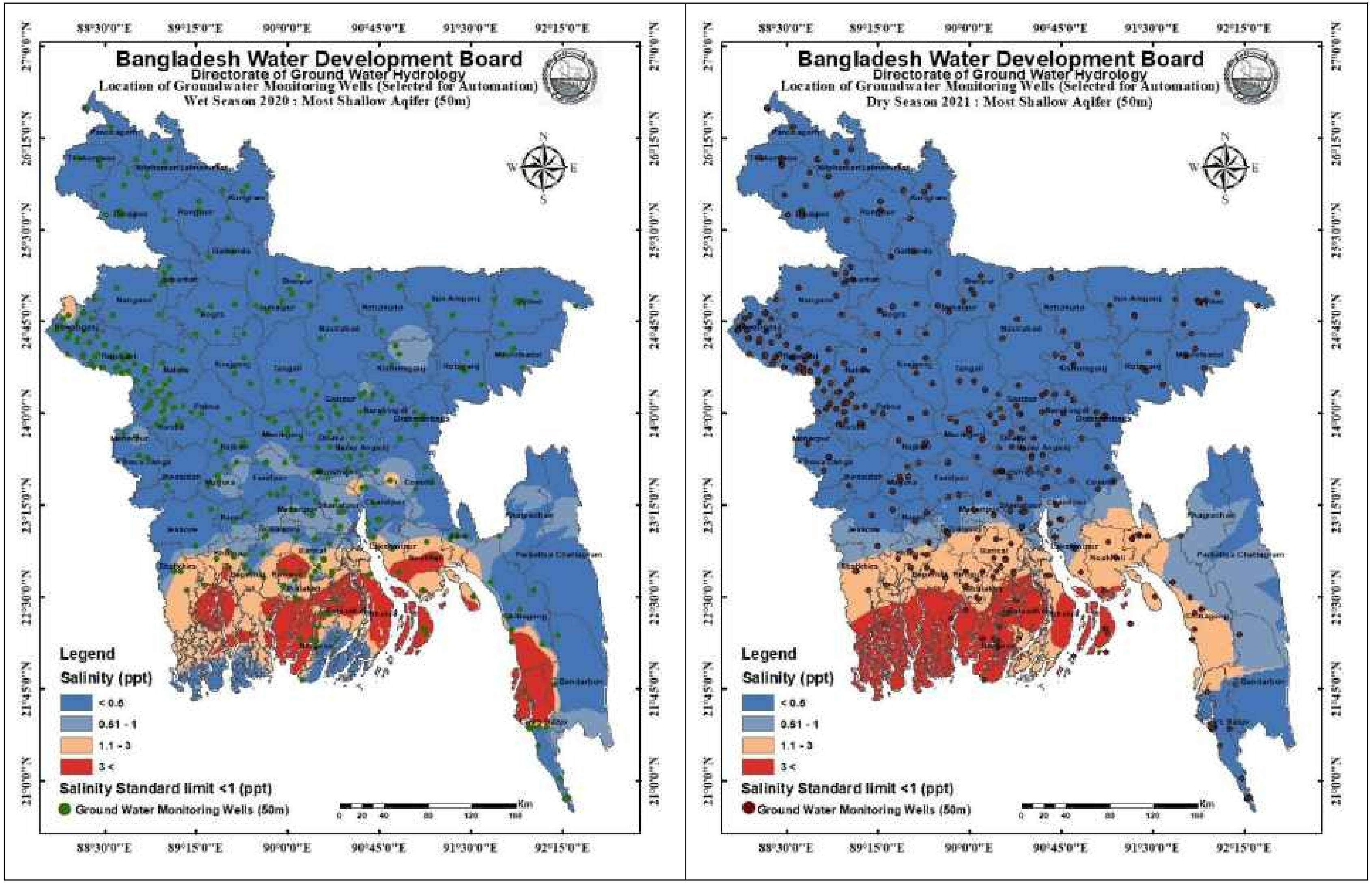


Figure 5-5: Groundwater Salinity at Very Shallow Aquifer (50m).

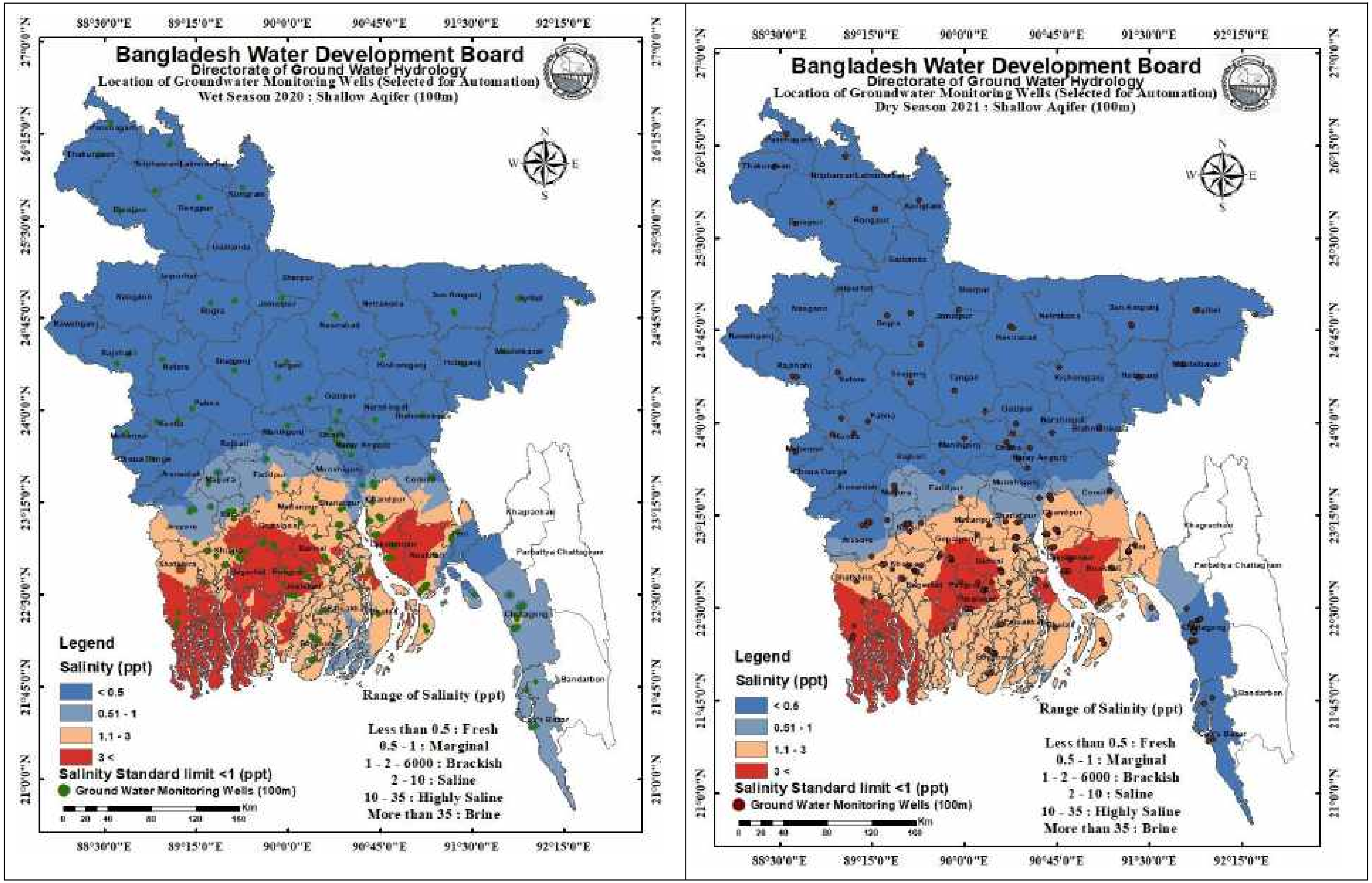


Figure 5-6: Groundwater Salinity at Shallow Aquifer (100m).

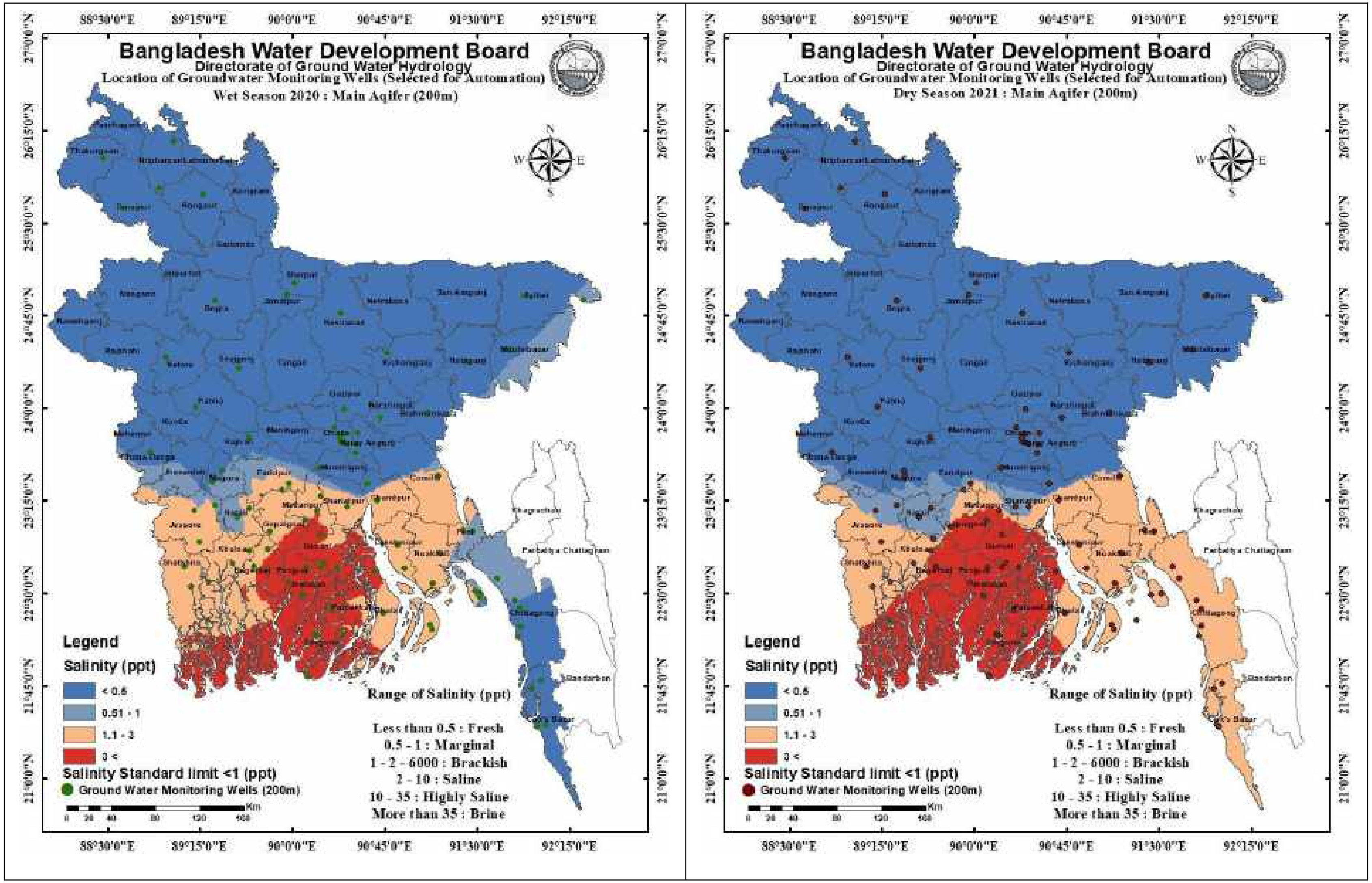


Figure 5-7: Groundwater Salinity at Main Aquifer (200m).

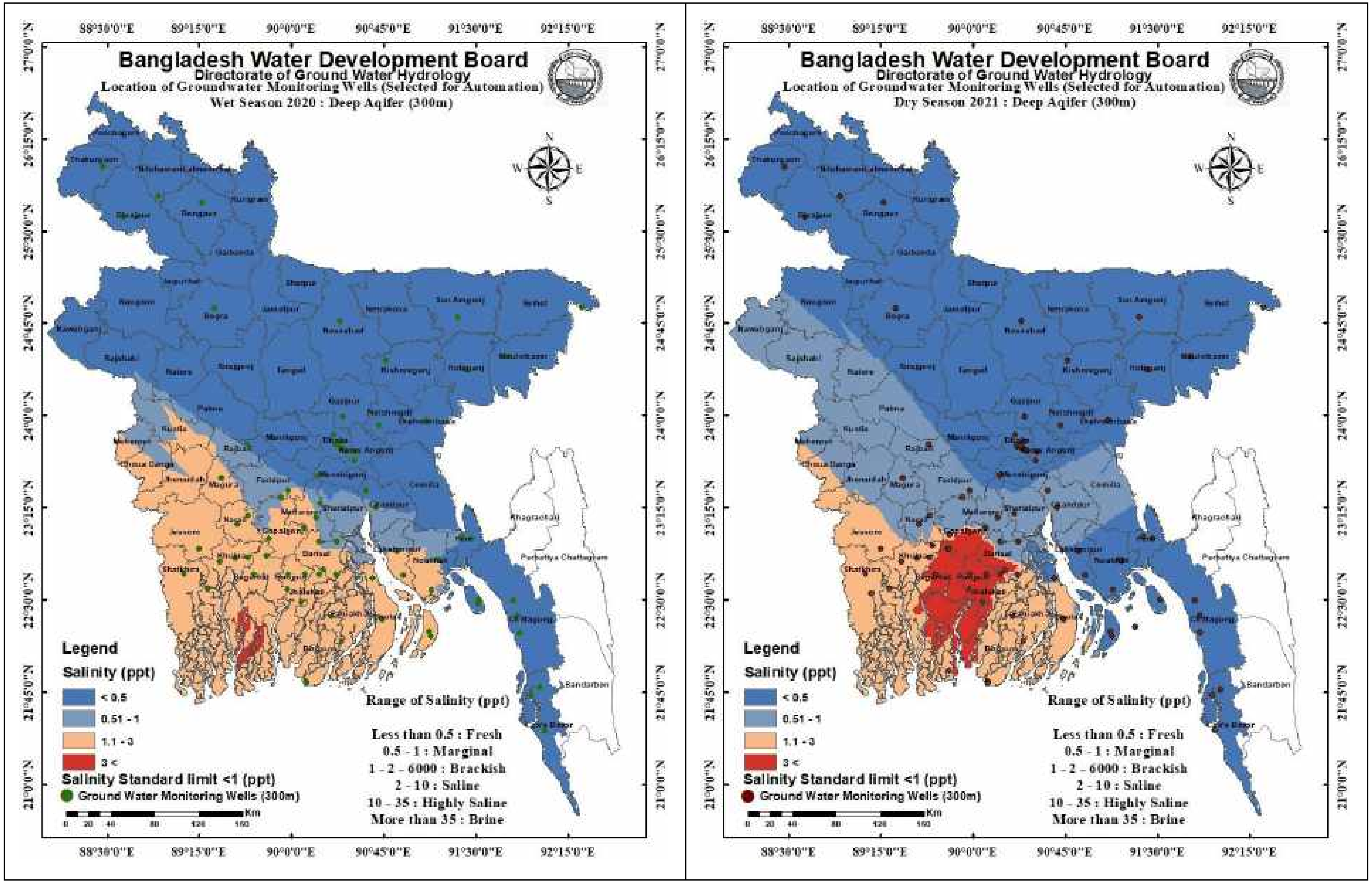


Figure 5-8: Groundwater Salinity at Deep Aquifer (300m).

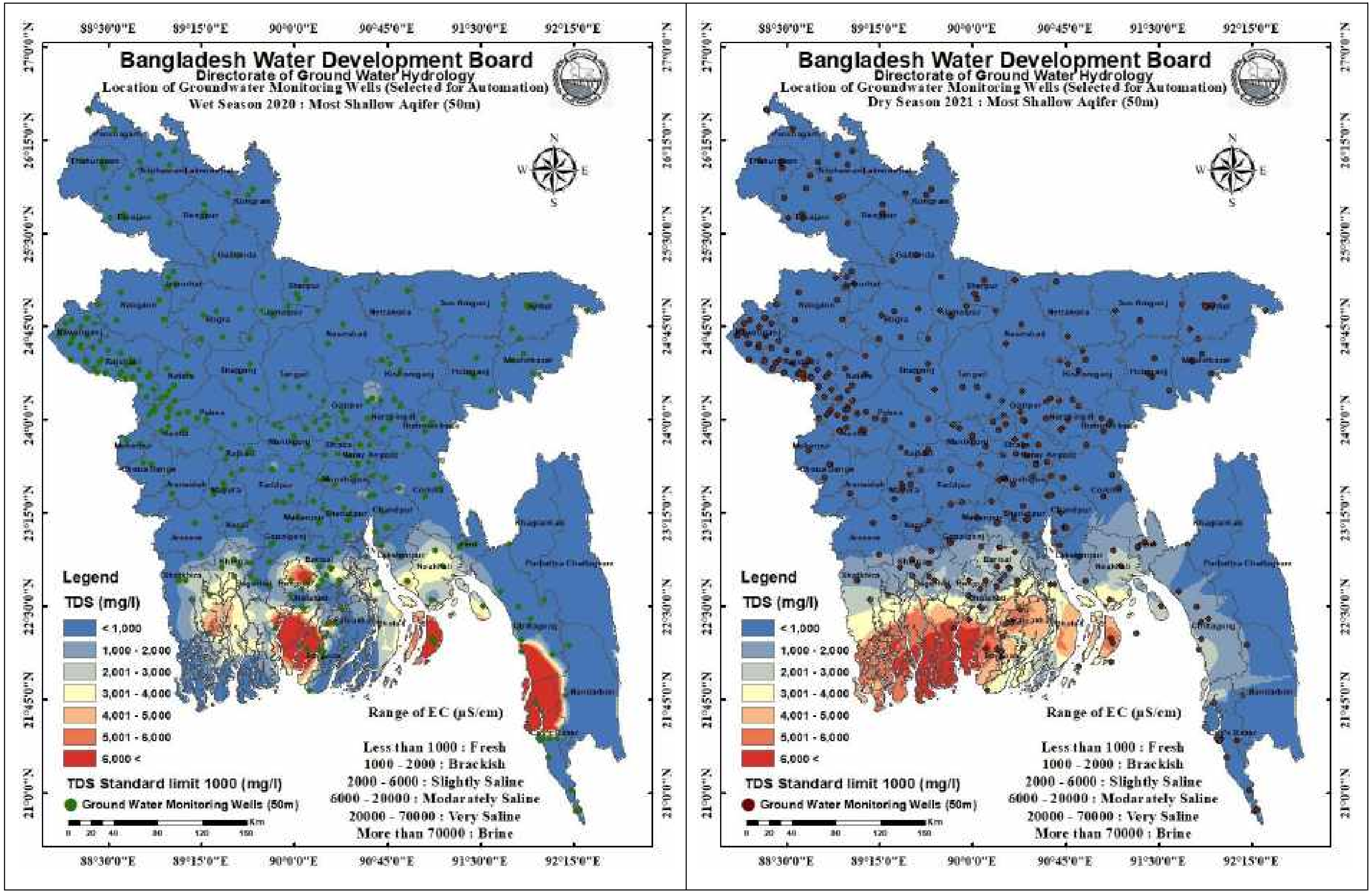


Figure 5-9: Groundwater TDS at Very Shallow Aquifer (50m).

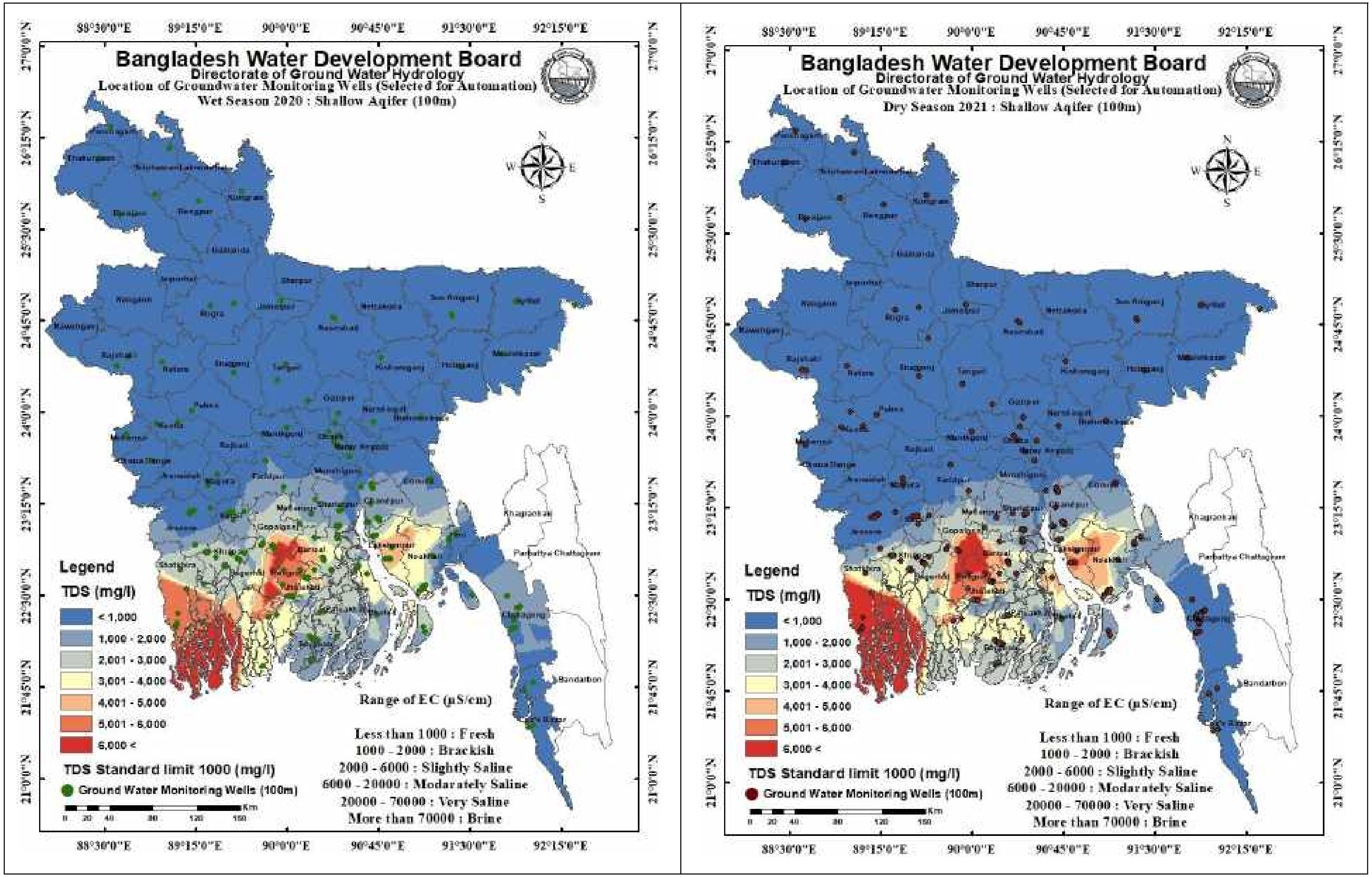


Figure 5-10: Groundwater TDS at Shallow Aquifer (100m).

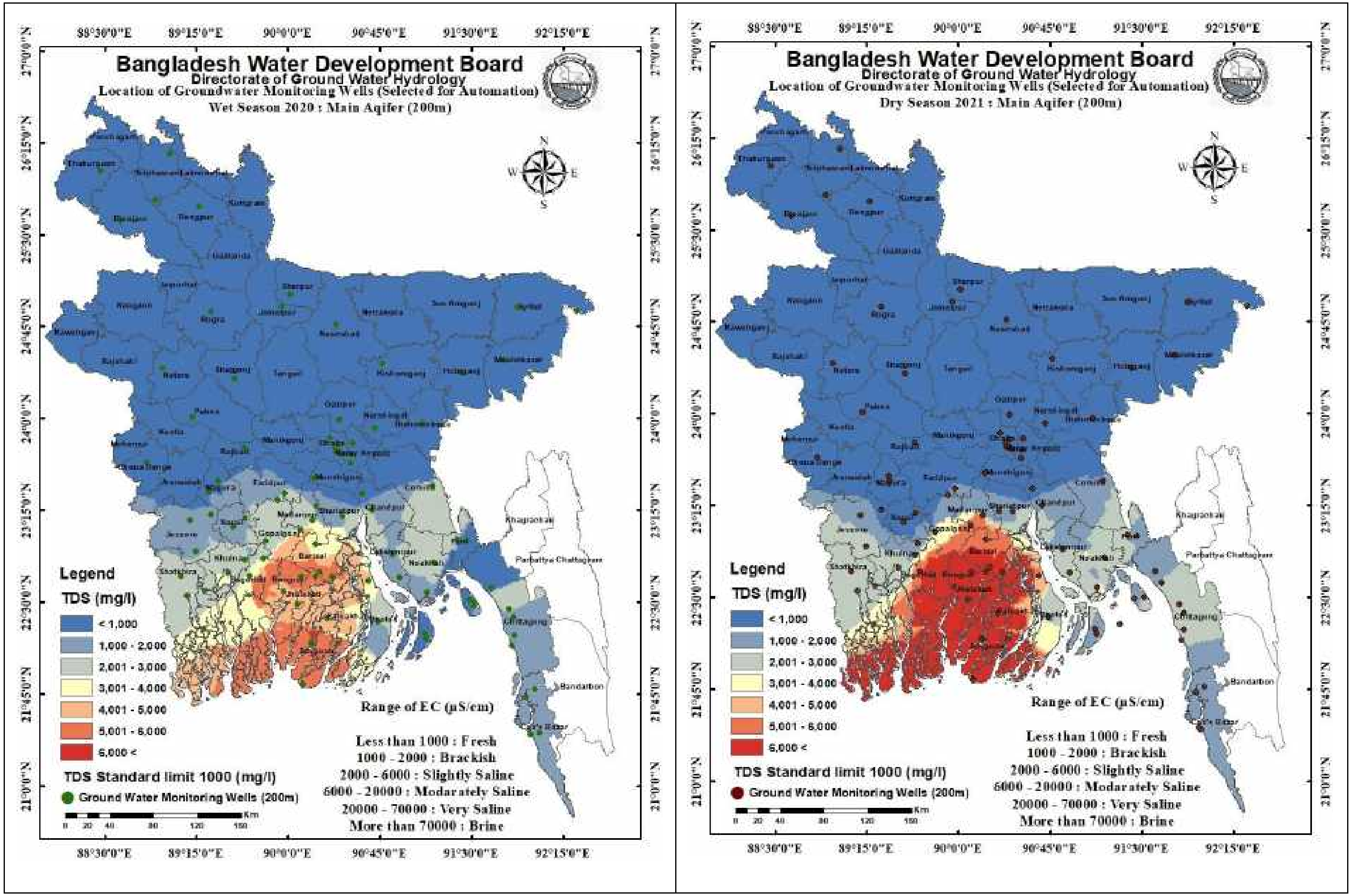


Figure 5-11: Groundwater TDS at Main Aquifer (200m).

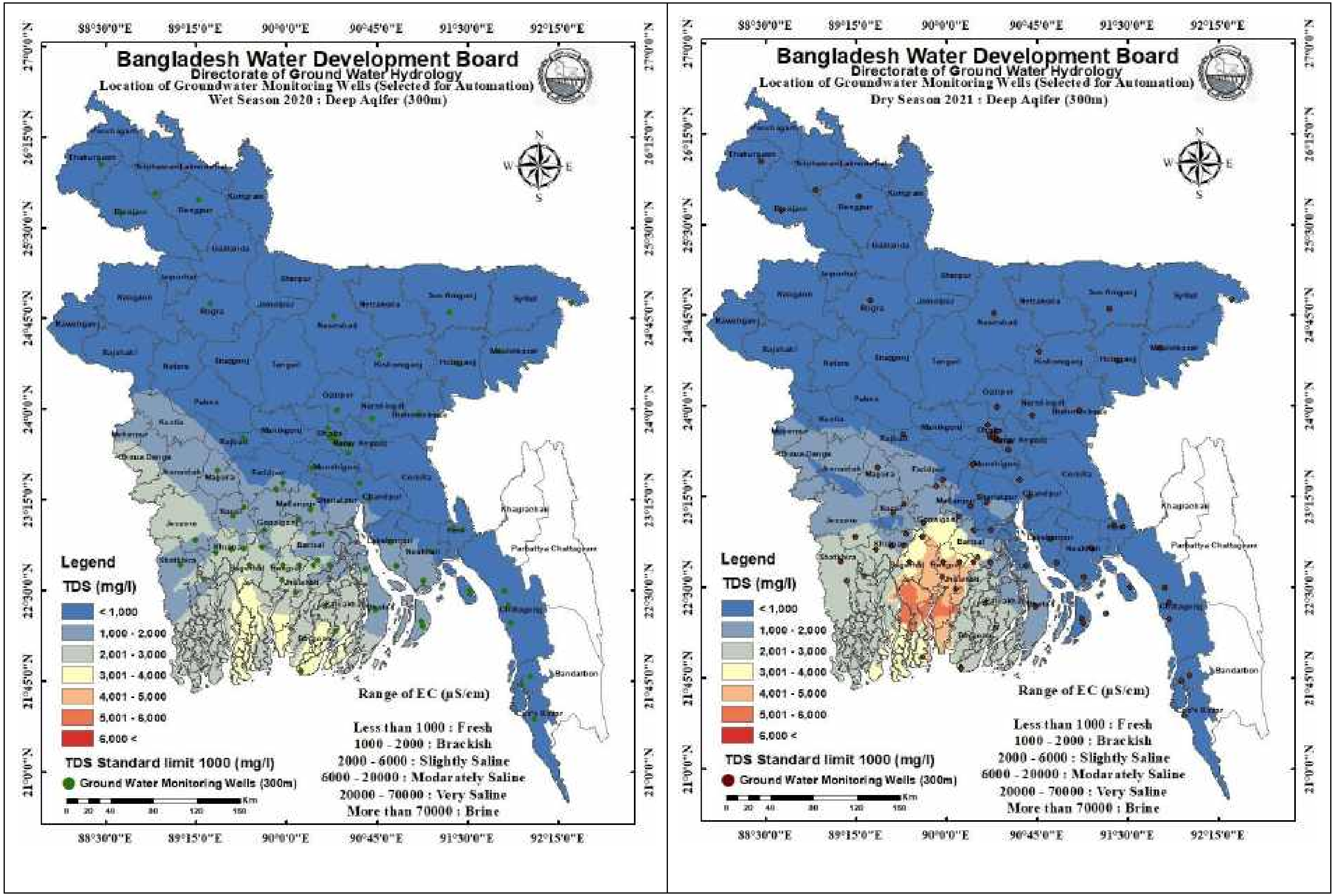


Figure 5-12: Groundwater TDS at Deep Aquifer (300m).

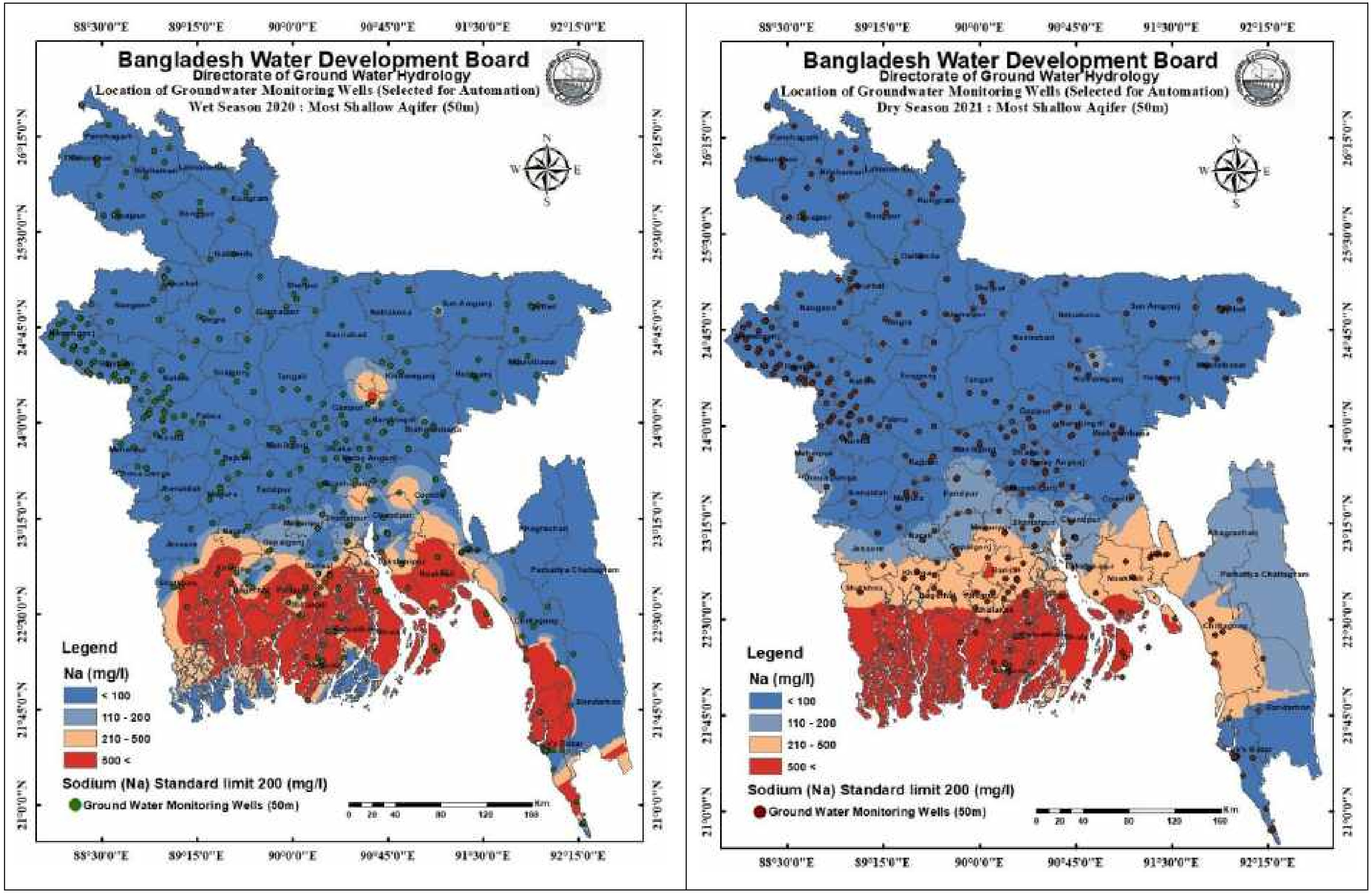


Figure 5-13: Groundwater Sodium (Na) at Very Shallow Aquifer (50m).

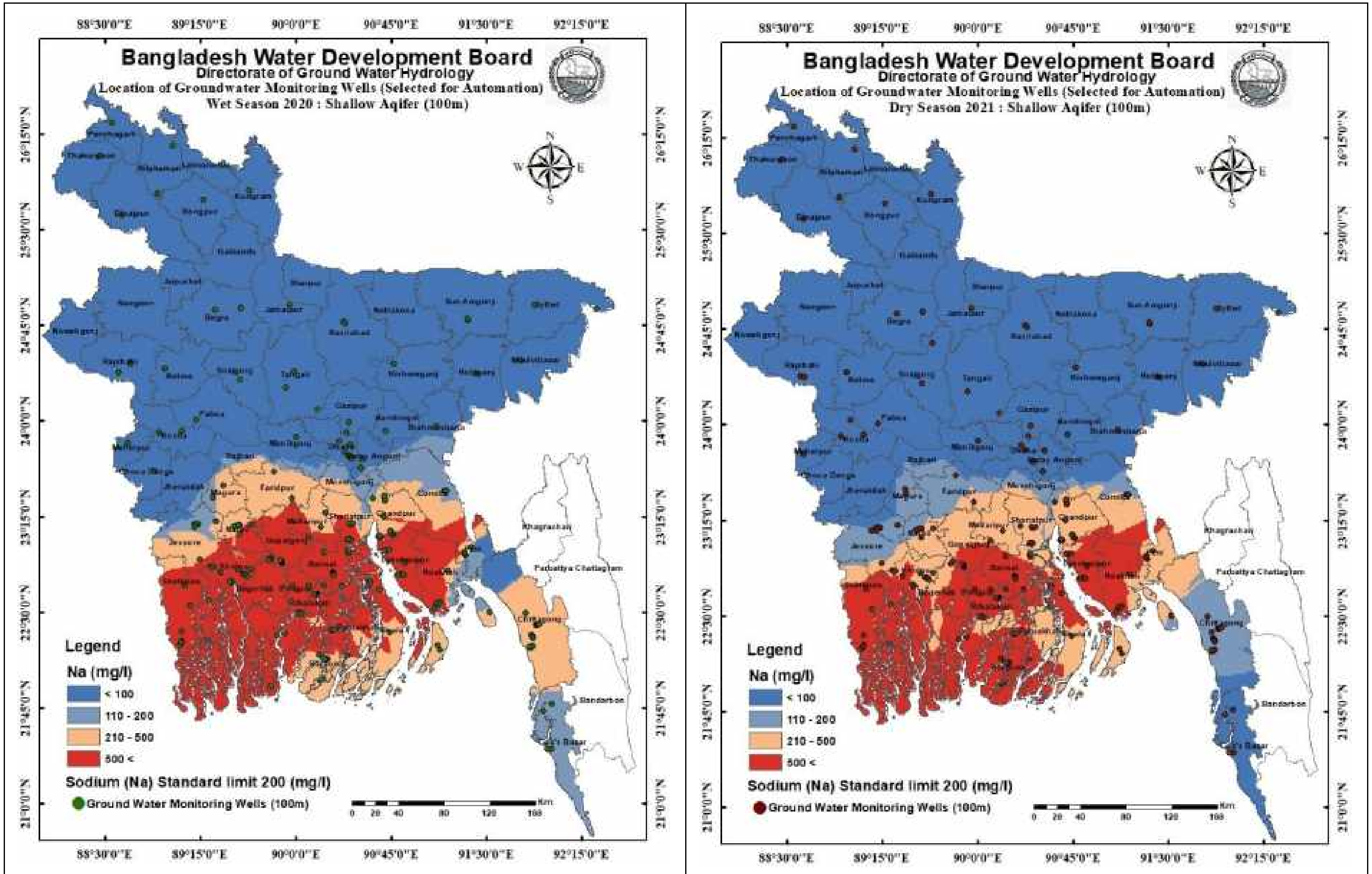


Figure 5-14: Groundwater Sodium (Na) at Shallow Aquifer (100m).

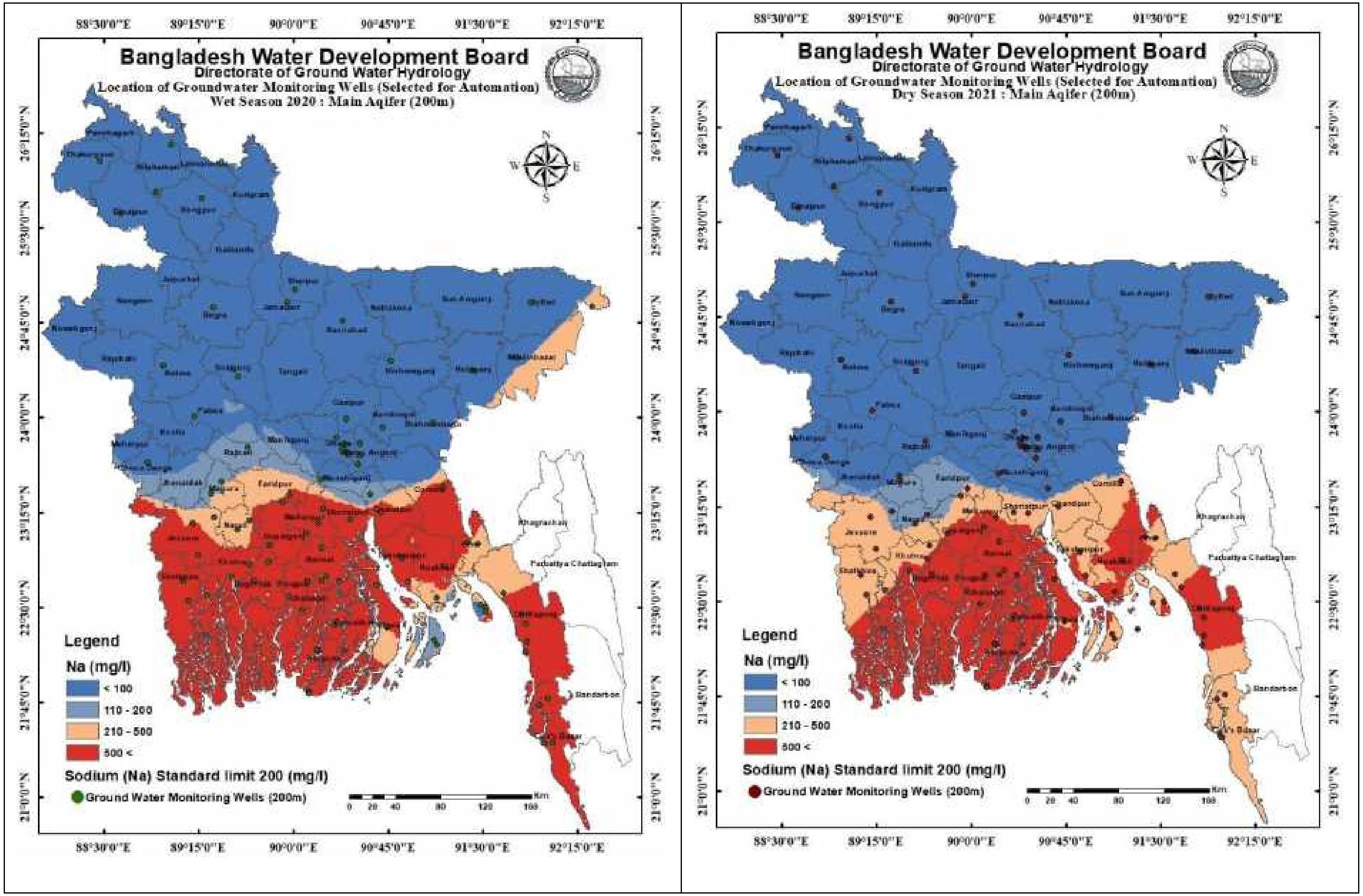


Figure 5-15: Groundwater Sodium (Na) at Main Aquifer (200m).

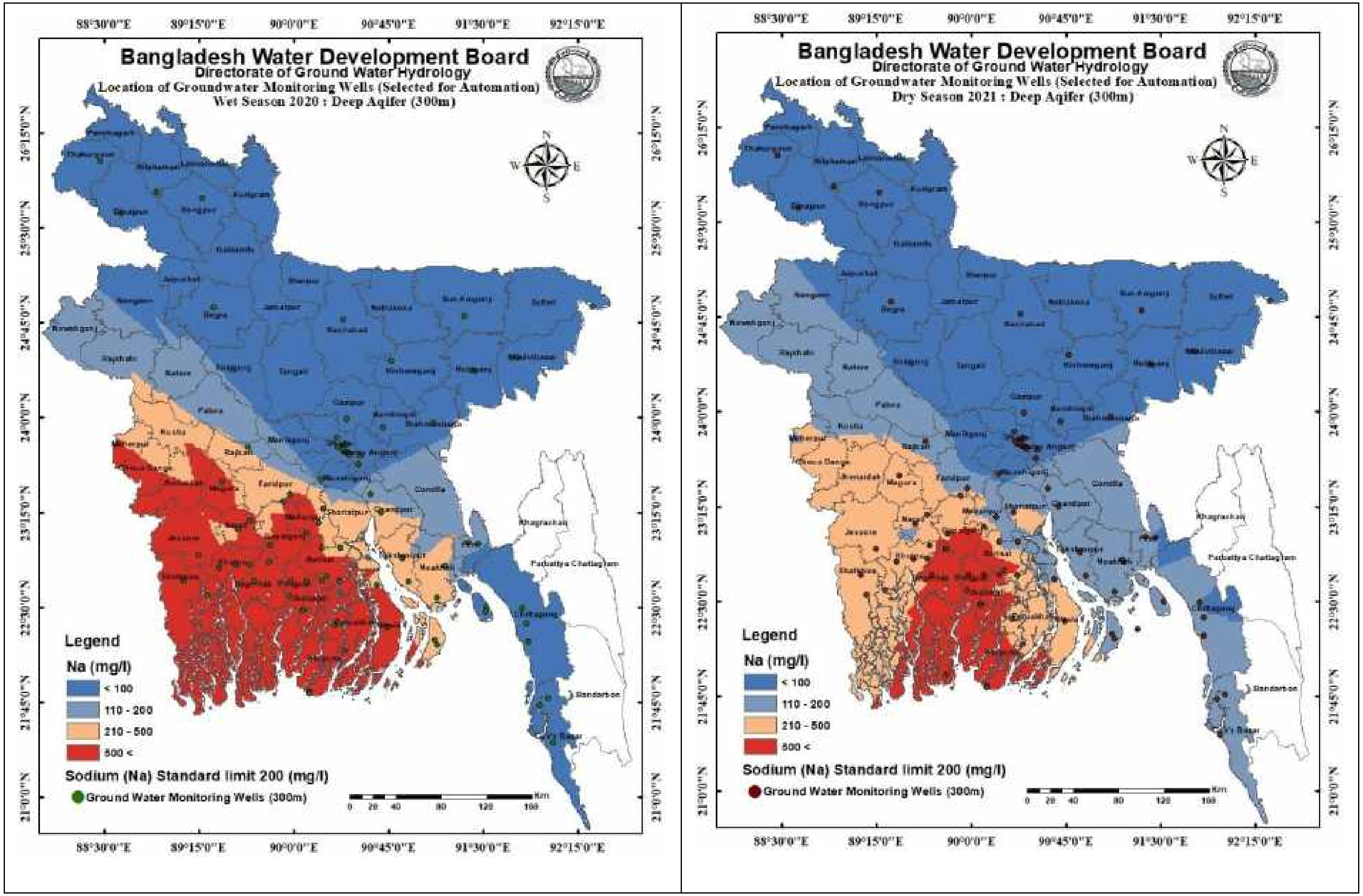


Figure 5-16: Groundwater Sodium (Na) at Deep Aquifer (300m).

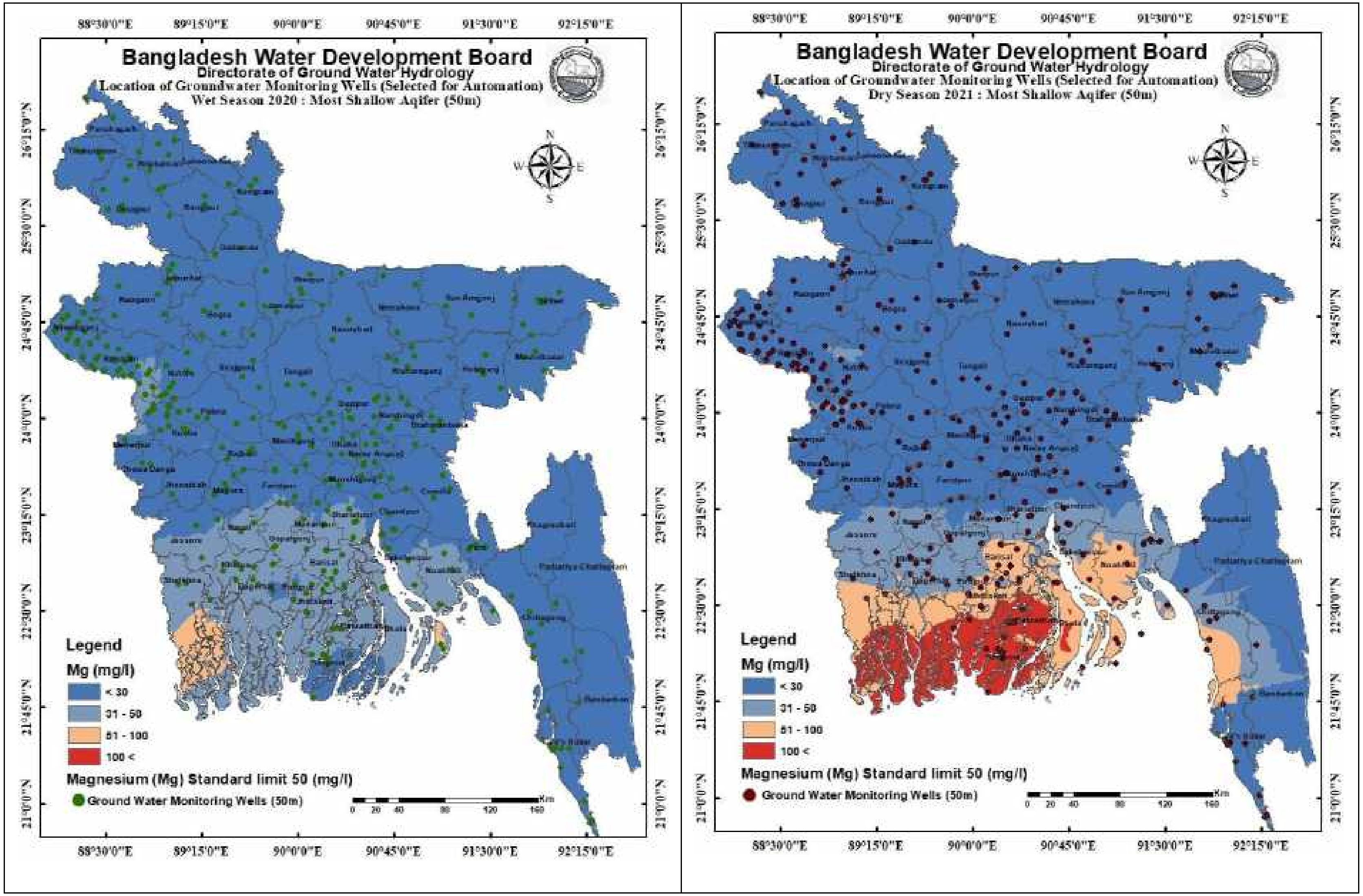


Figure 5-17: Groundwater Magnesium (Mg) at Very Shallow Aquifer (50m).

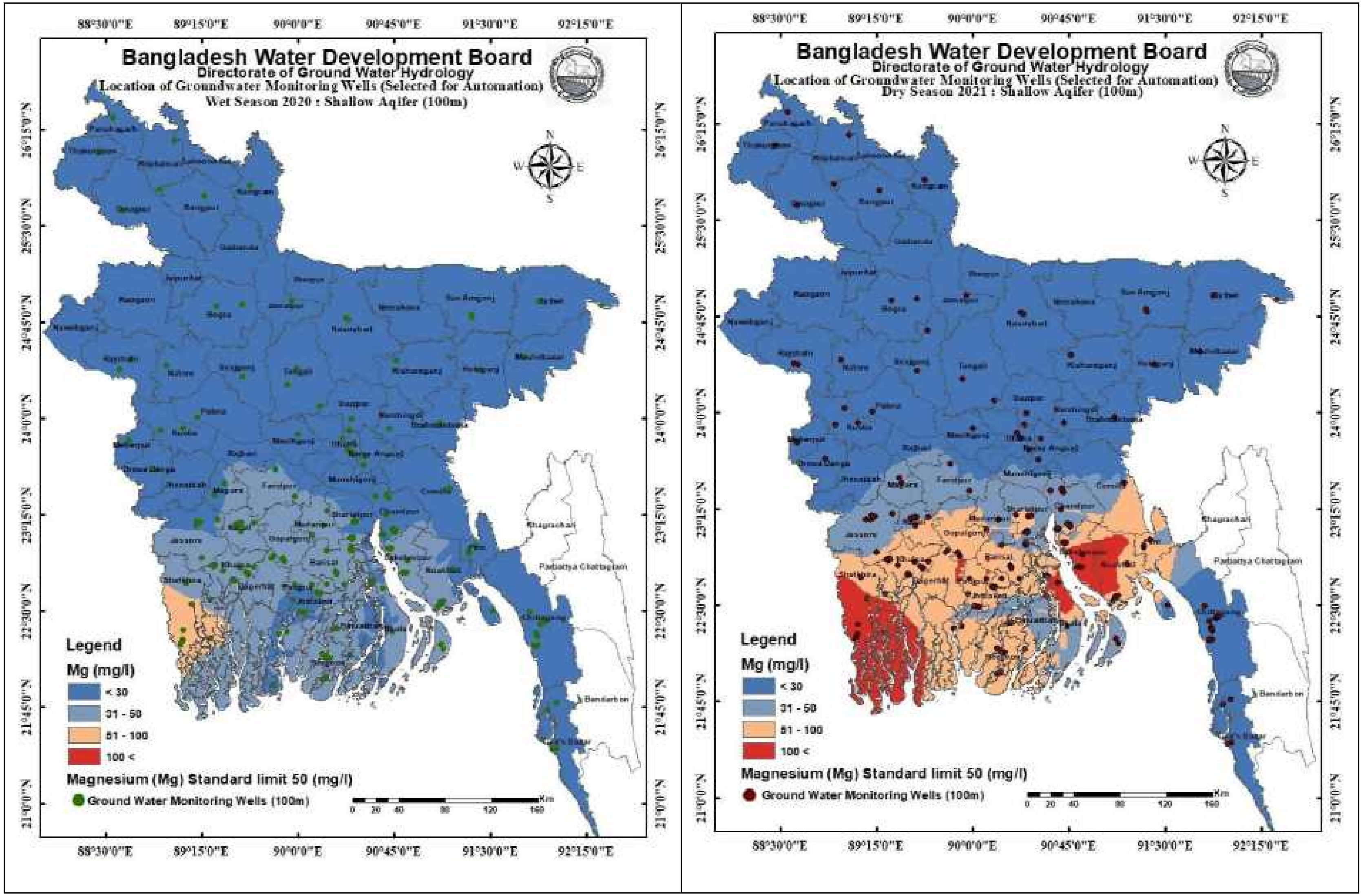


Figure 5-18: Groundwater Magnesium (Mg) at Shallow Aquifer (100m).

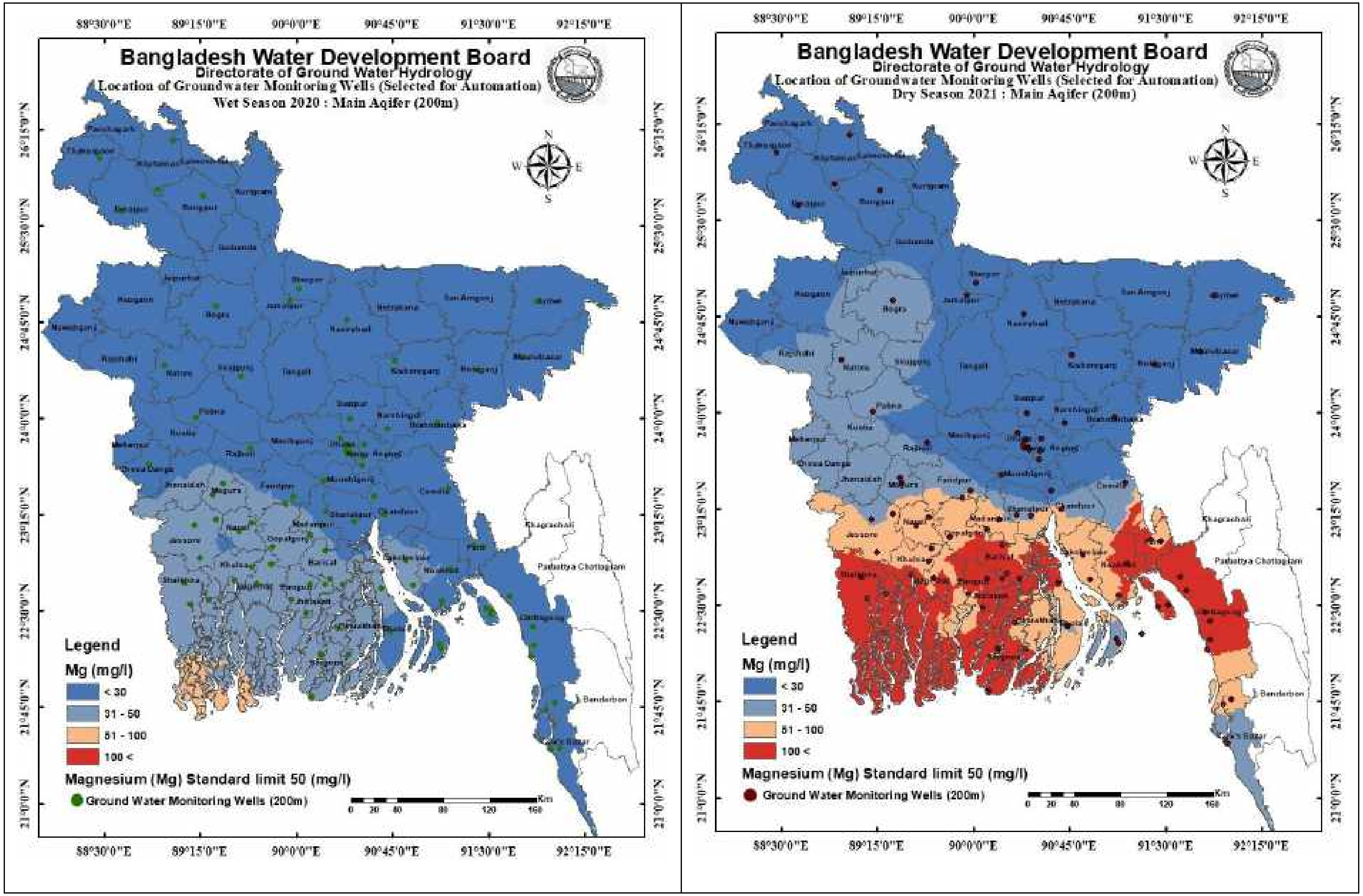


Figure 5-19: Groundwater Magnesium (Mg) at Main Aquifer (200m).

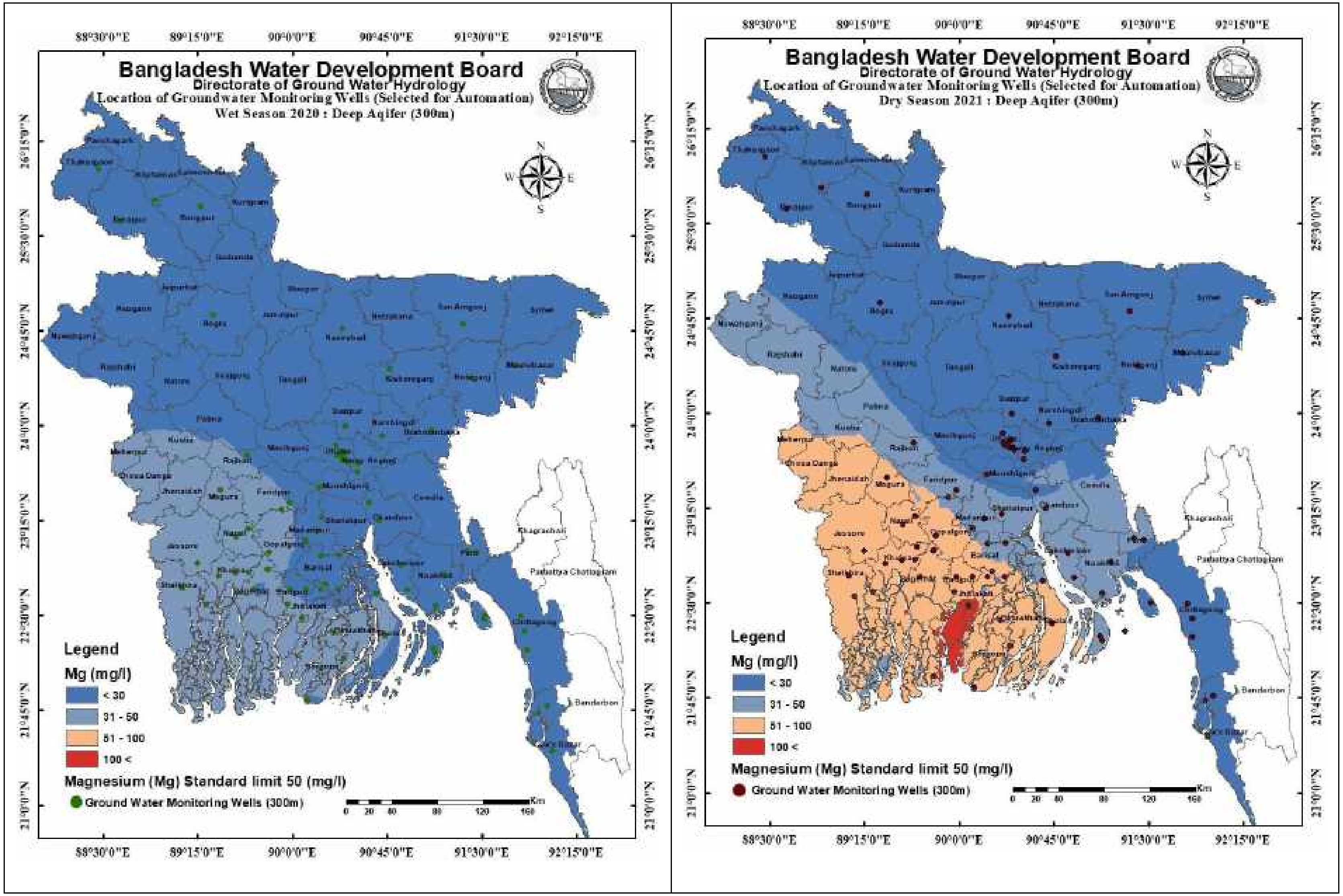


Figure 5-20: Groundwater Magnesium (Mg) at Deep Aquifer (300m).

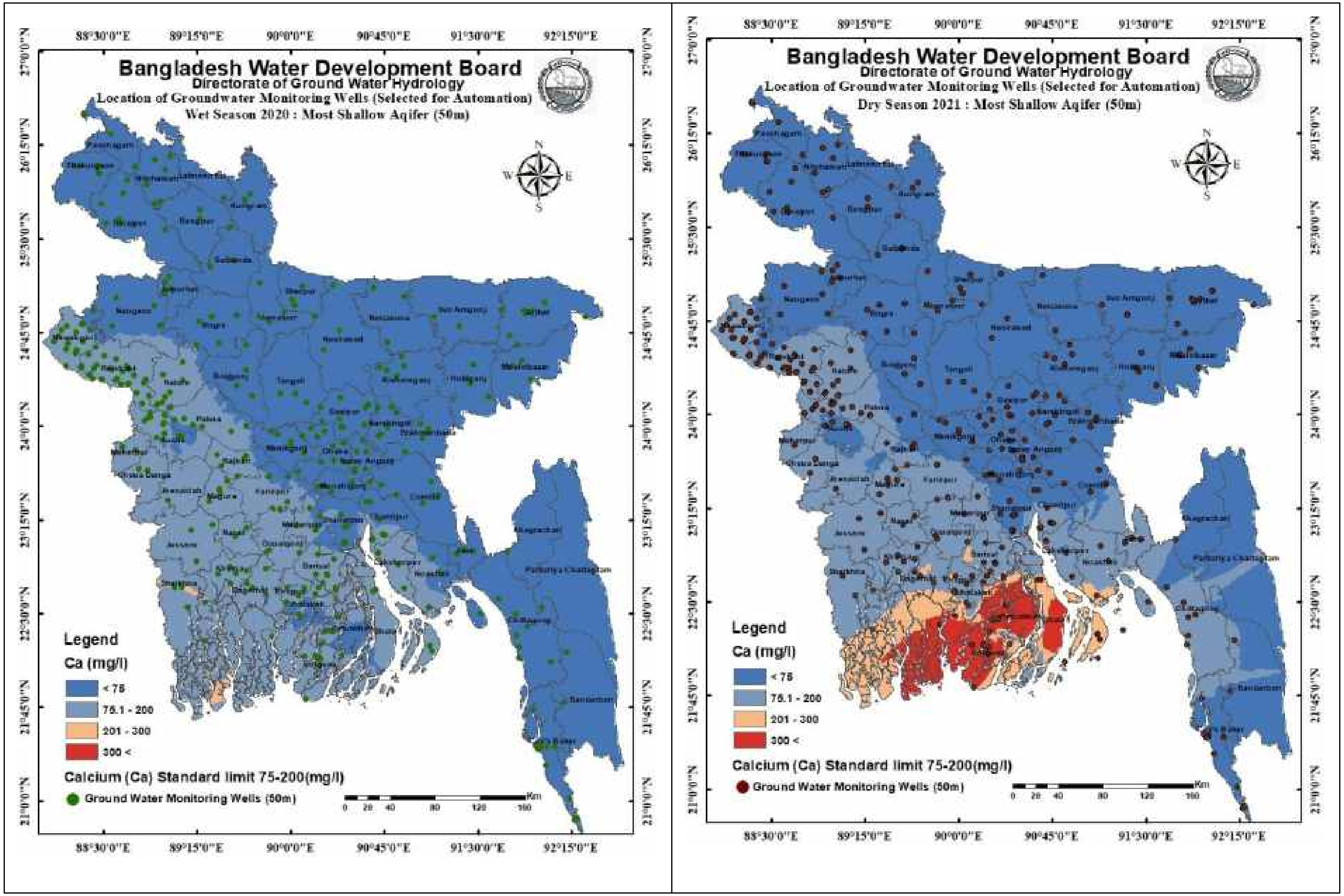


Figure 5-21: Groundwater Calcium (Ca) at Very Shallow Aquifer (50m).

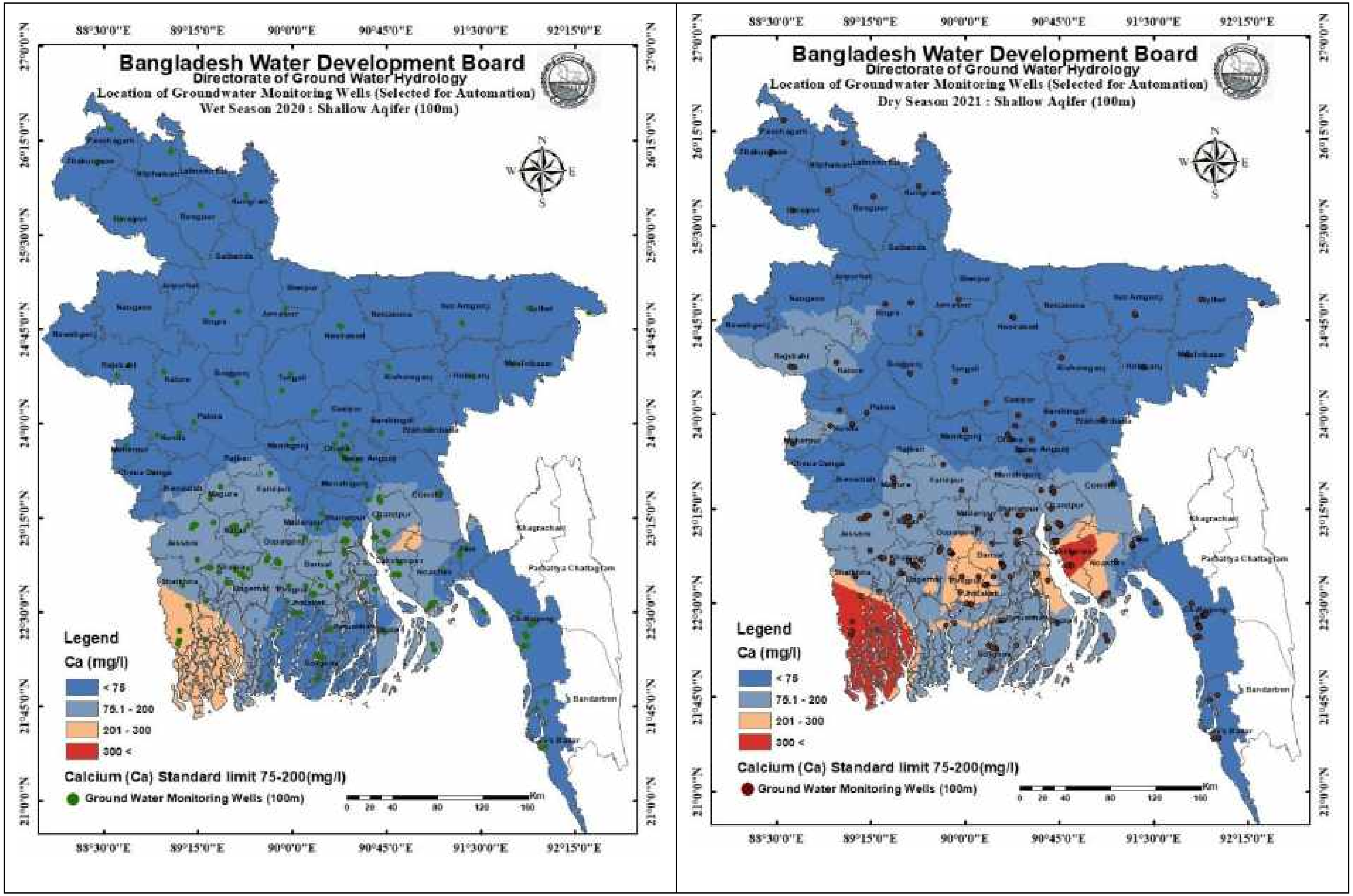


Figure 5-22: Groundwater Calcium (Ca) at Shallow Aquifer (100m).

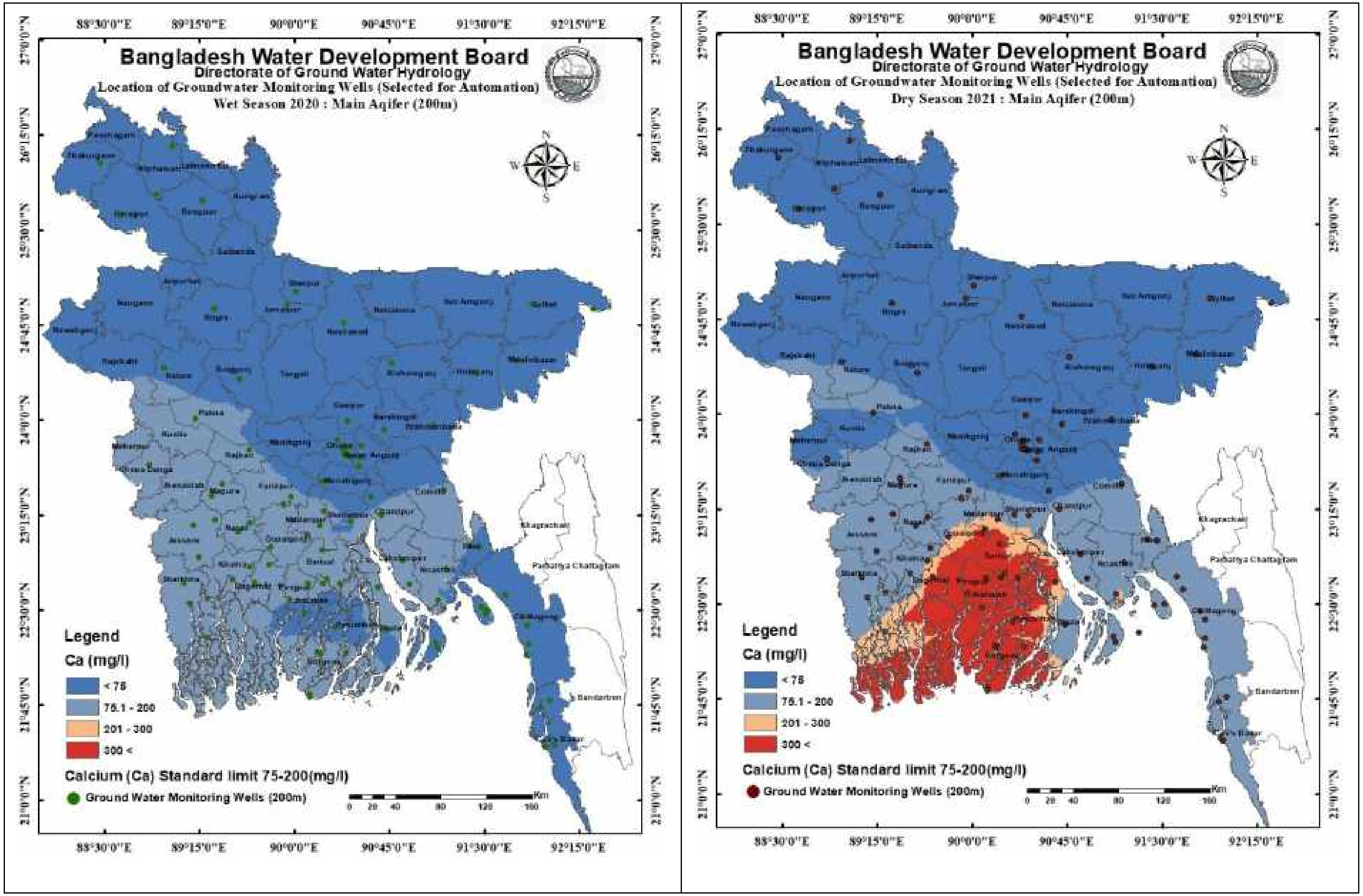


Figure 5-23: Groundwater Calcium (Ca) at Main Aquifer (200m).

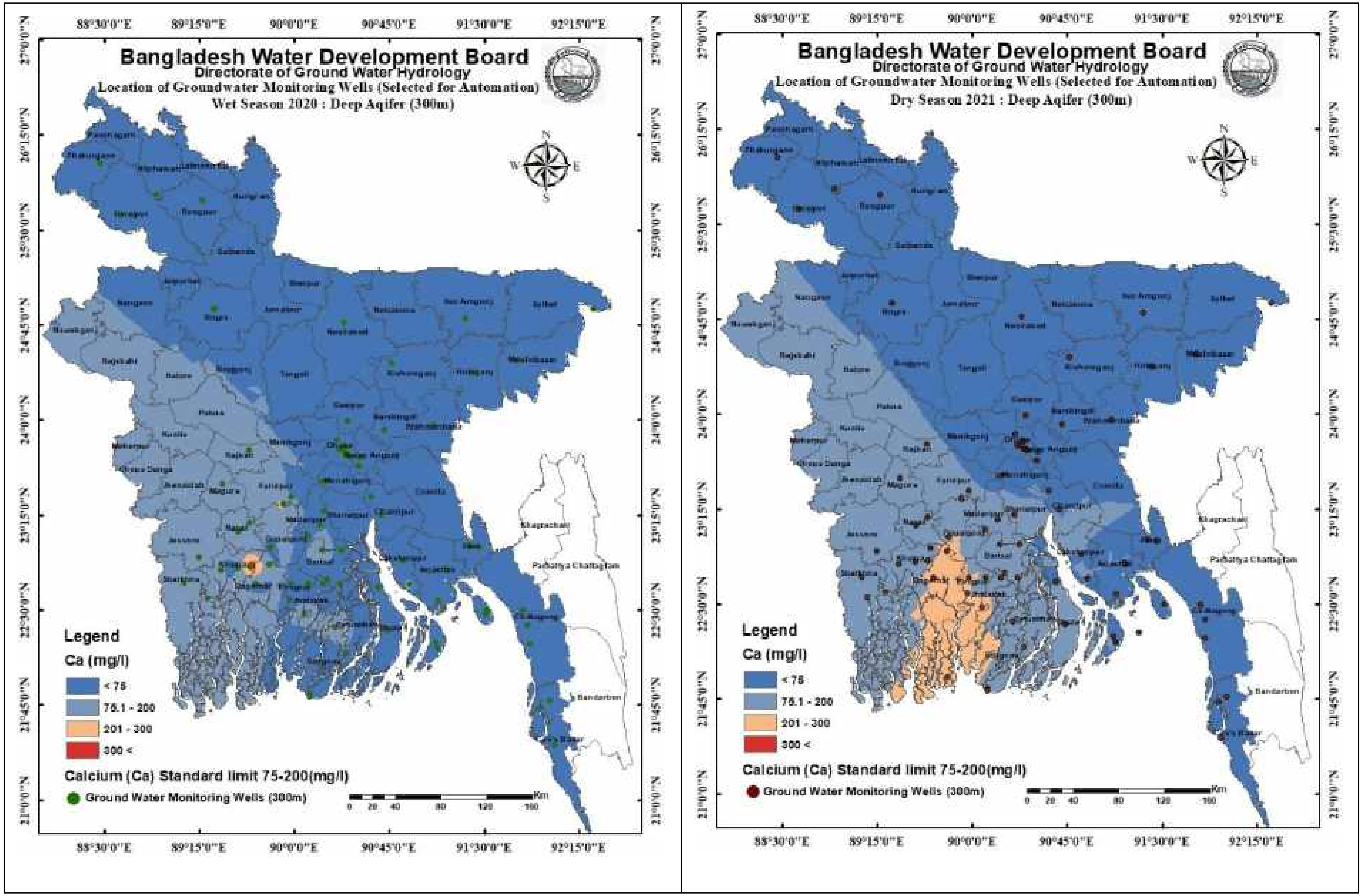


Figure 5-24: Groundwater Calcium (Ca) at Deep Aquifer (300m).

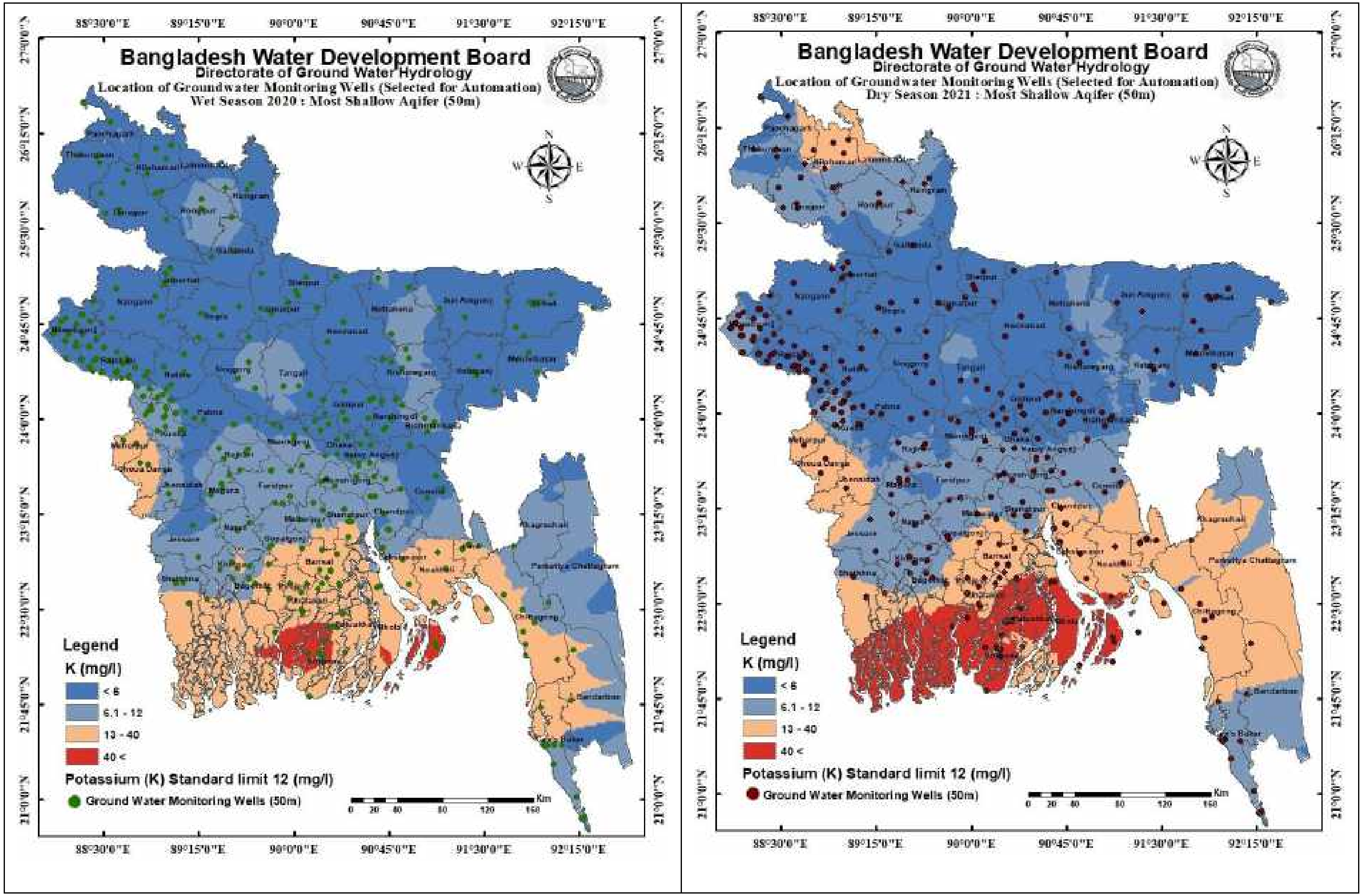


Figure 5-25: Groundwater Potassium (K) at Very Shallow Aquifer (50m).

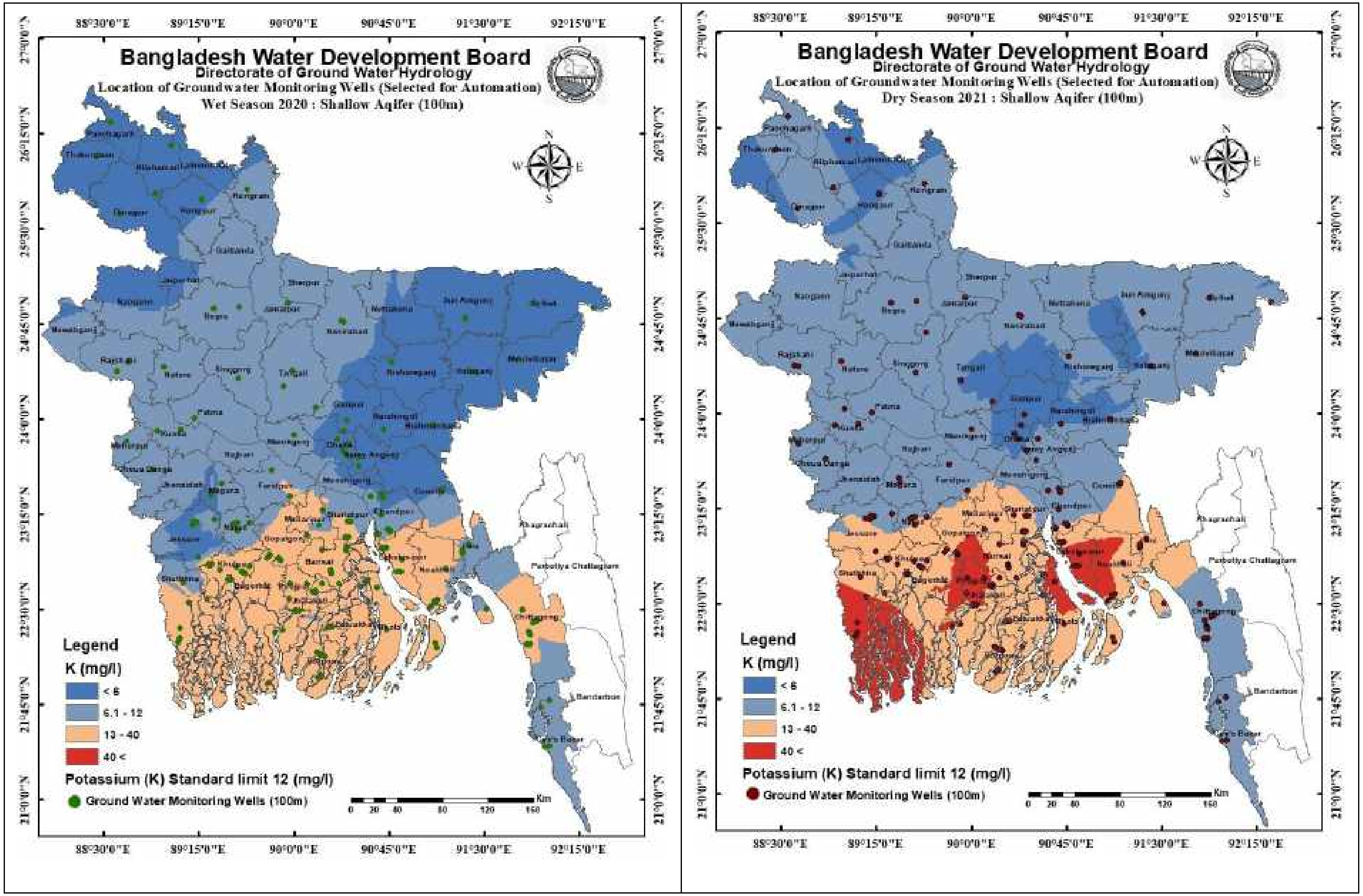


Figure 5-26: Groundwater Potassium (K) at Shallow Aquifer (100m).

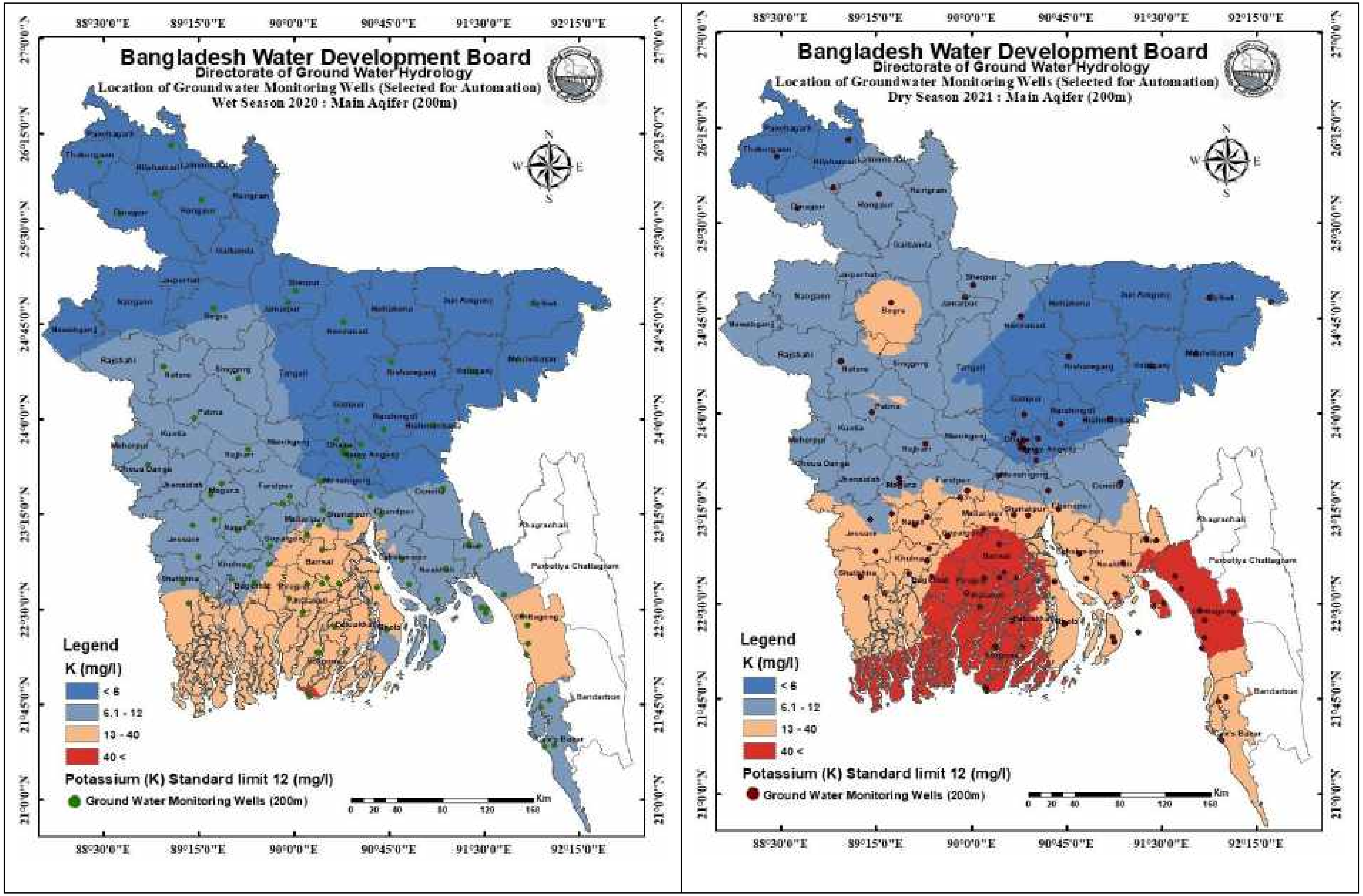


Figure 5-27: Groundwater Potassium (K) at Main Aquifer (200m).

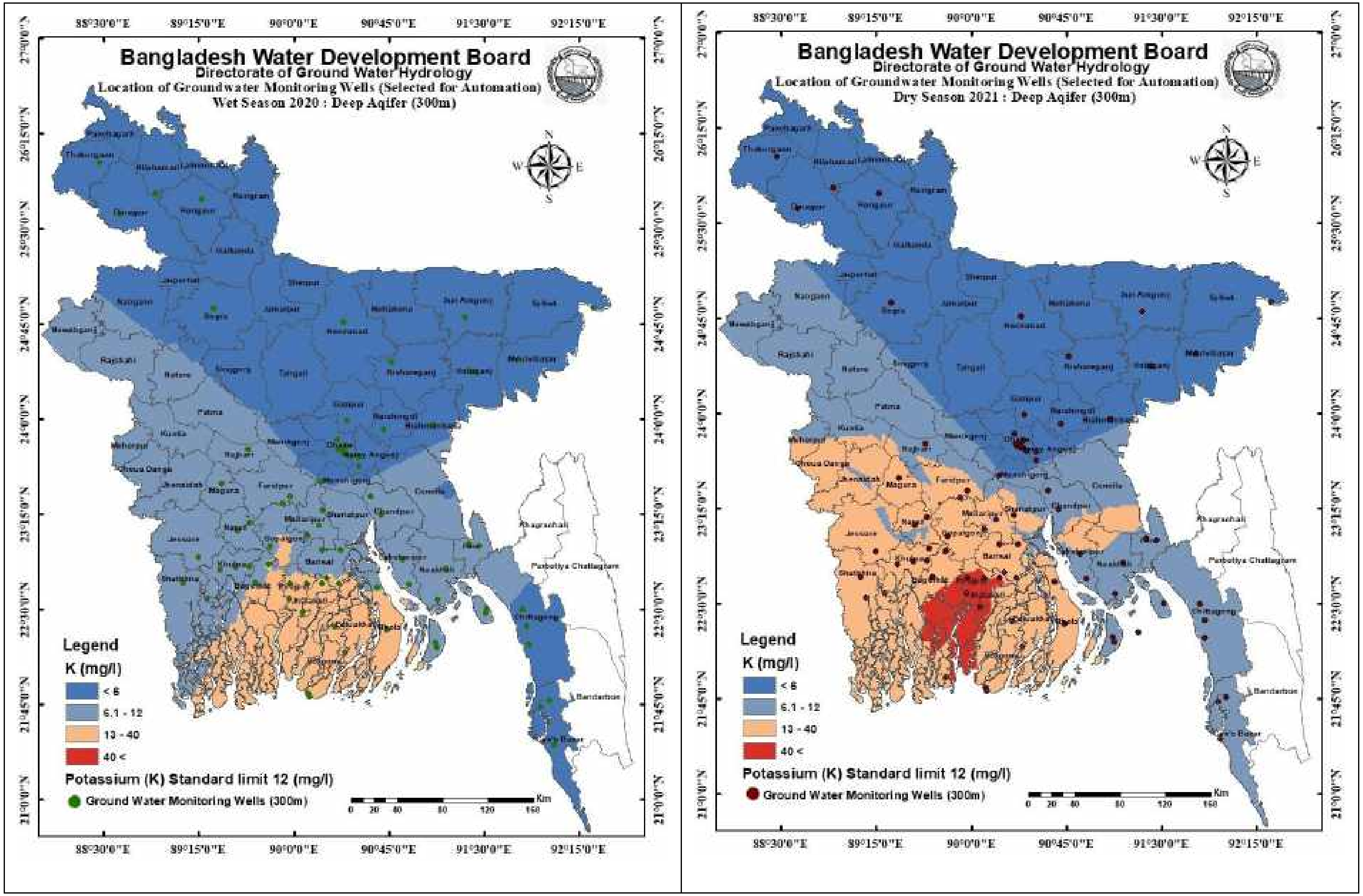


Figure 5-28: Groundwater Potassium (K) at Deep Aquifer (300m).

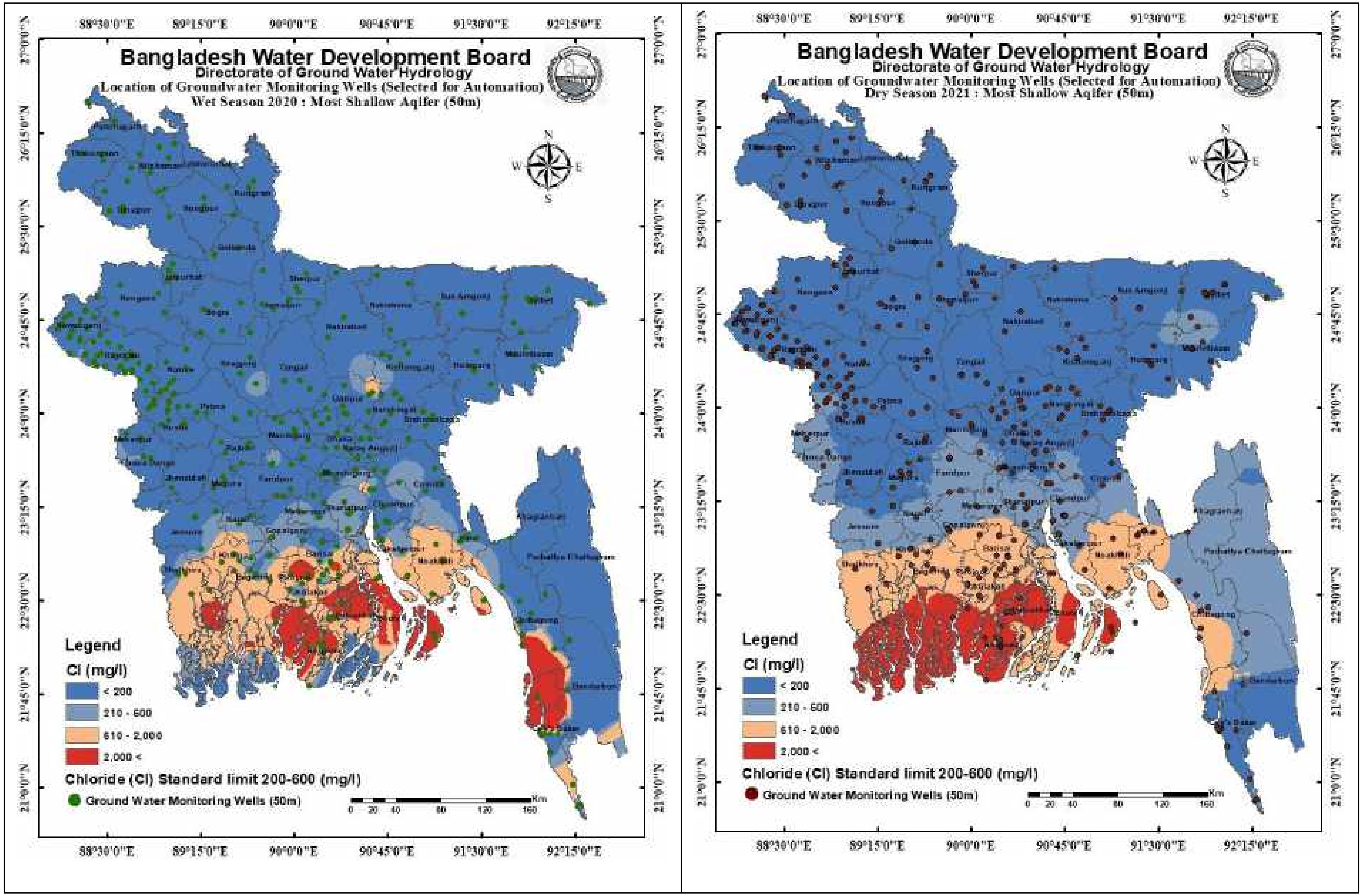


Figure 5-29: Groundwater Chloride (Cl) at Very Shallow Aquifer (50m).

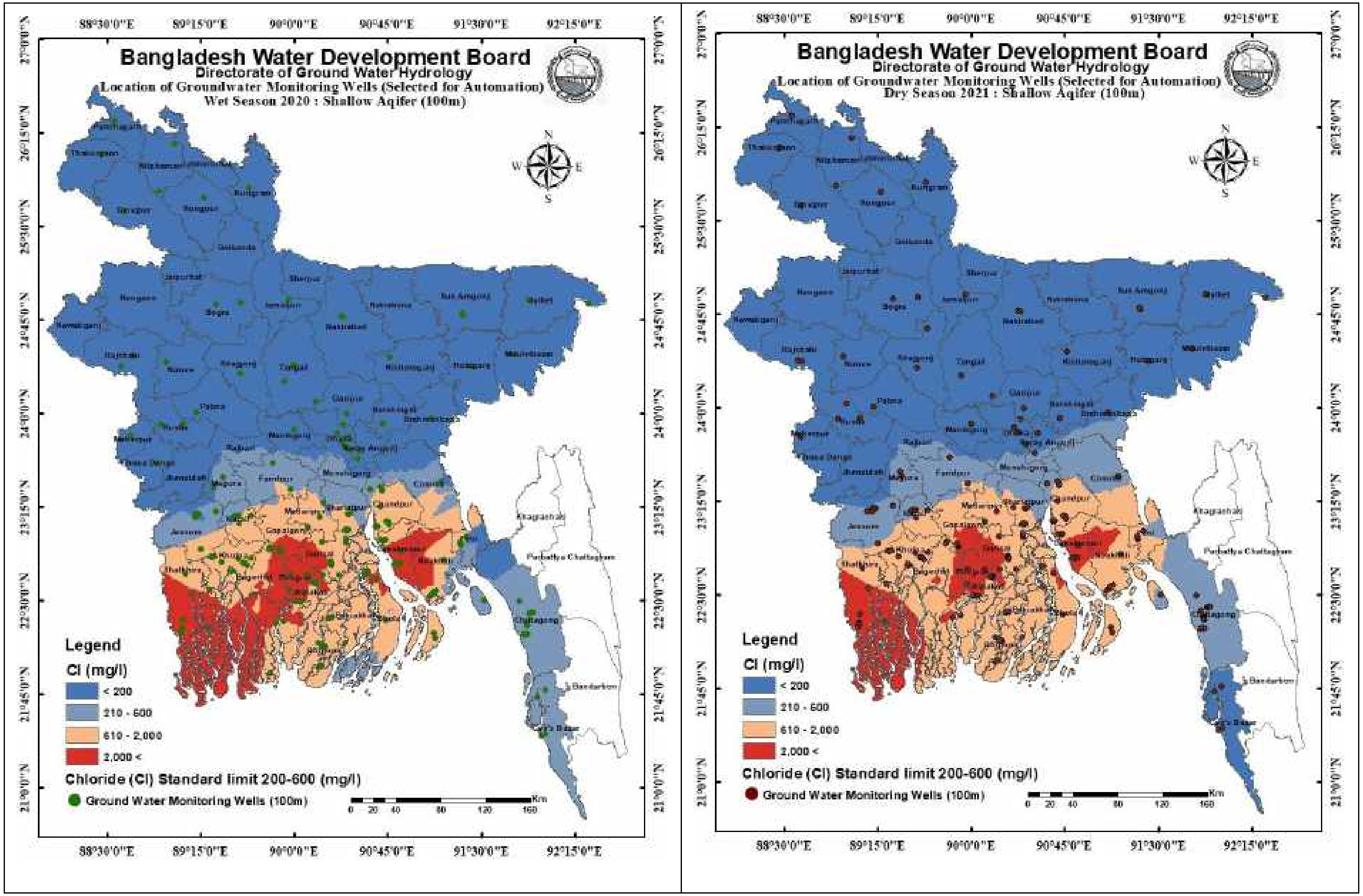


Figure 5-30: Groundwater Chloride (Cl) at Shallow Aquifer (100m).

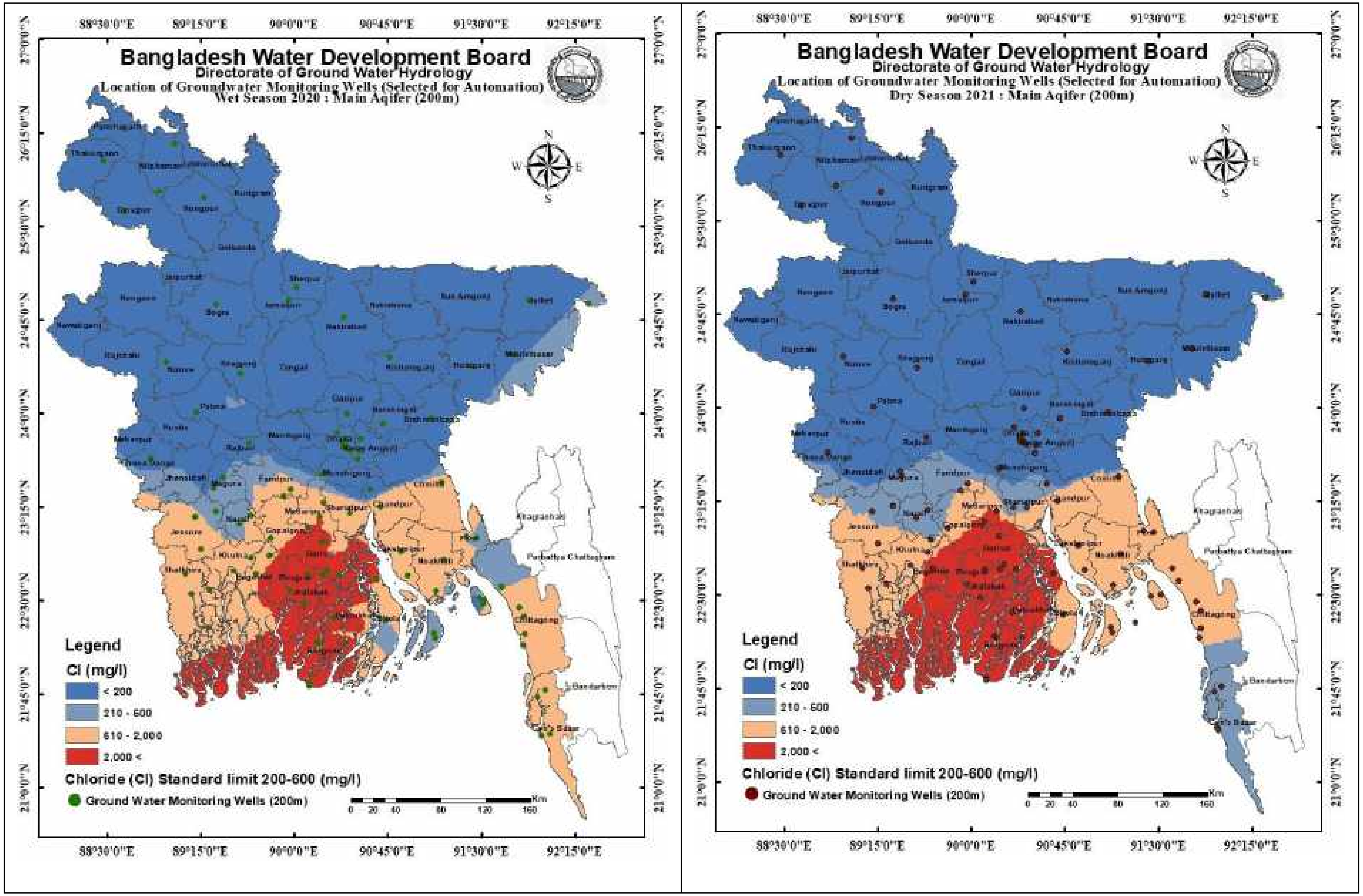


Figure 5-31: Groundwater Chloride (Cl) at Main Aquifer (200m).

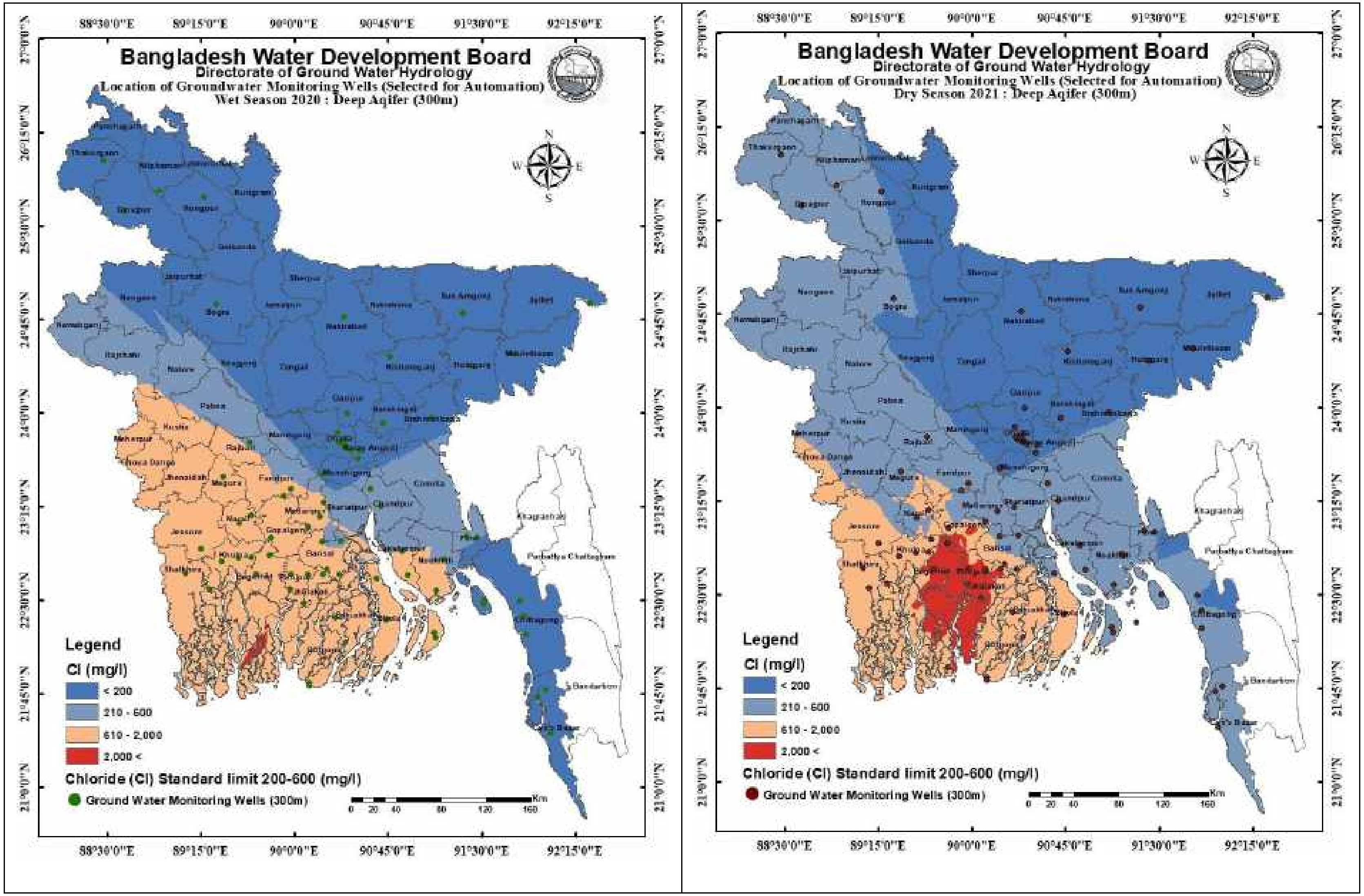


Figure 5-32: Groundwater Chloride (Cl) at Deep Aquifer (300m).

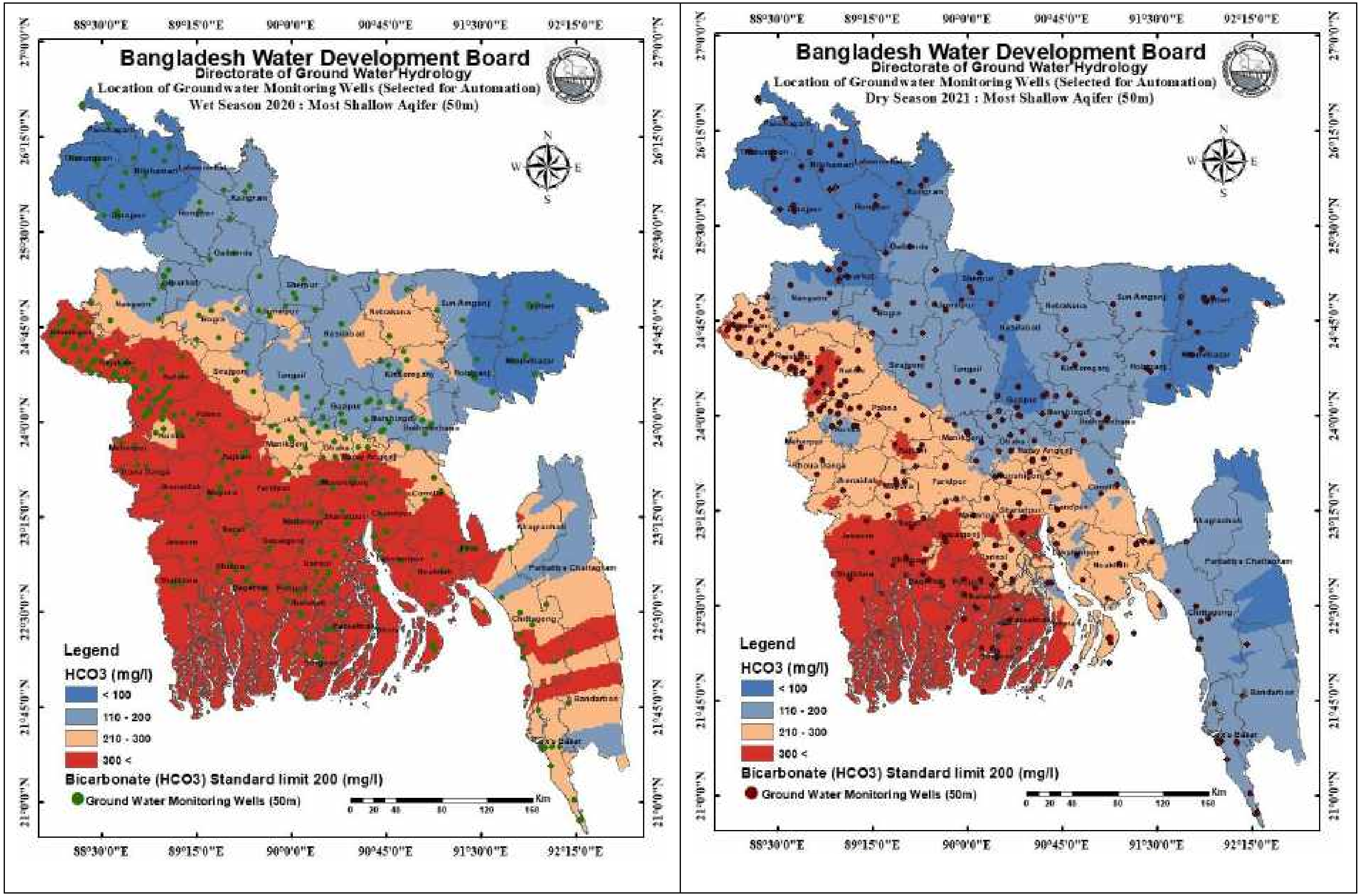


Figure 5-33: Groundwater Bicarbonate (HCO3) at Very Shallow Aquifer (50m).

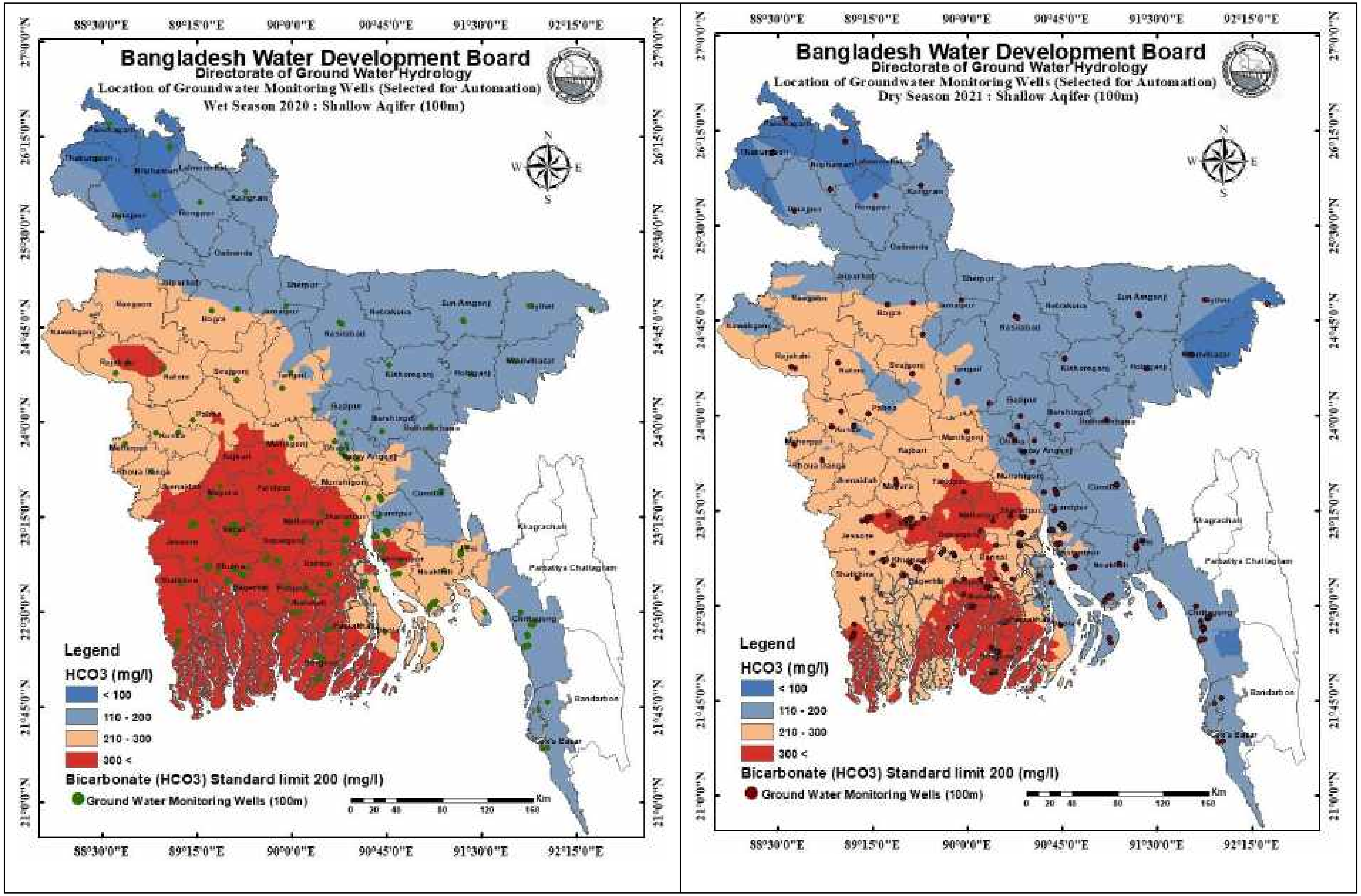


Figure 5-34: Groundwater Bicarbonate (HCO3) at Shallow Aquifer (100m).

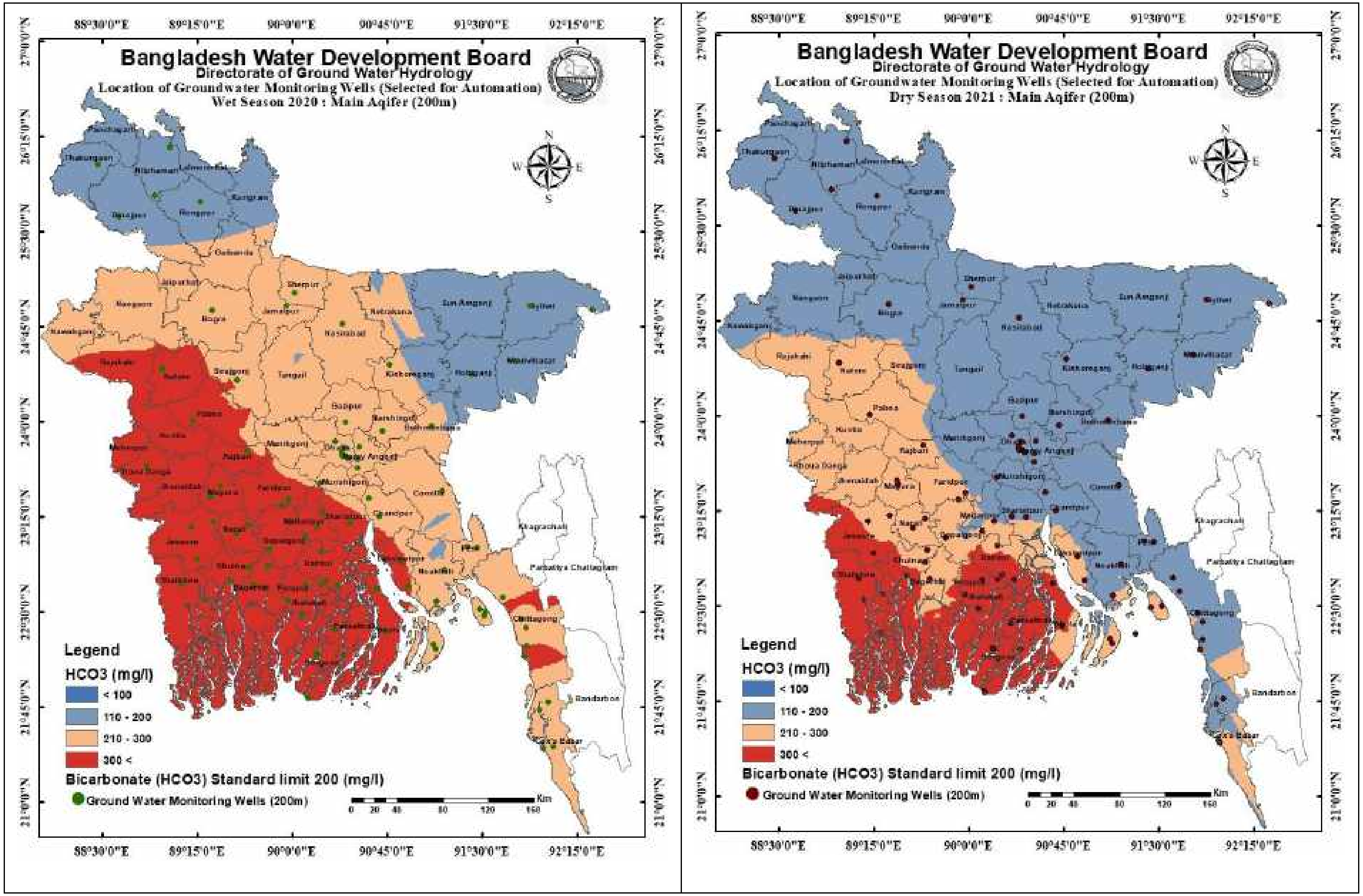


Figure 5-35: Groundwater Bicarbonate (HCO3) at Main Aquifer (200m).

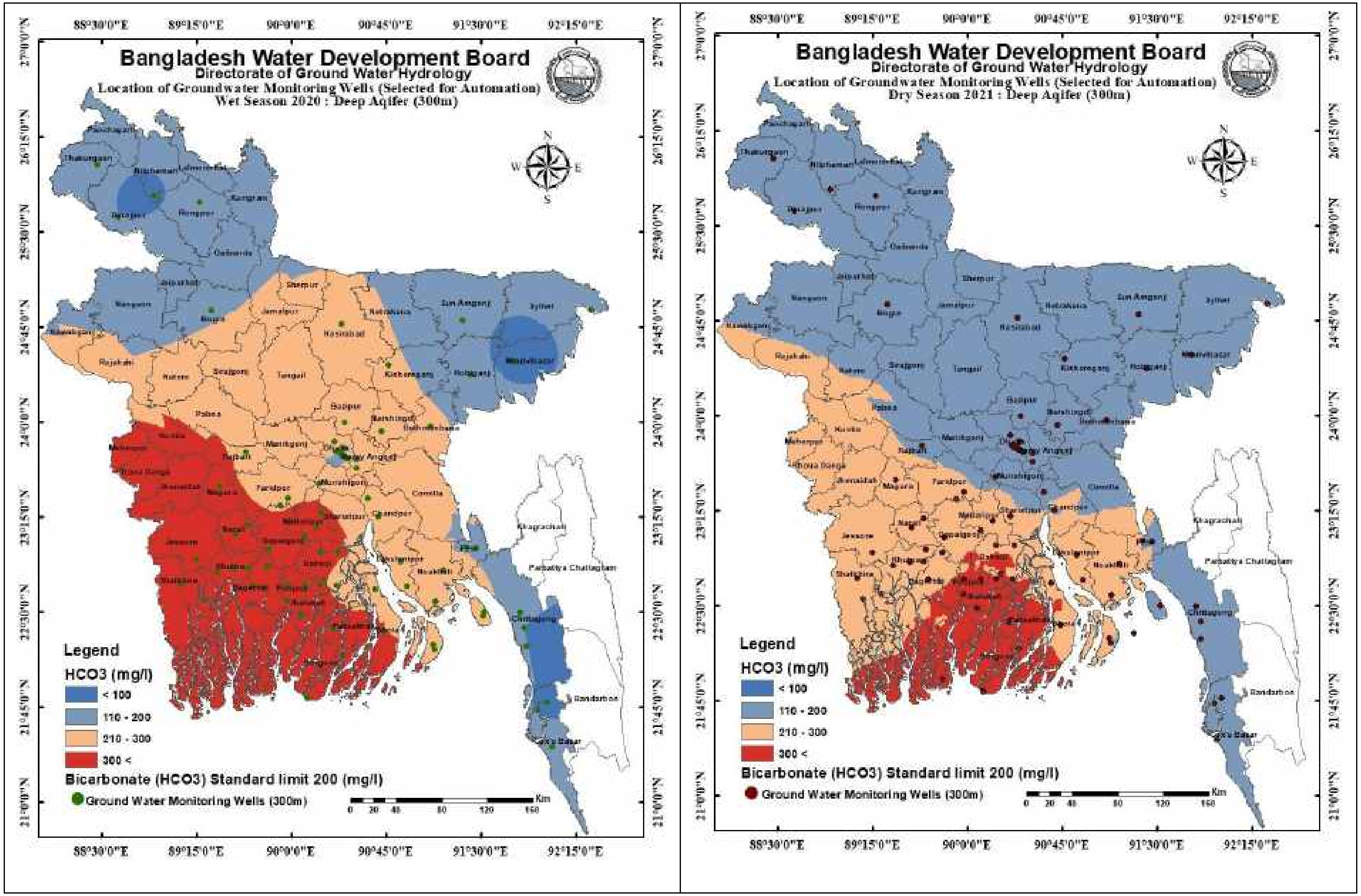


Figure 5-36: Groundwater Bicarbonate (HCO3) at Deep Aquifer (300m).

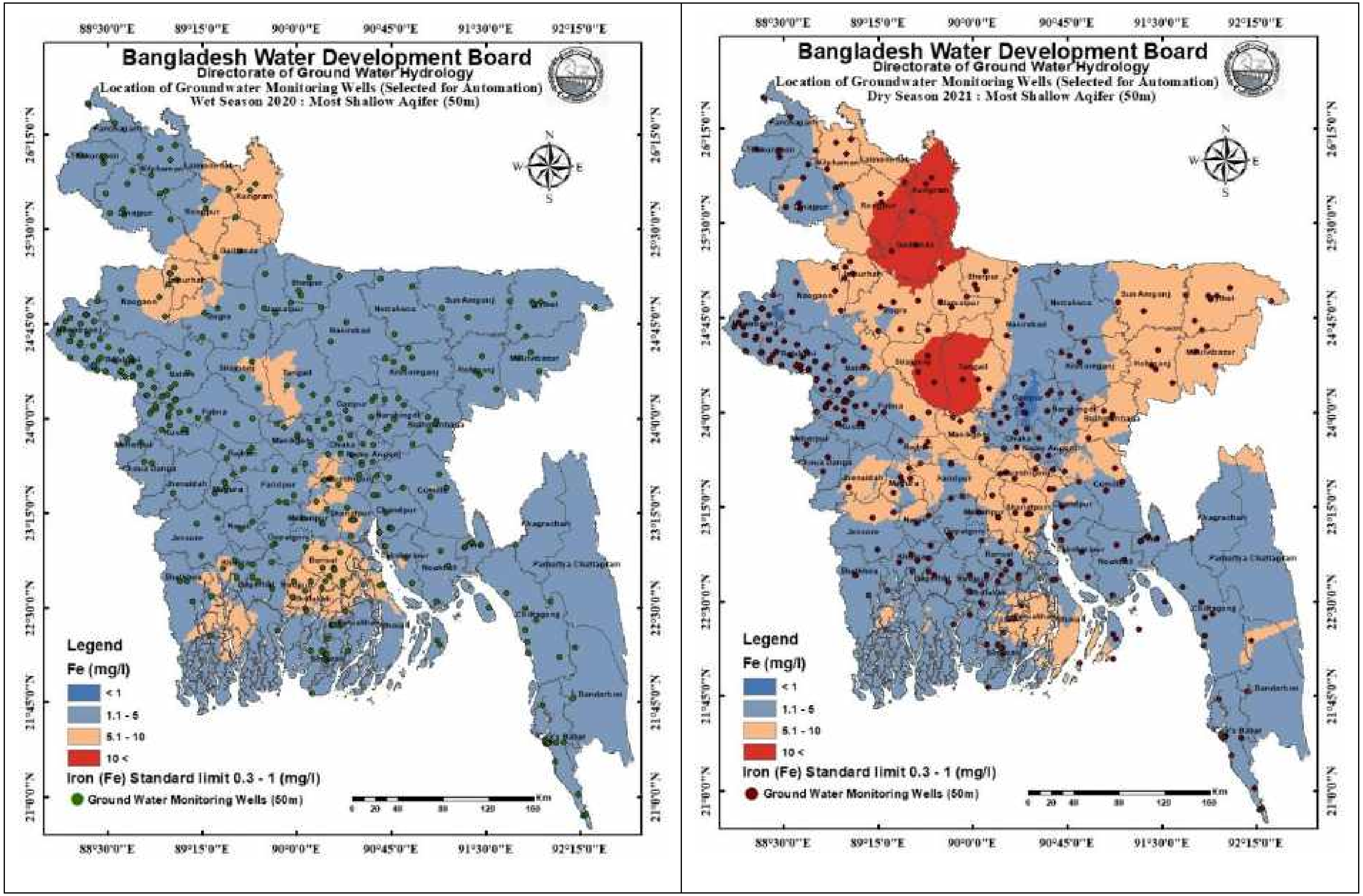


Figure 5-37: Groundwater Iron (Fe) at Very Shallow Aquifer (50m).

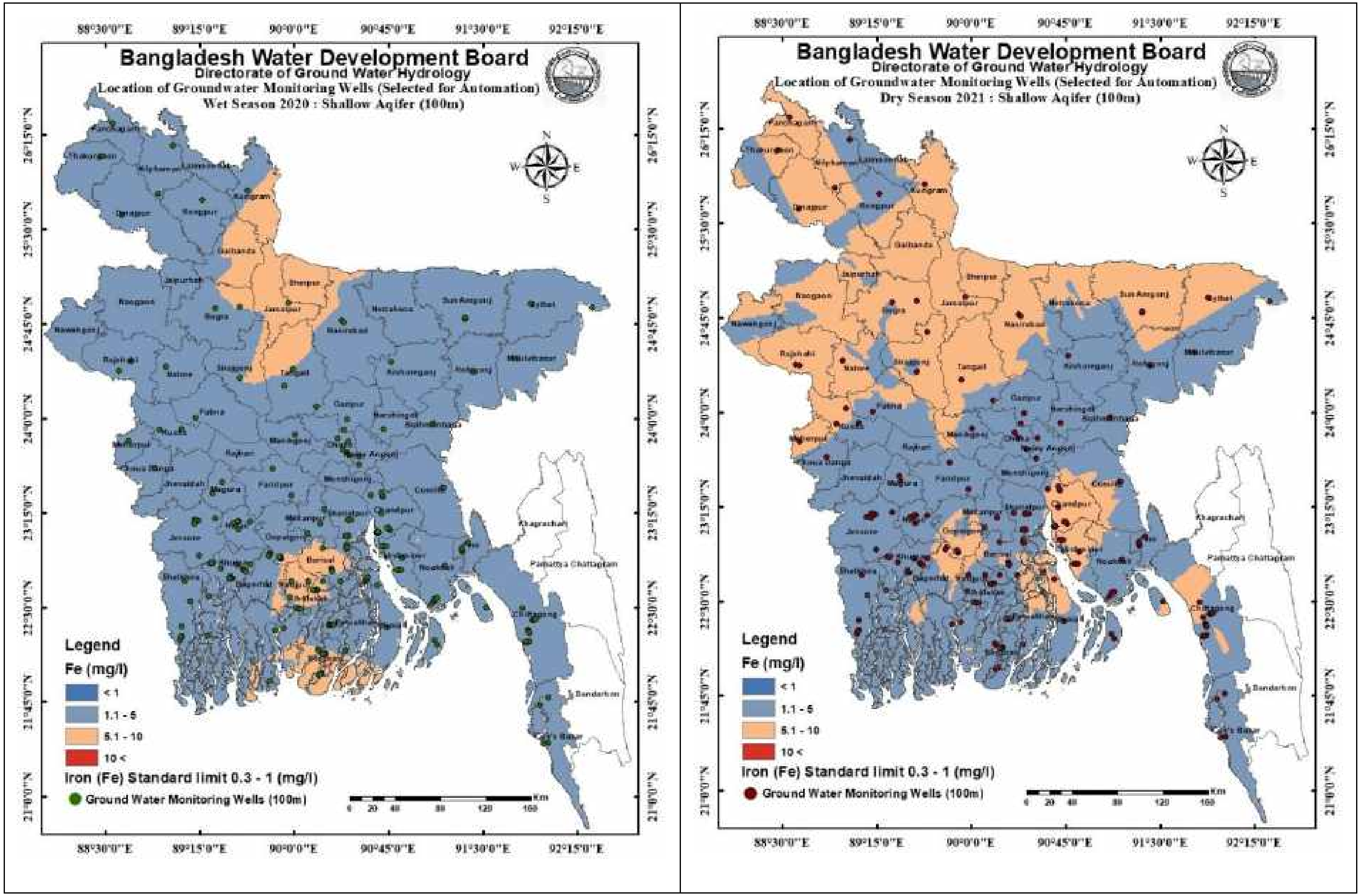


Figure 5-38: Groundwater Iron (Fe) at Shallow Aquifer (100m).

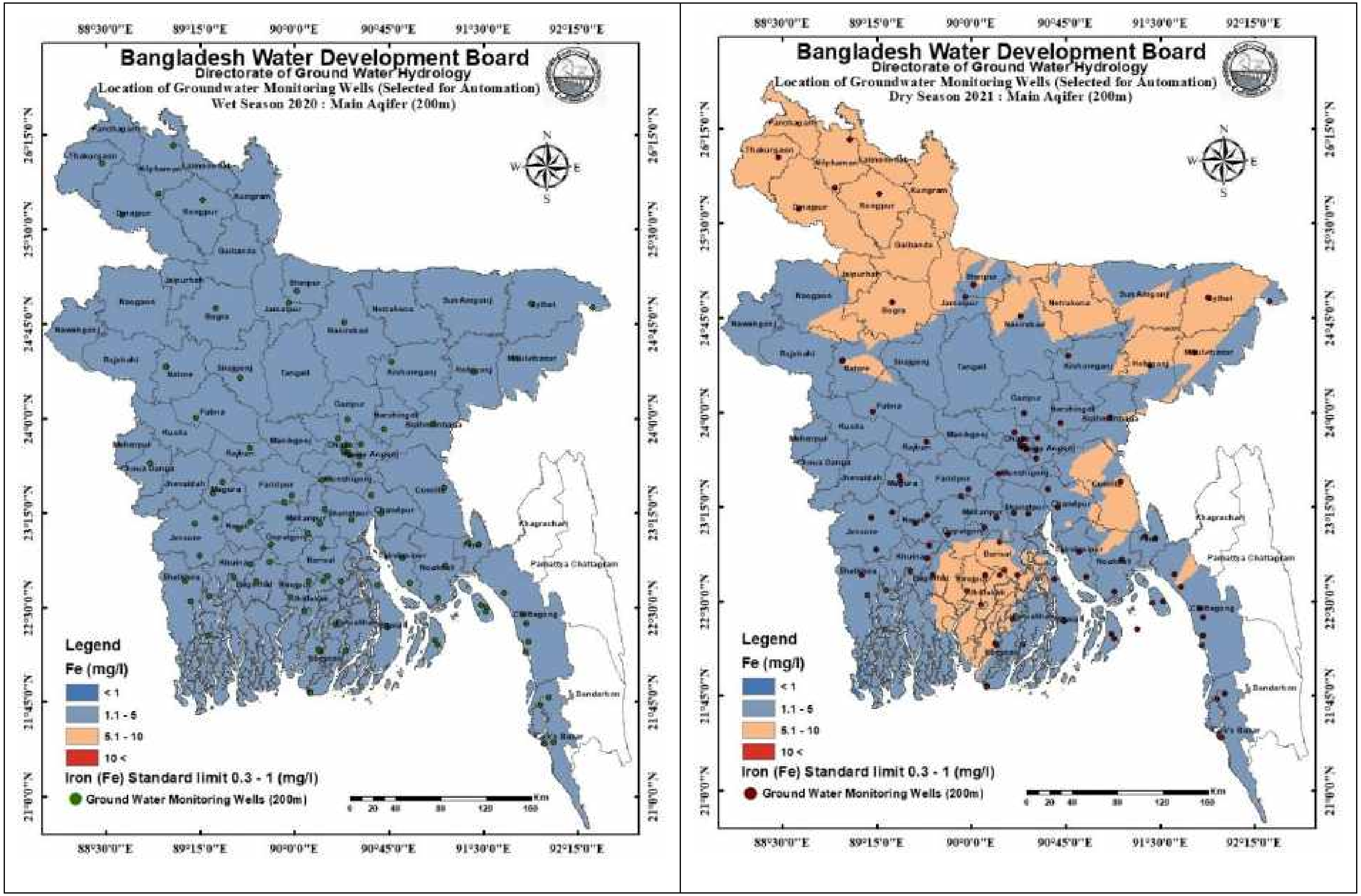


Figure 5-39: Groundwater Iron (Fe) at Main Aquifer (200m).

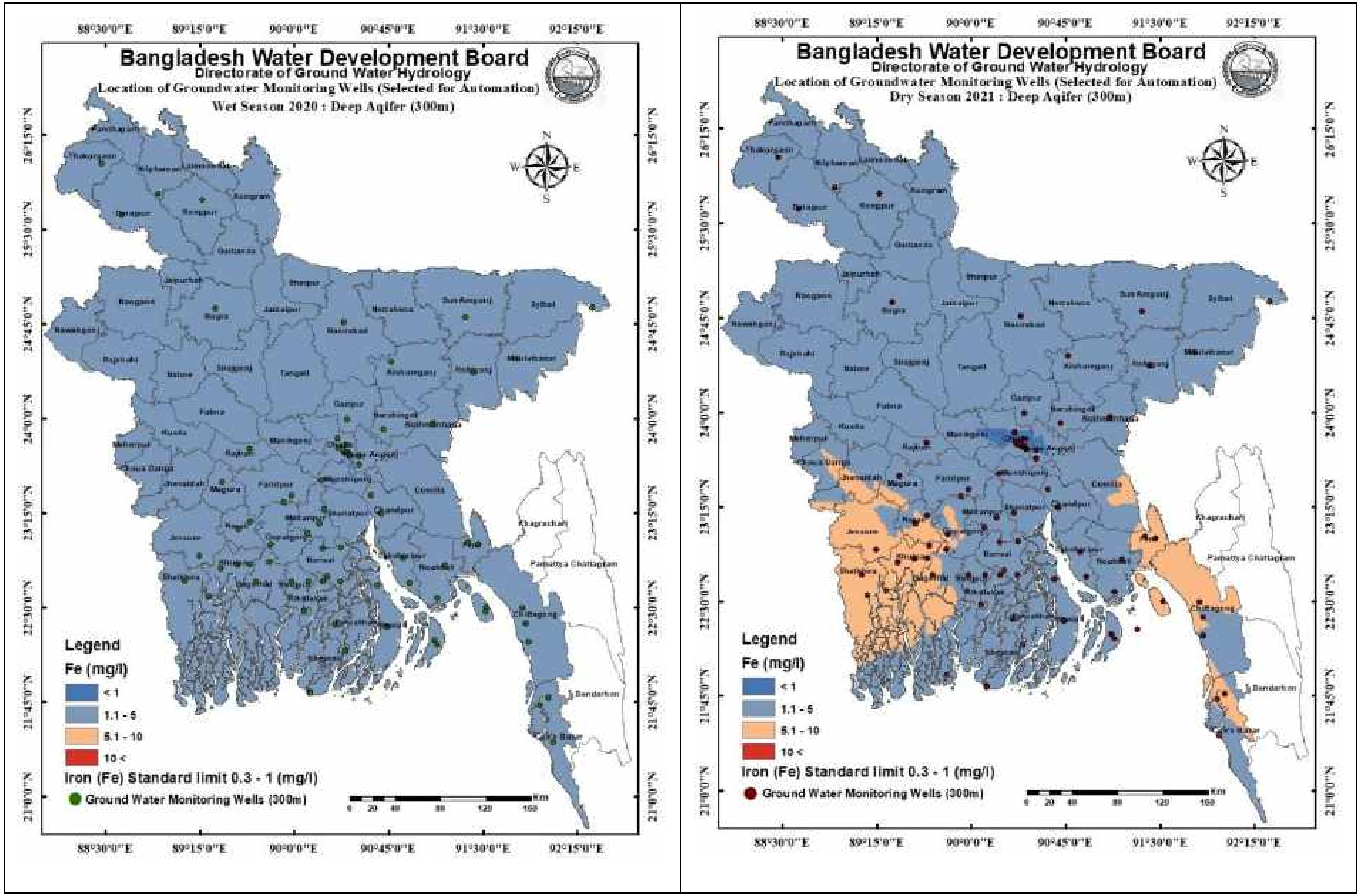


Figure 5-40: Groundwater Iron (Fe) at Deep Aquifer (300m).

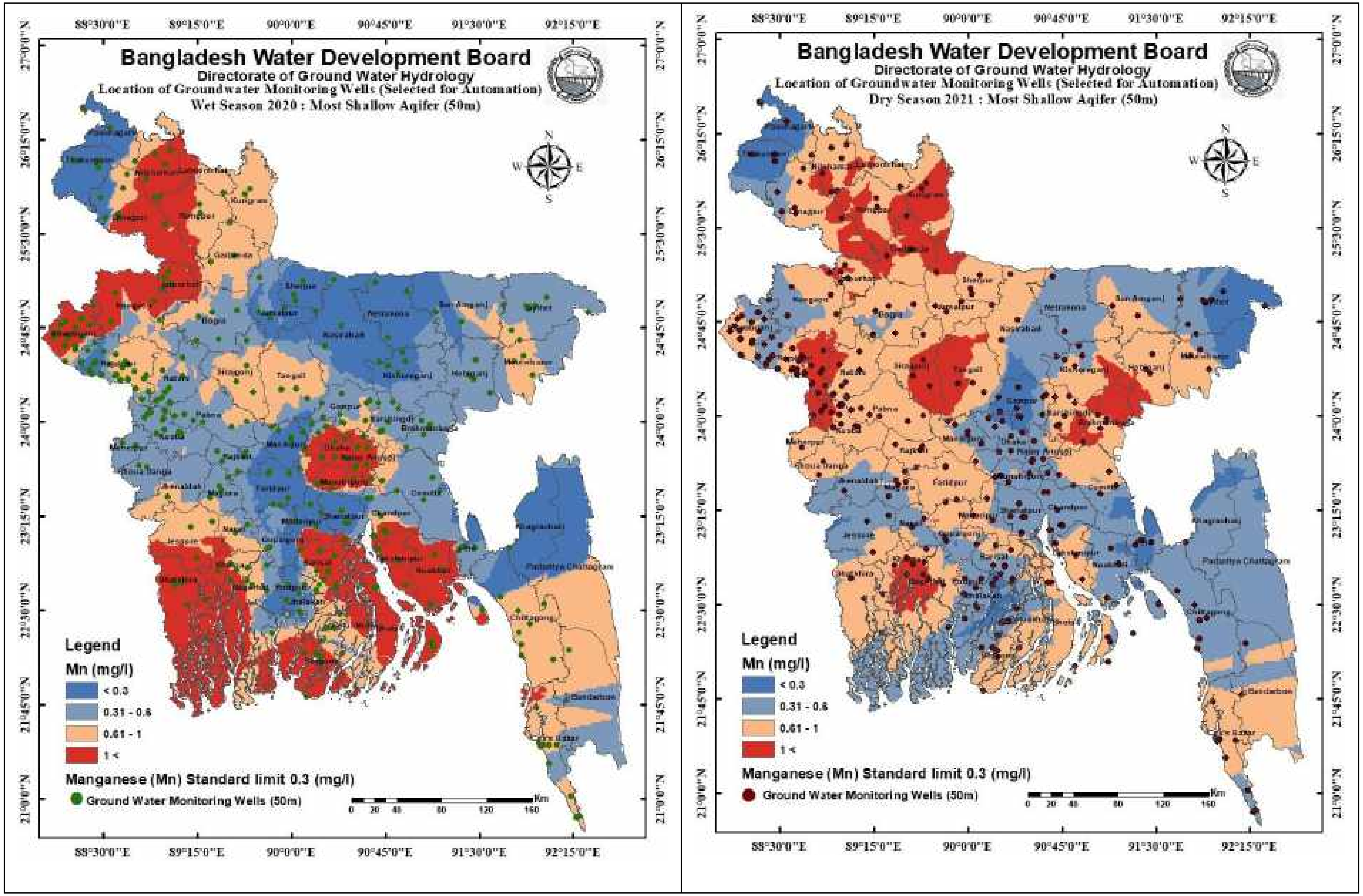


Figure 5-41: Groundwater Manganese (Mn) at Very Shallow Aquifer (50m).

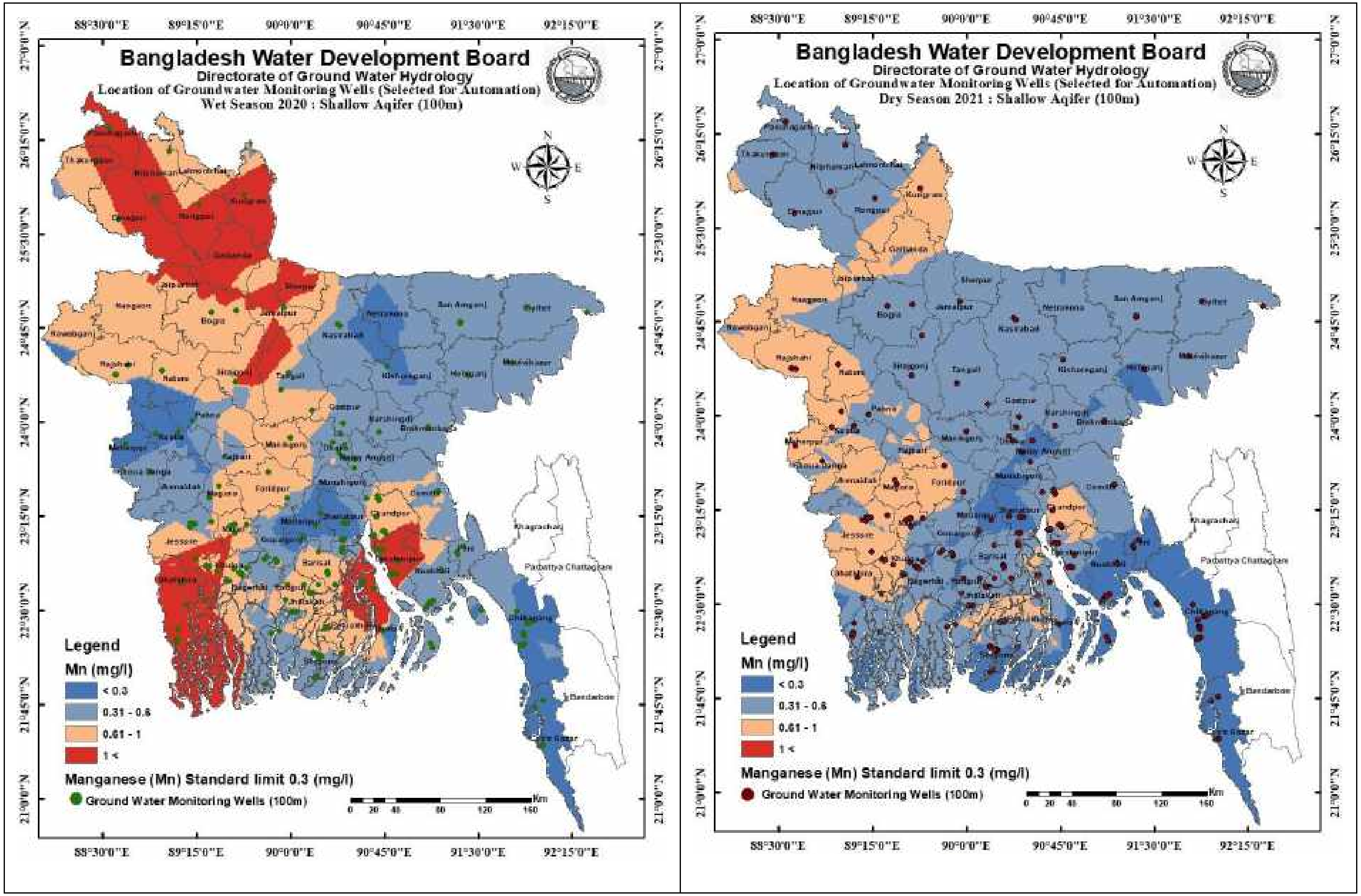


Figure 5-42: Groundwater Manganese (Mn) at Shallow Aquifer (100m).

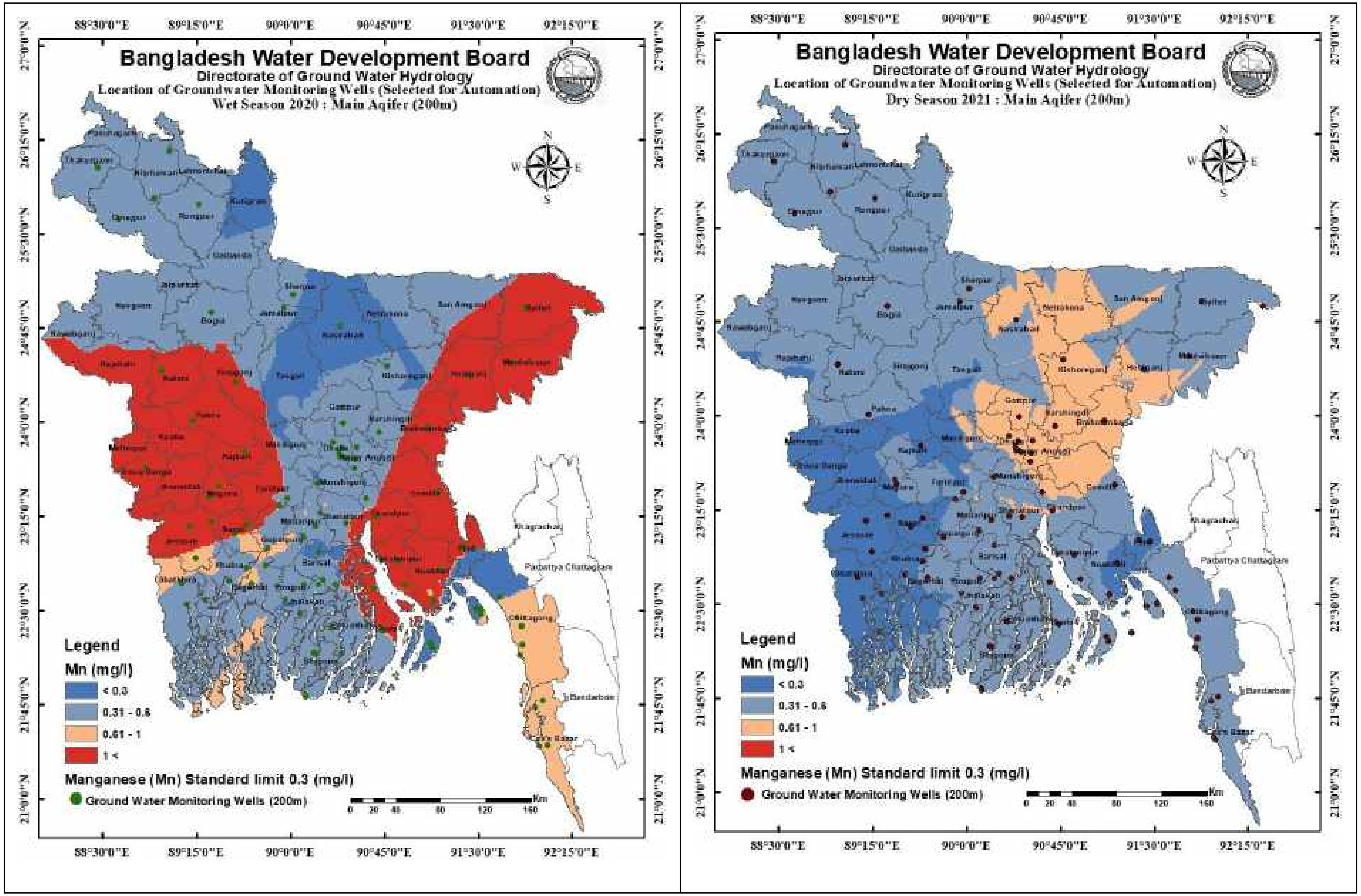


Figure 5-43: Groundwater Manganese (Mn) at Main Aquifer (200m).

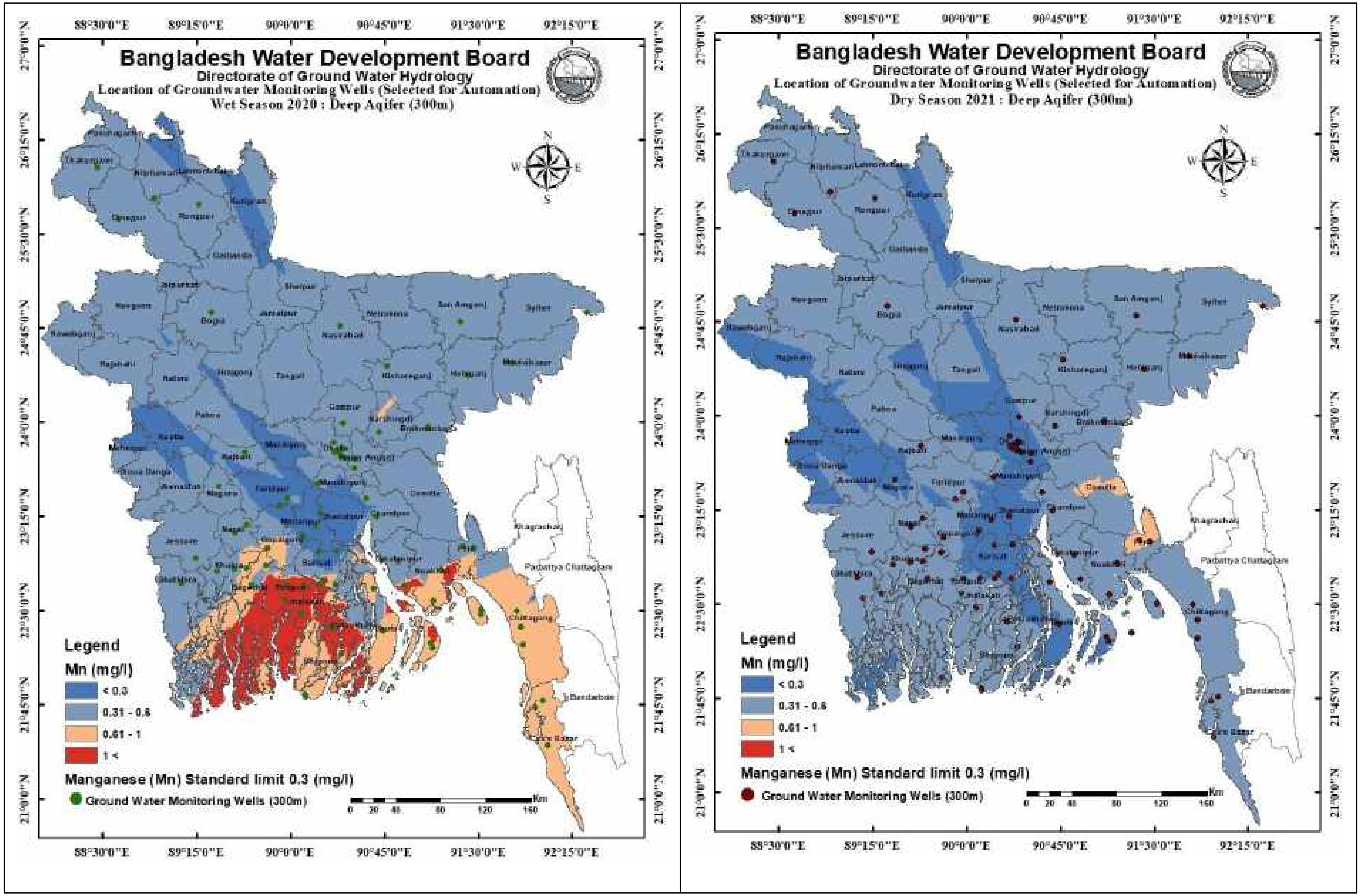


Figure 5-44: Groundwater Manganese (Mn) at Deep Aquifer (300m).

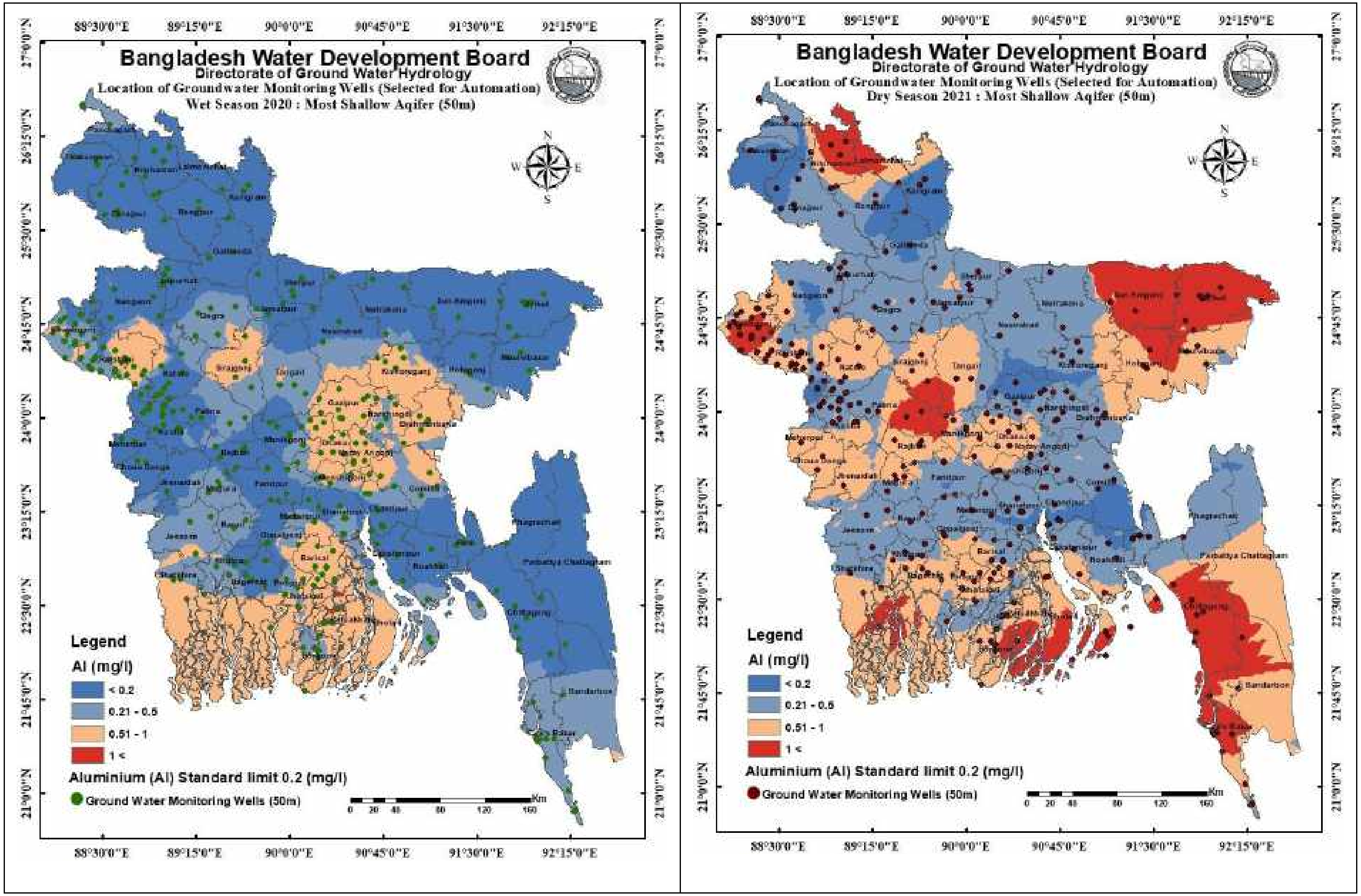


Figure 5-45: Groundwater Aluminium (Al) at Very Shallow Aquifer (50m).

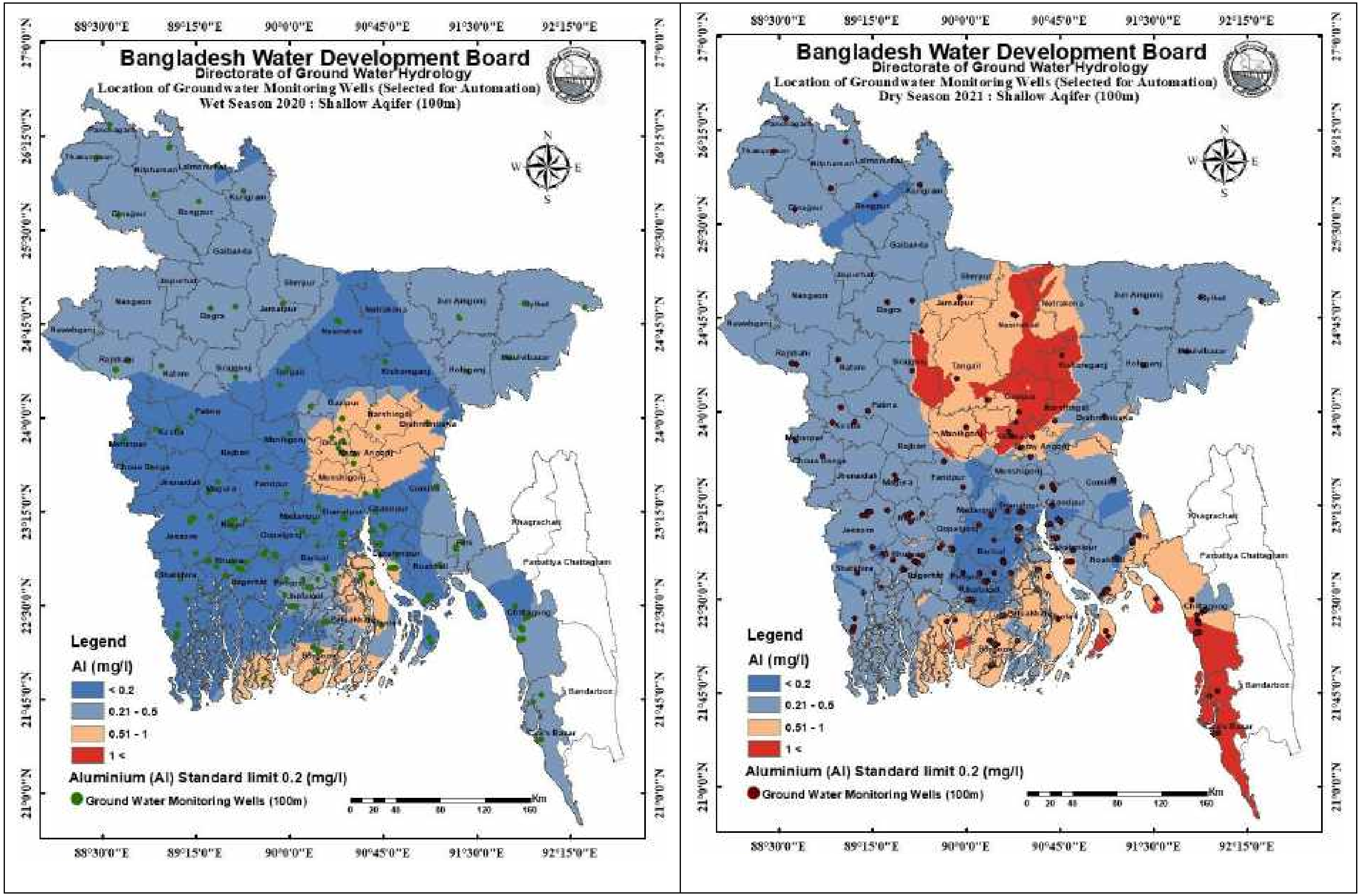


Figure 5-46: Groundwater Aluminium (Al) at Shallow Aquifer (100m).

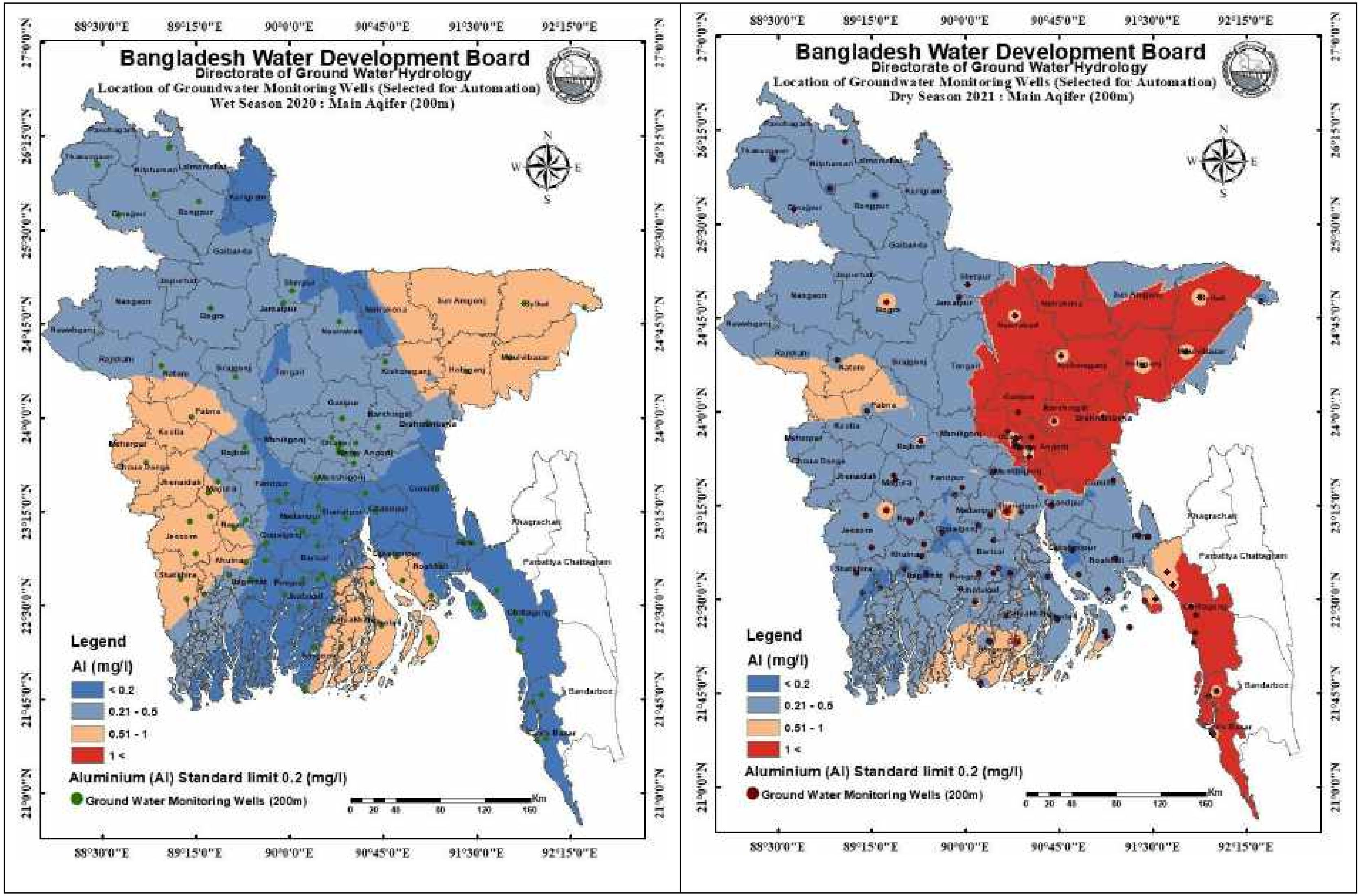


Figure 5-47: Groundwater Aluminium (Al) at Main Aquifer (200m).

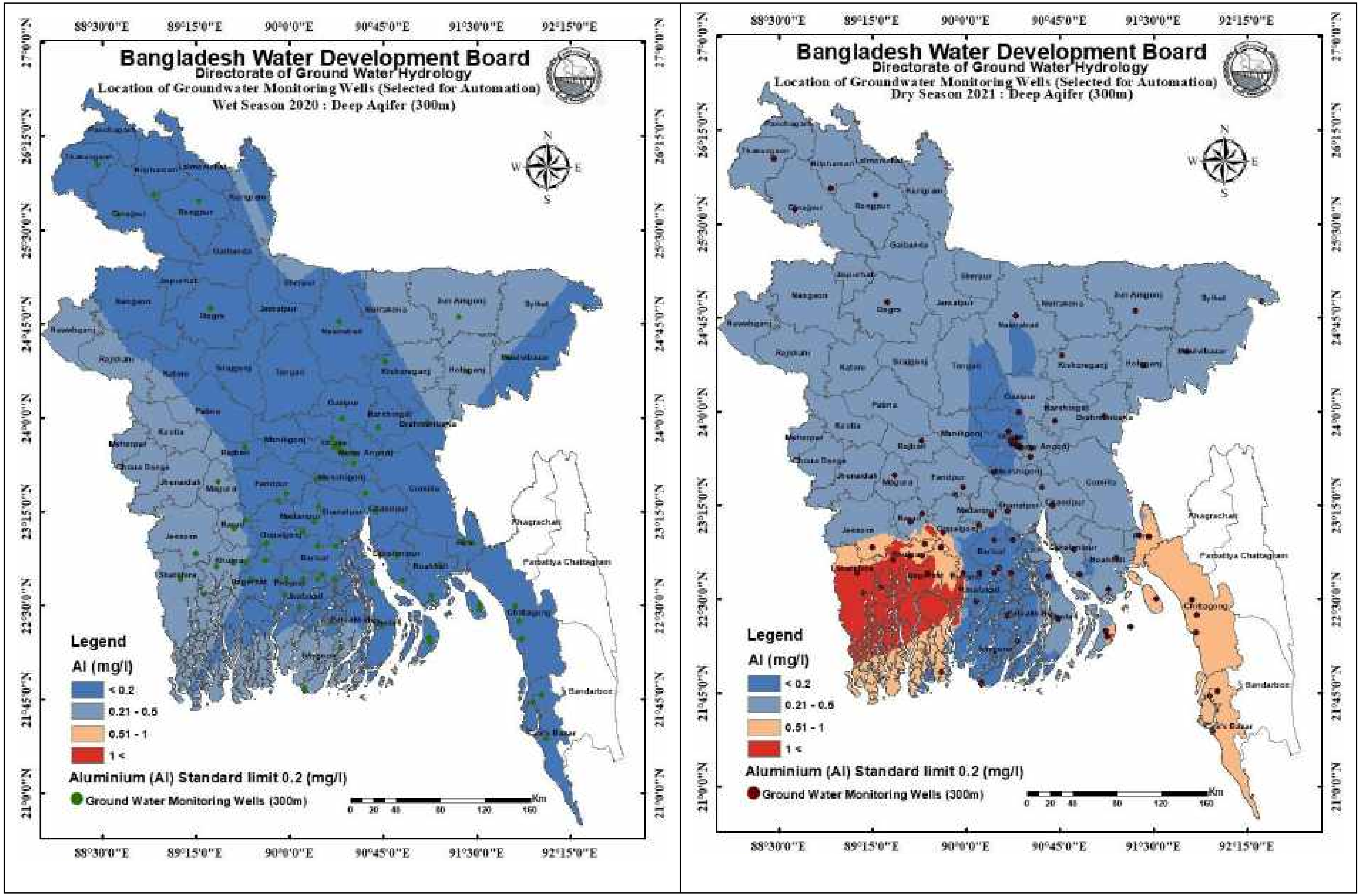


Figure 5-48: Groundwater Aluminium (Al) at Deep Aquifer (300m).

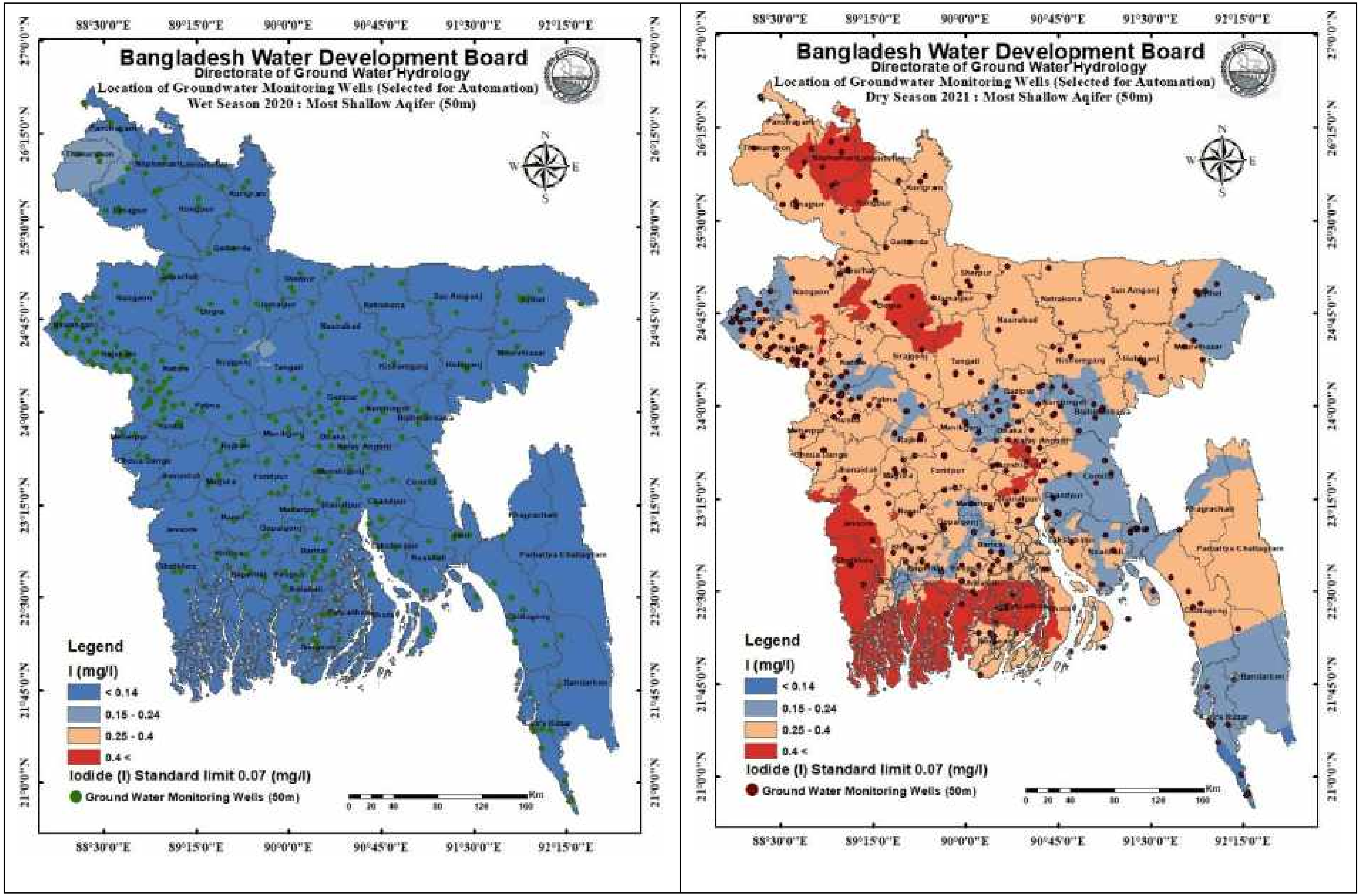


Figure 5-49: Groundwater Iodine (I) at Very Shallow Aquifer (50m).

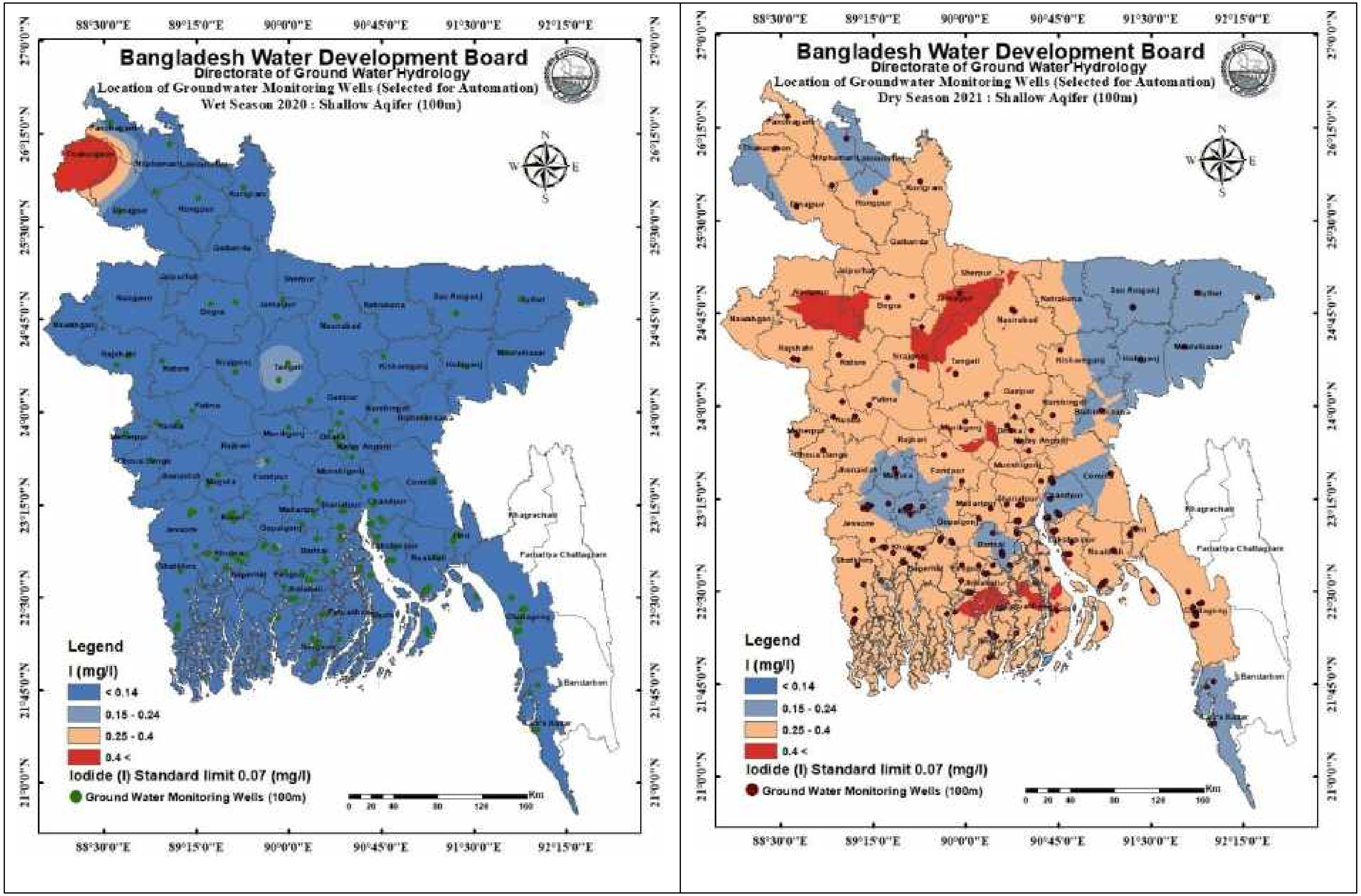


Figure 5-50: Groundwater Iodine (I) at Shallow Aquifer (100m).

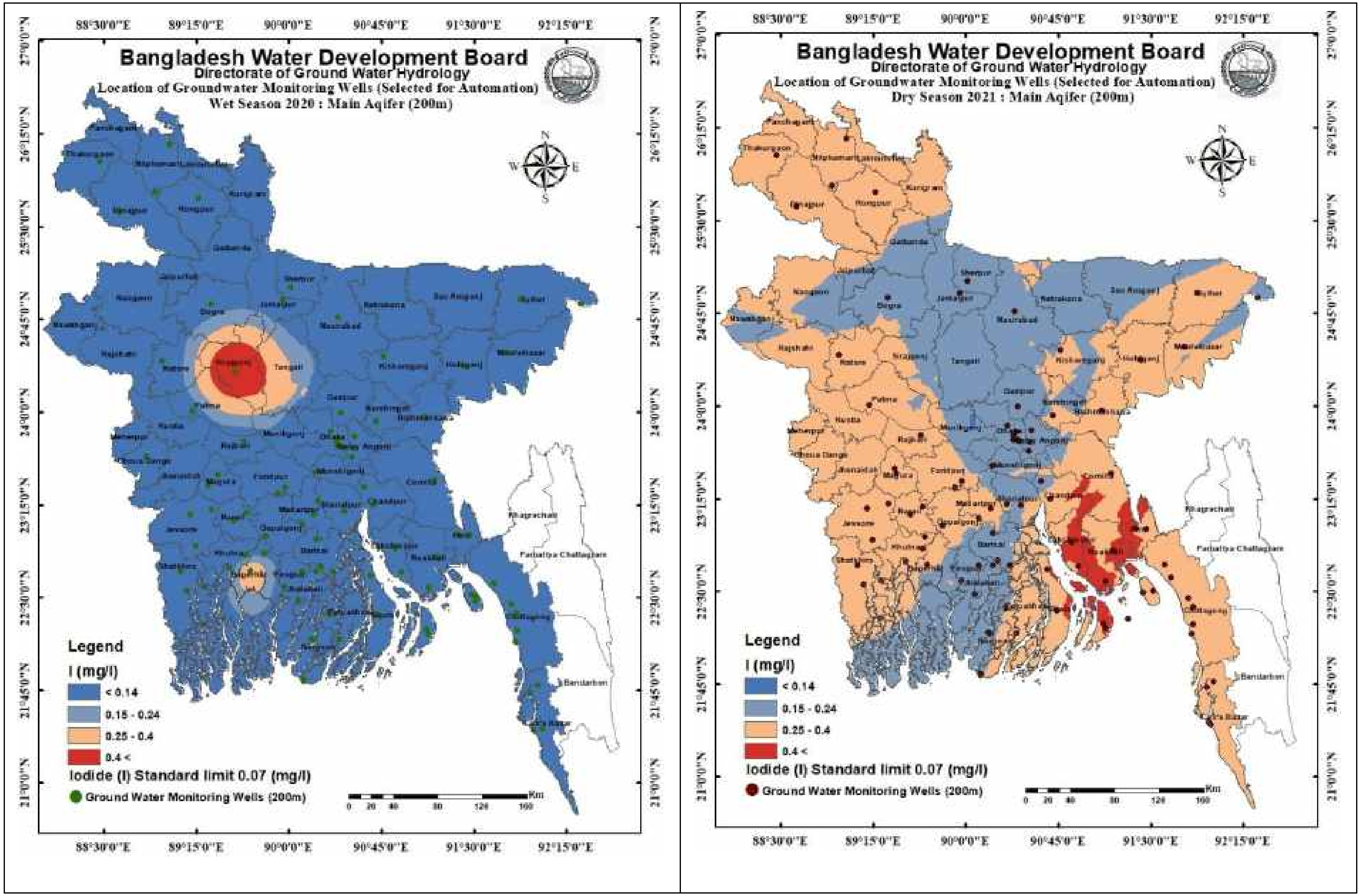


Figure 5-51: Groundwater Iodine (I) at Main Aquifer (200m).

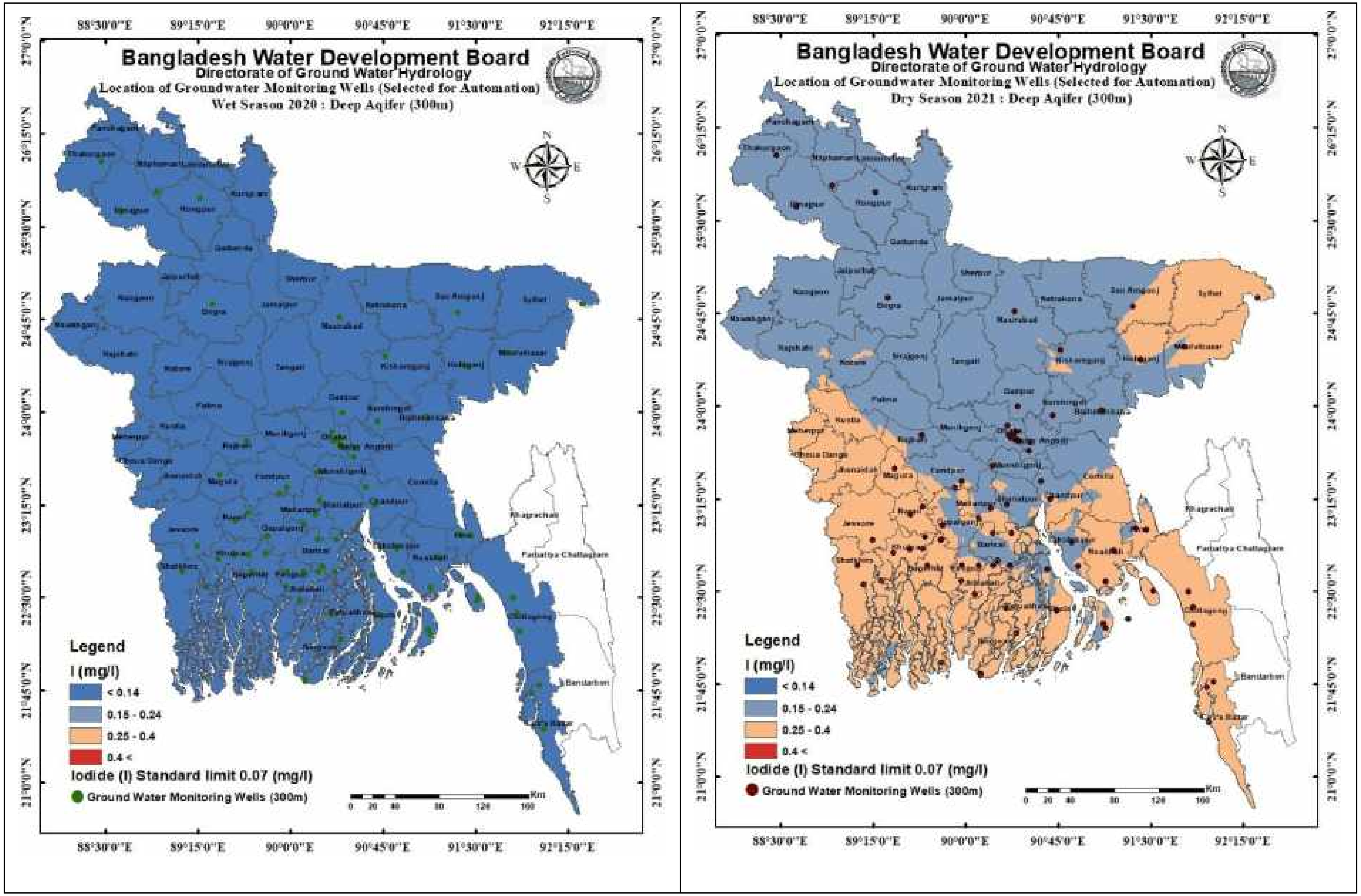


Figure 5-52: Groundwater Iodine (I) at Deep Aquifer (300m).

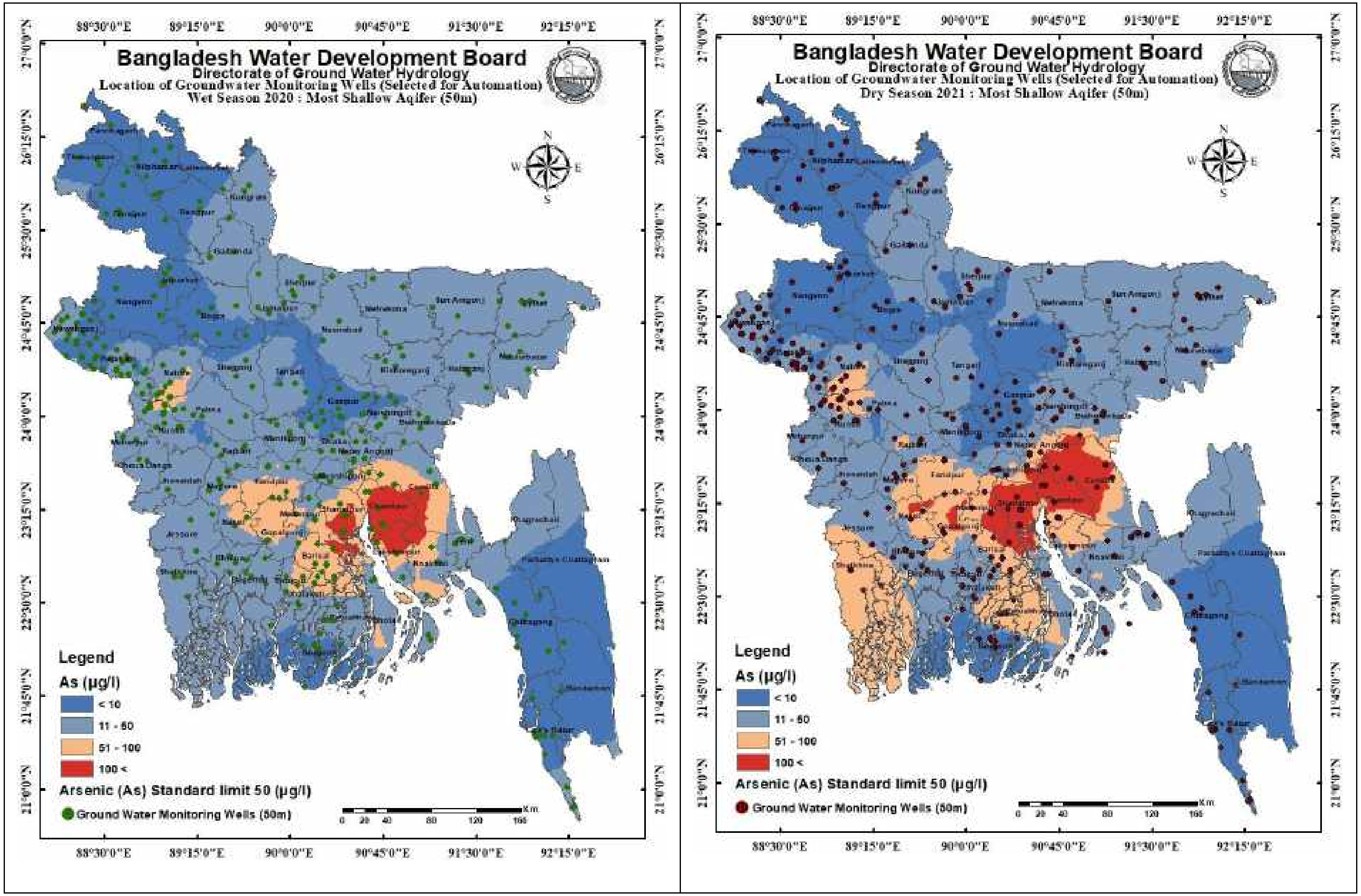


Figure 5-53: Groundwater Arsenic (As) at Very Shallow Aquifer (50m).

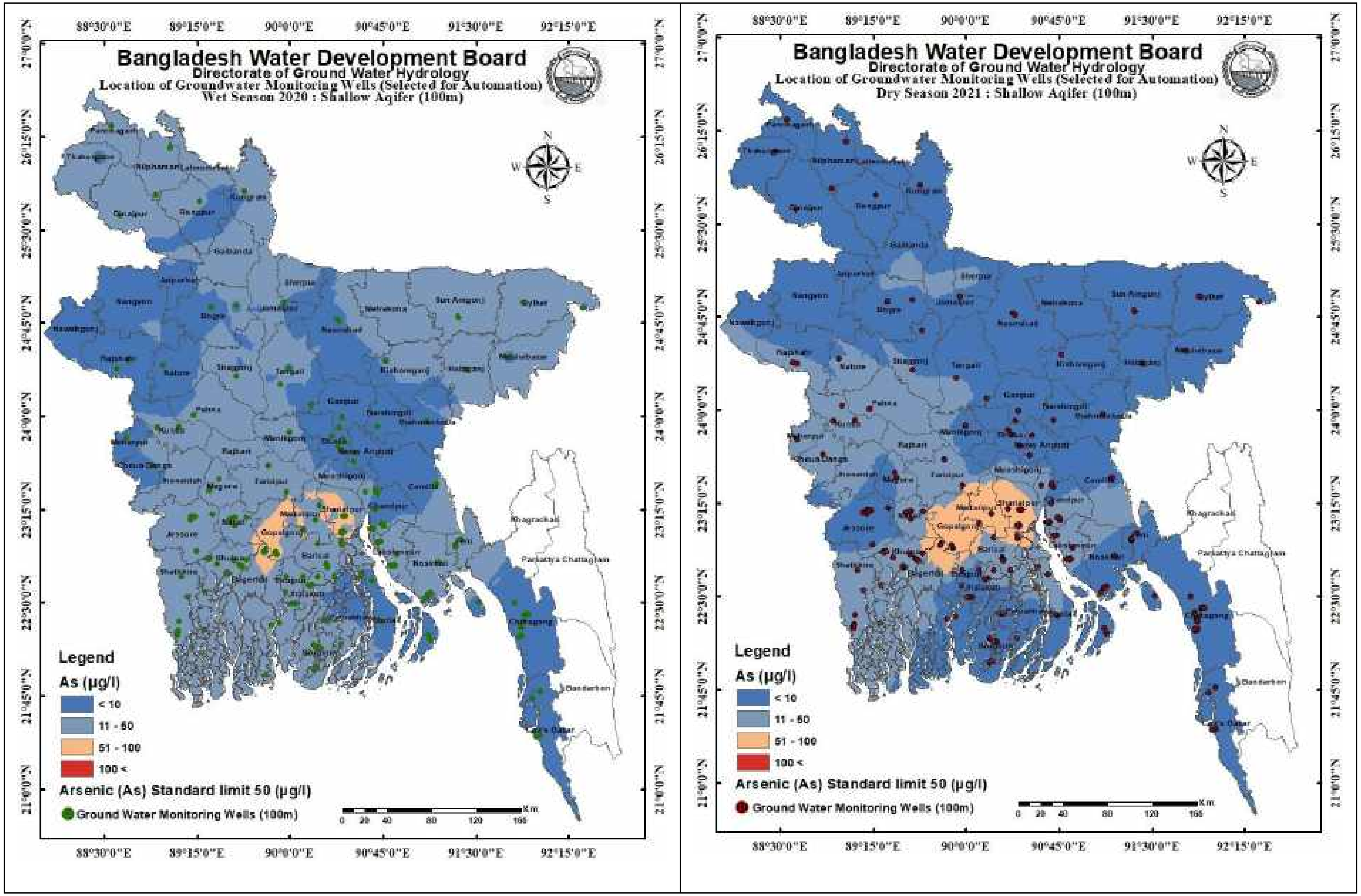


Figure 5-54: Groundwater Arsenic (As) at Shallow Aquifer (100m).

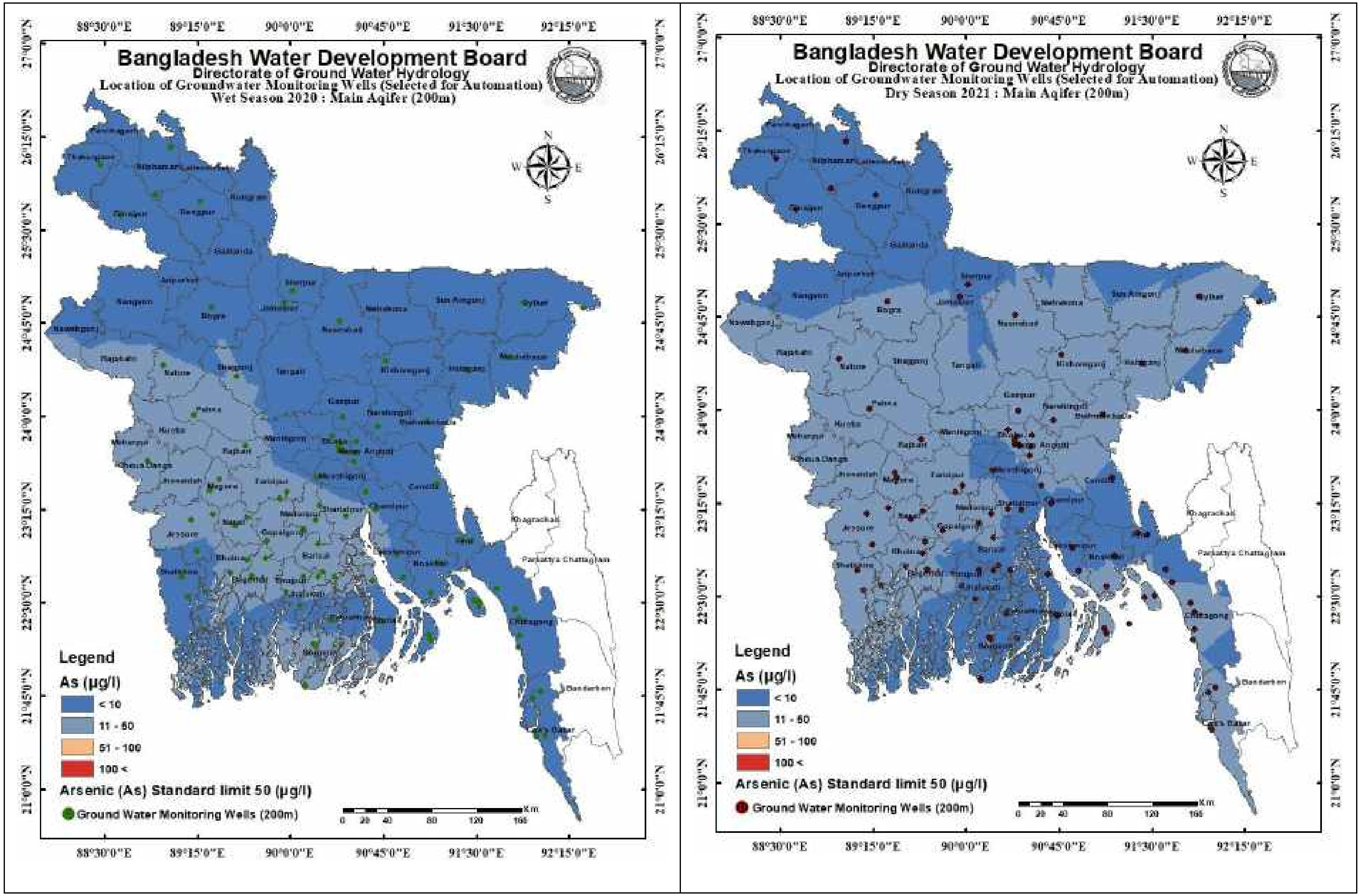


Figure 5-55: Groundwater Arsenic (As) at Main Aquifer (200m).

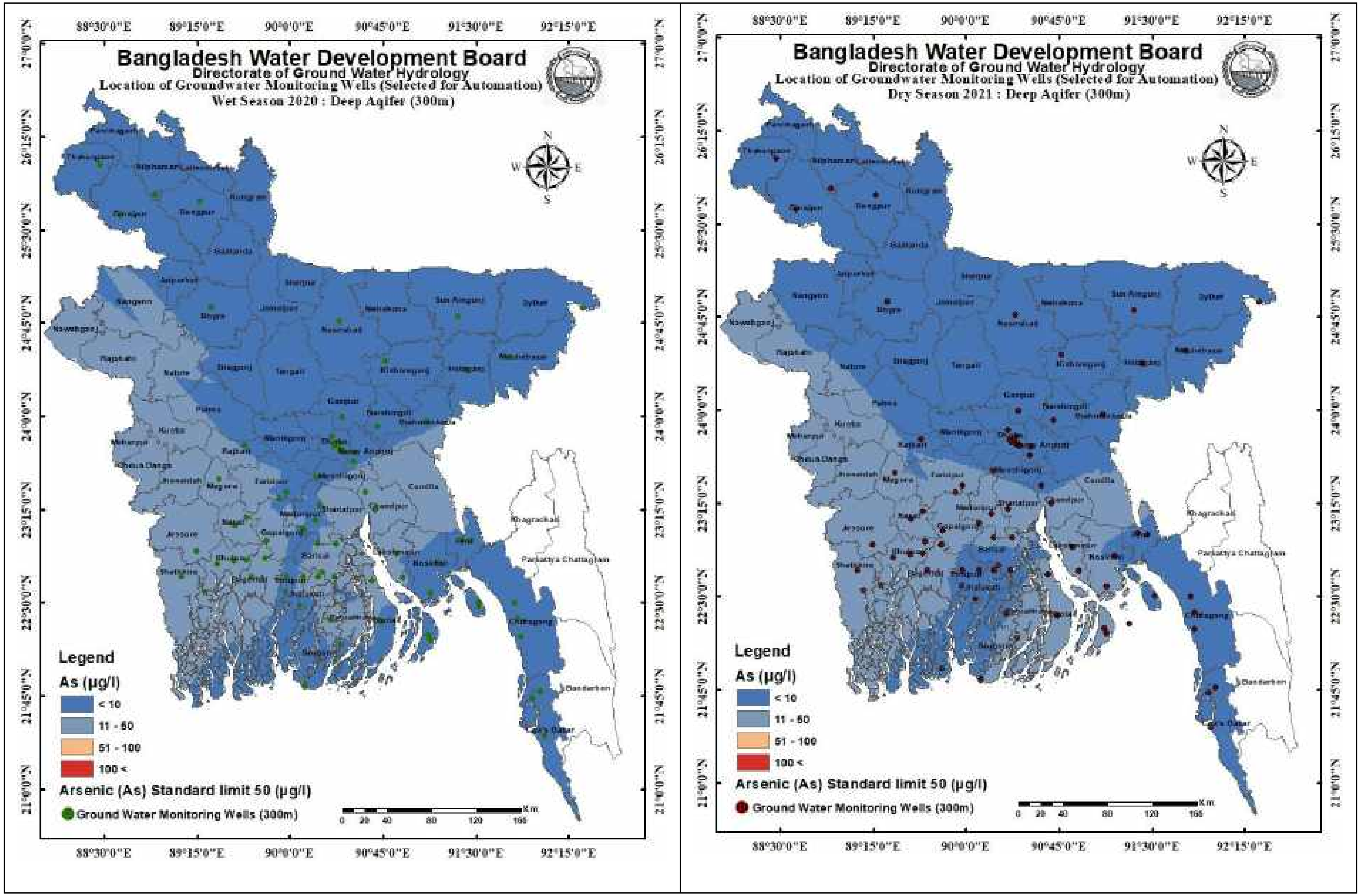
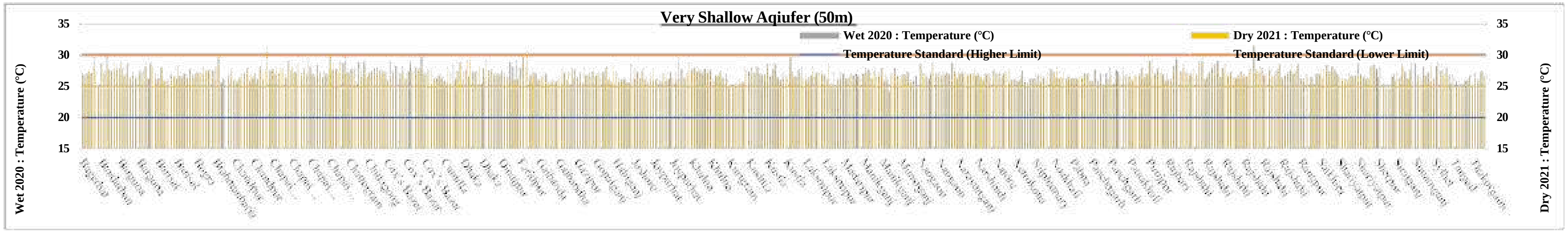
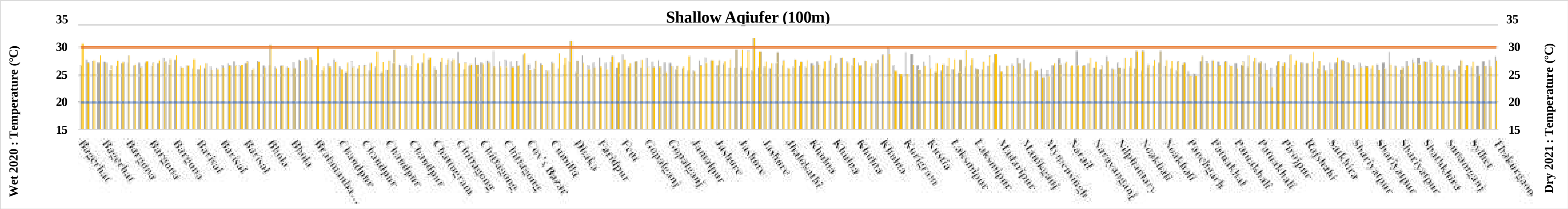
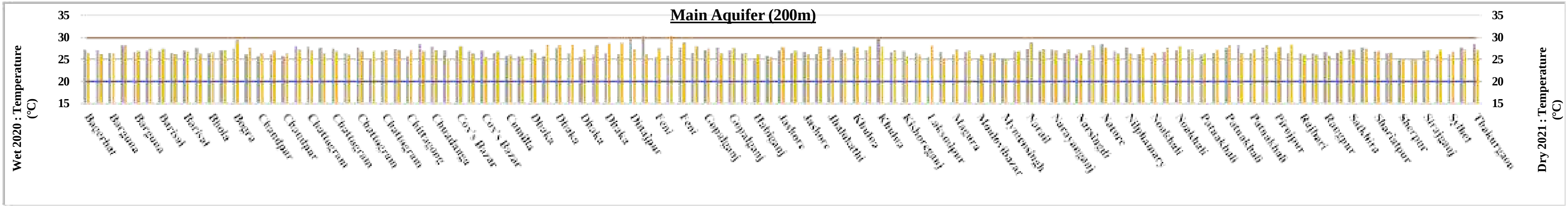


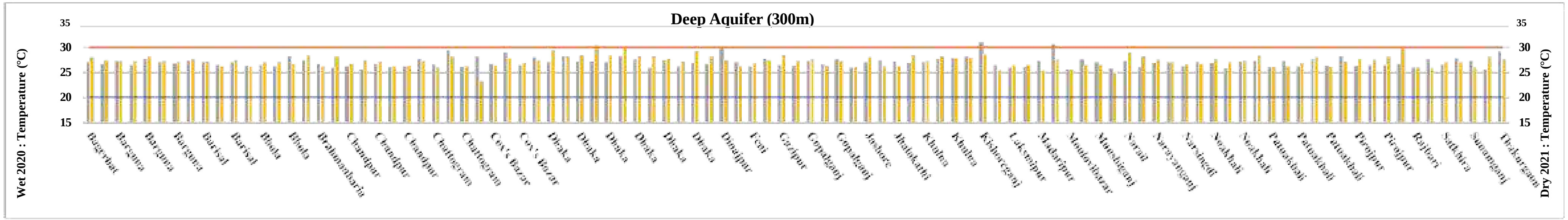
Figure 5-56: Groundwater Arsenic (As) at Deep Aquifer (300m).

Annexure C


Very Shallow Aqiufer (50m)
Wet 2020 : Temperature (°C)
Dry 2021 : Temperature (°C)
Temperature Standard (Higher Limit)
Temperature Standard (Lower Limit)
Wet 2020 : Temperature (°C)
Dry 2021 : Temperature (°C)
35
30
25
20
15


Shallow Aqiufer (100m)
Wet 2020 : Temperature (°C)
Dry 2021 : Temperature (°C)
35
30
25
20
15


Main Aquifer (200m)
Wet 2020 : Temperature (°C)
Dry 2021 : Temperature (°C)
35
30
25
20
15


Deep Aquifer (300m)
Wet 2020 : Temperature (°C)
Dry 2021 : Temperature (°C)
35
30
25
20
15

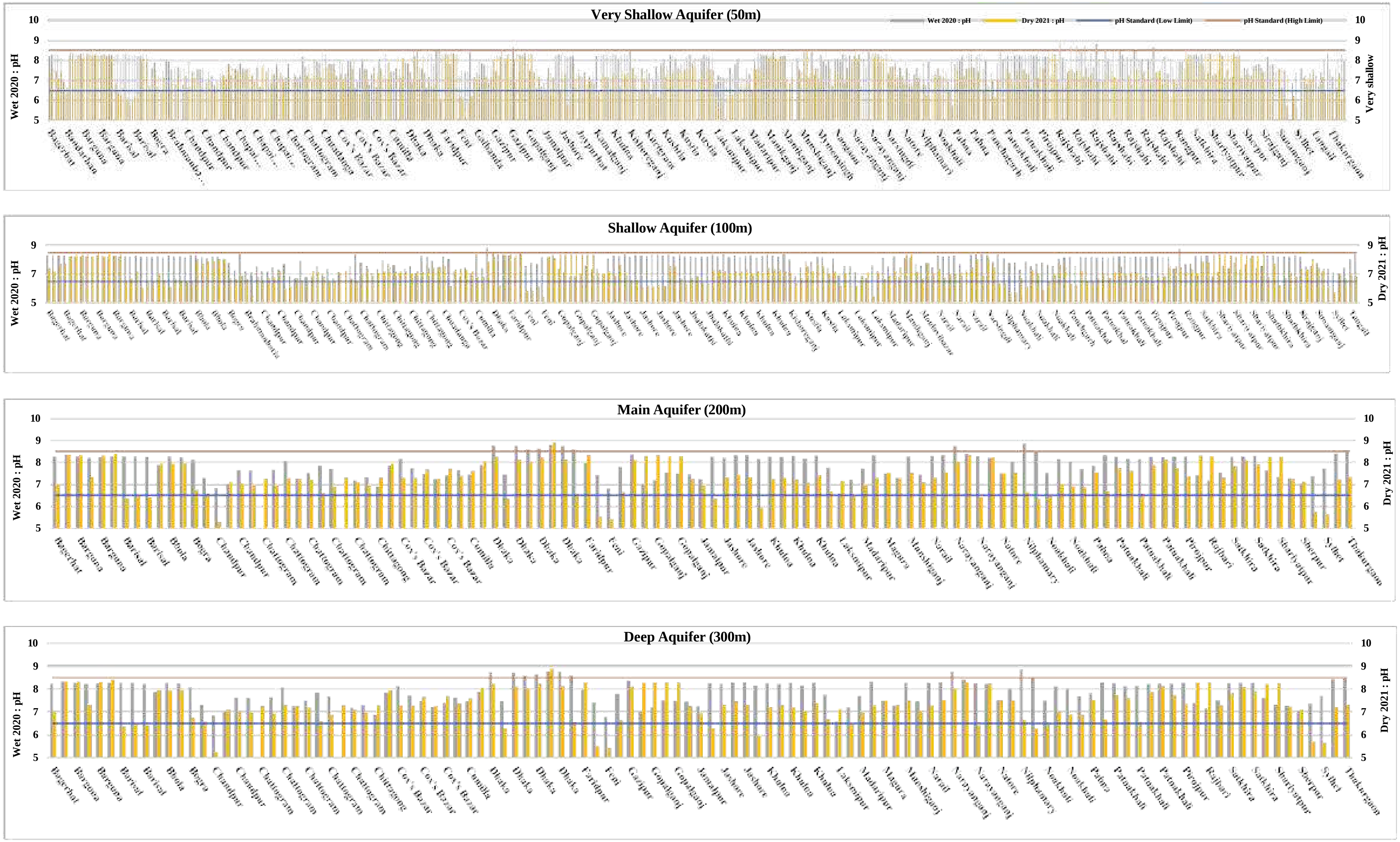


Figure 5-58: Groundwater pH at Different Depth levels in Bangladesh Groundwater.

Figure 5-59: DO Concentration at Different Depth levels in Bangladesh Groundwater.

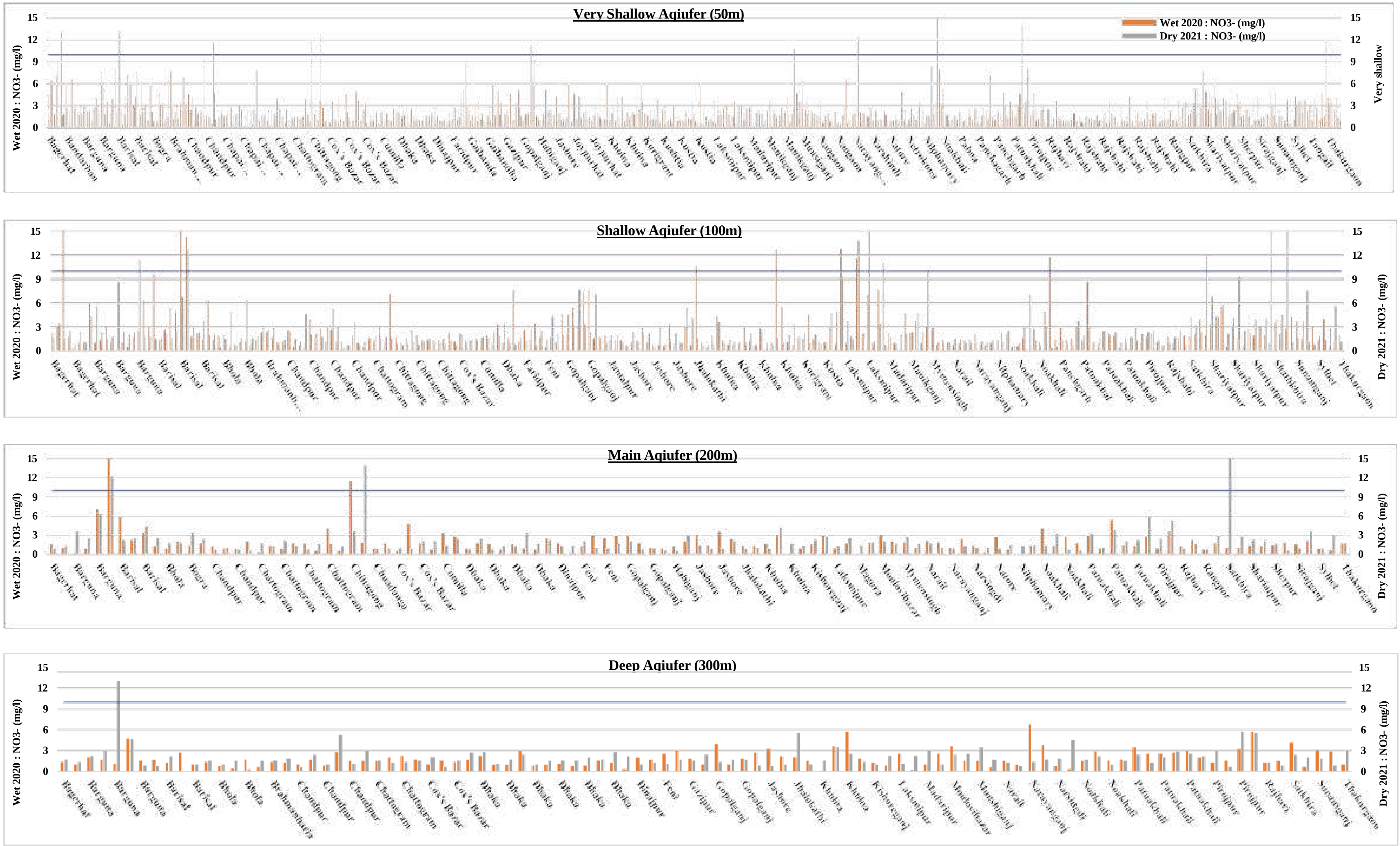
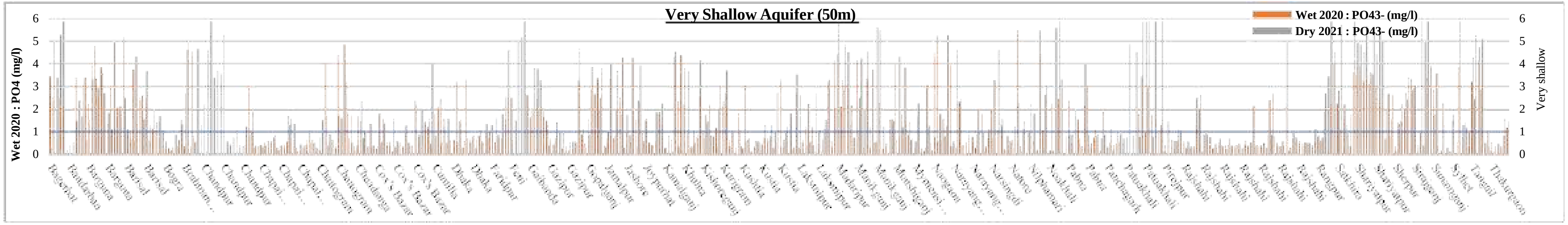
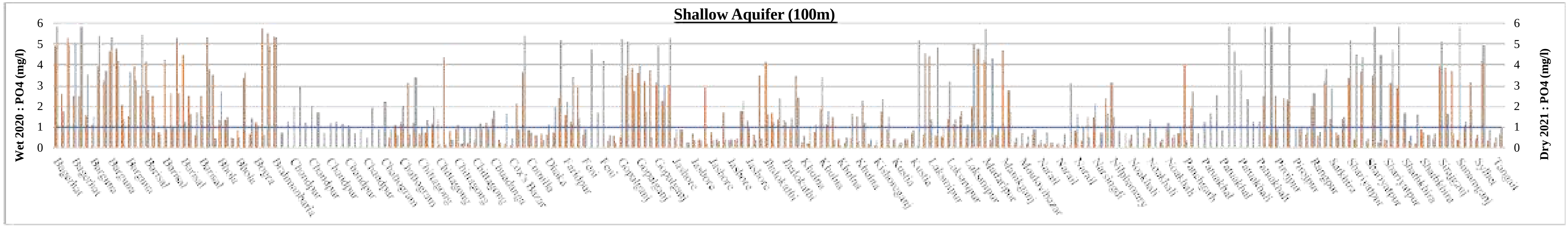
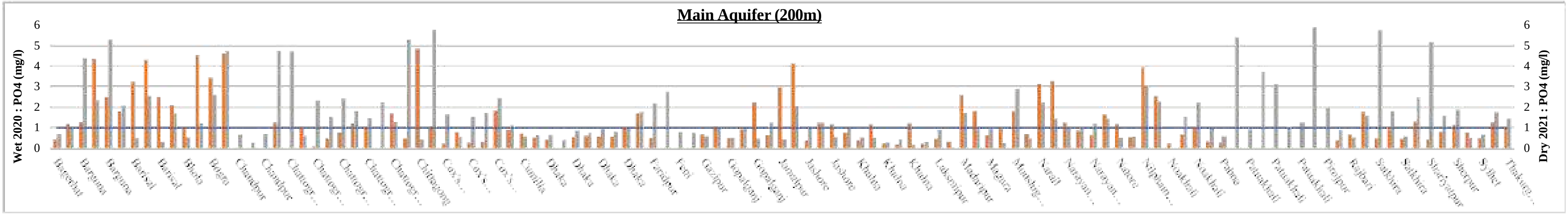


Figure 5-60: Groundwater Nitrate (NO_3) Concentration at Different Depth levels in Bangladesh Groundwater.


Very Shallow Aquifer (50m)


Shallow Aquifer (100m)


Main Aquifer (200m)

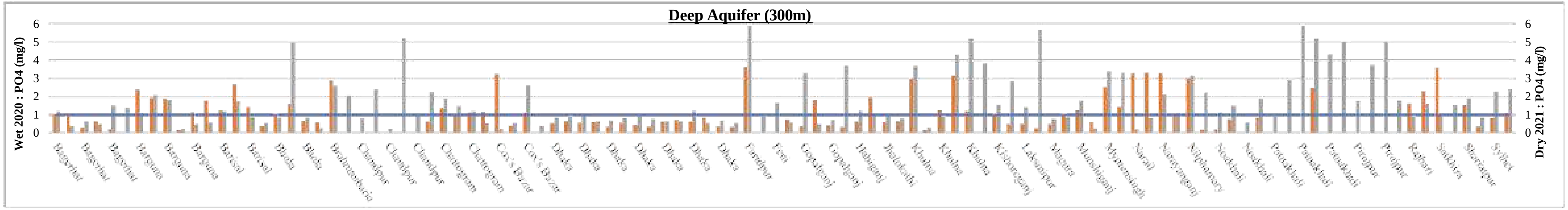

Deep Aquifer (300m)

Figure 5-61: Phosphate (PO_4) Concentration at Different Depth levels in Bangladesh Groundwater.

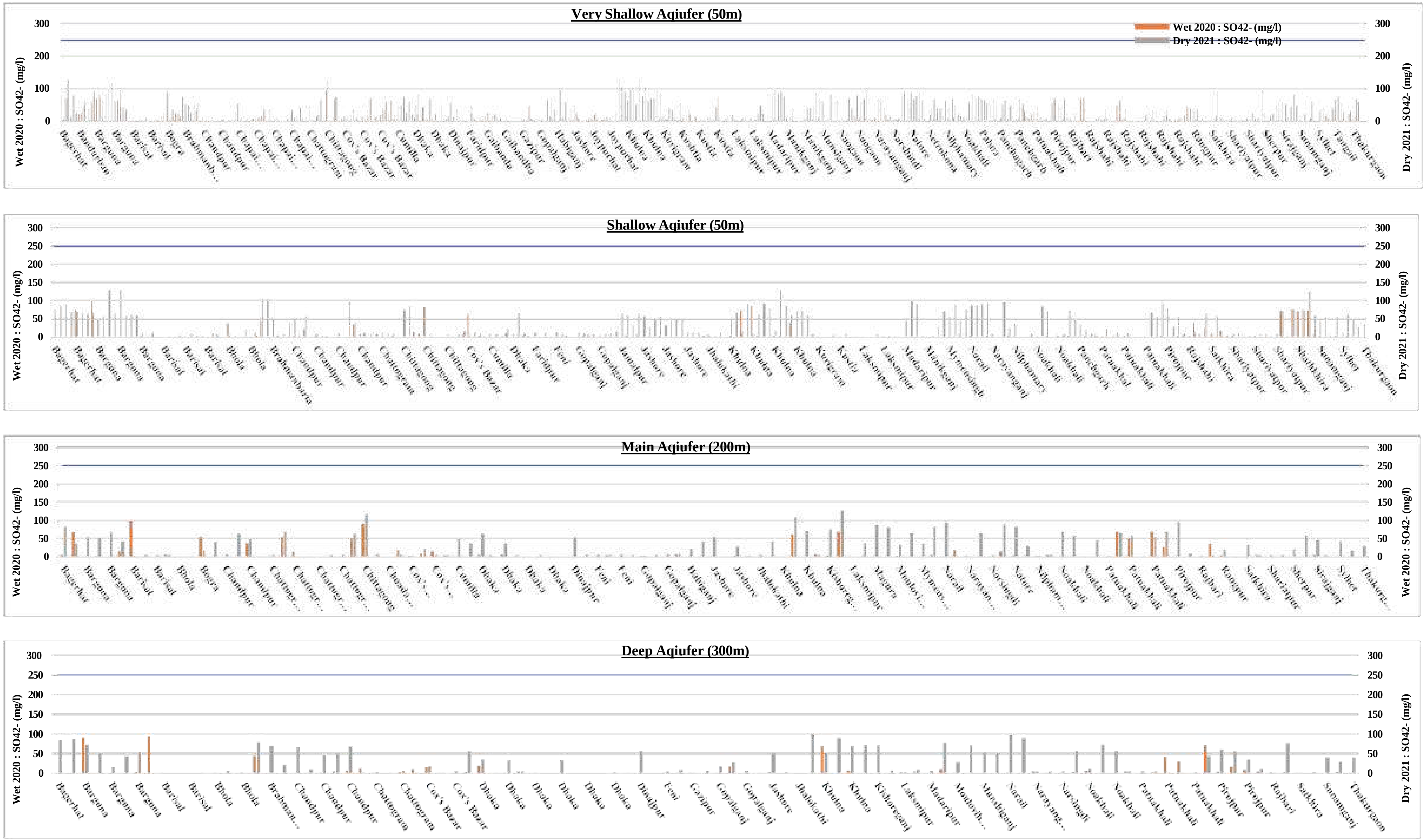


Figure 5-62: Groundwater Sulphate (SO_4) Concentration at Different Depth levels in Bangladesh Groundwater.

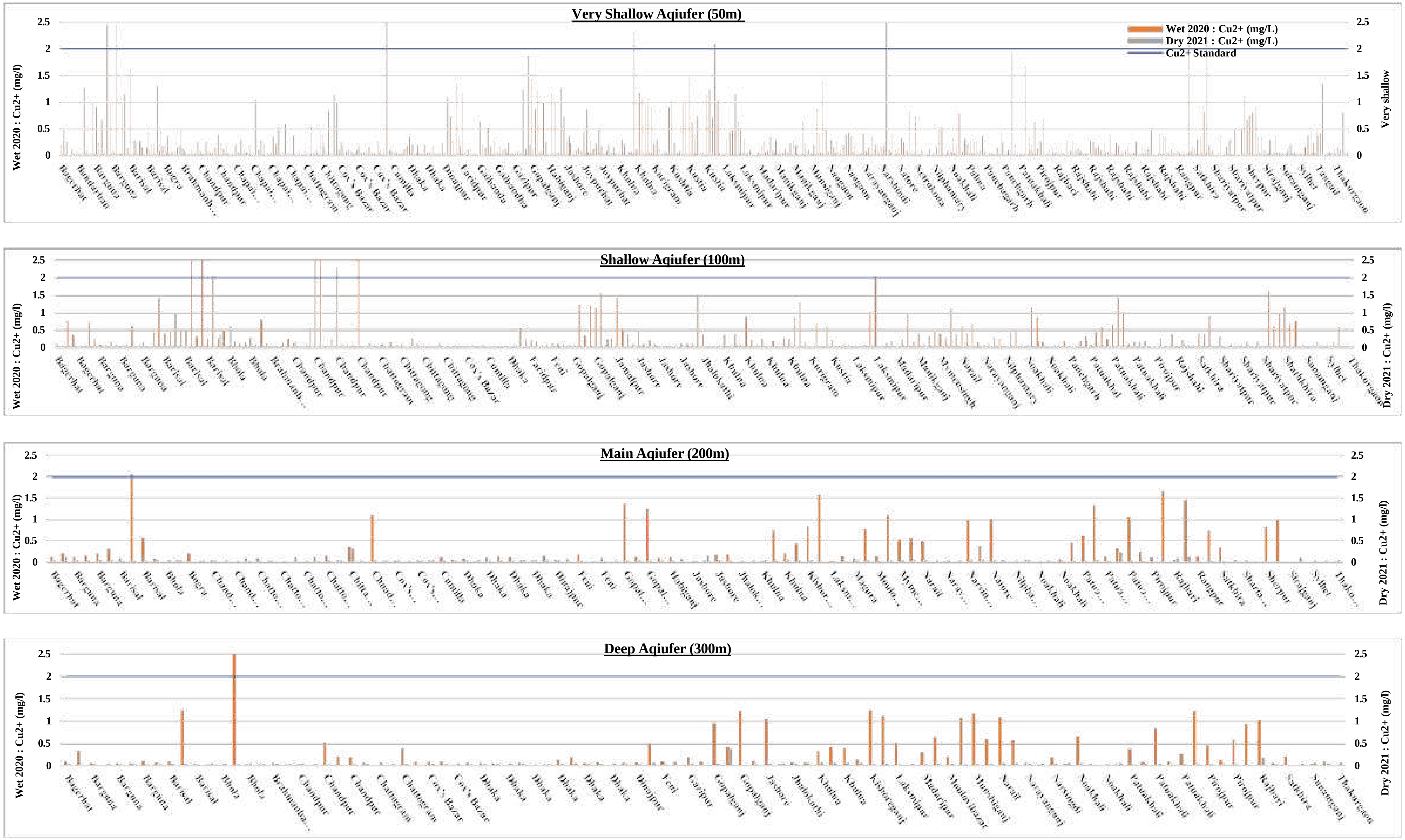


Figure 5-63: Copper (Cu) Concentration at Different Depth levels in Bangladesh Groundwater.

Figure 5-64: Carbonate (CO_3) Concentration at Different Depth levels in Bangladesh Groundwater.

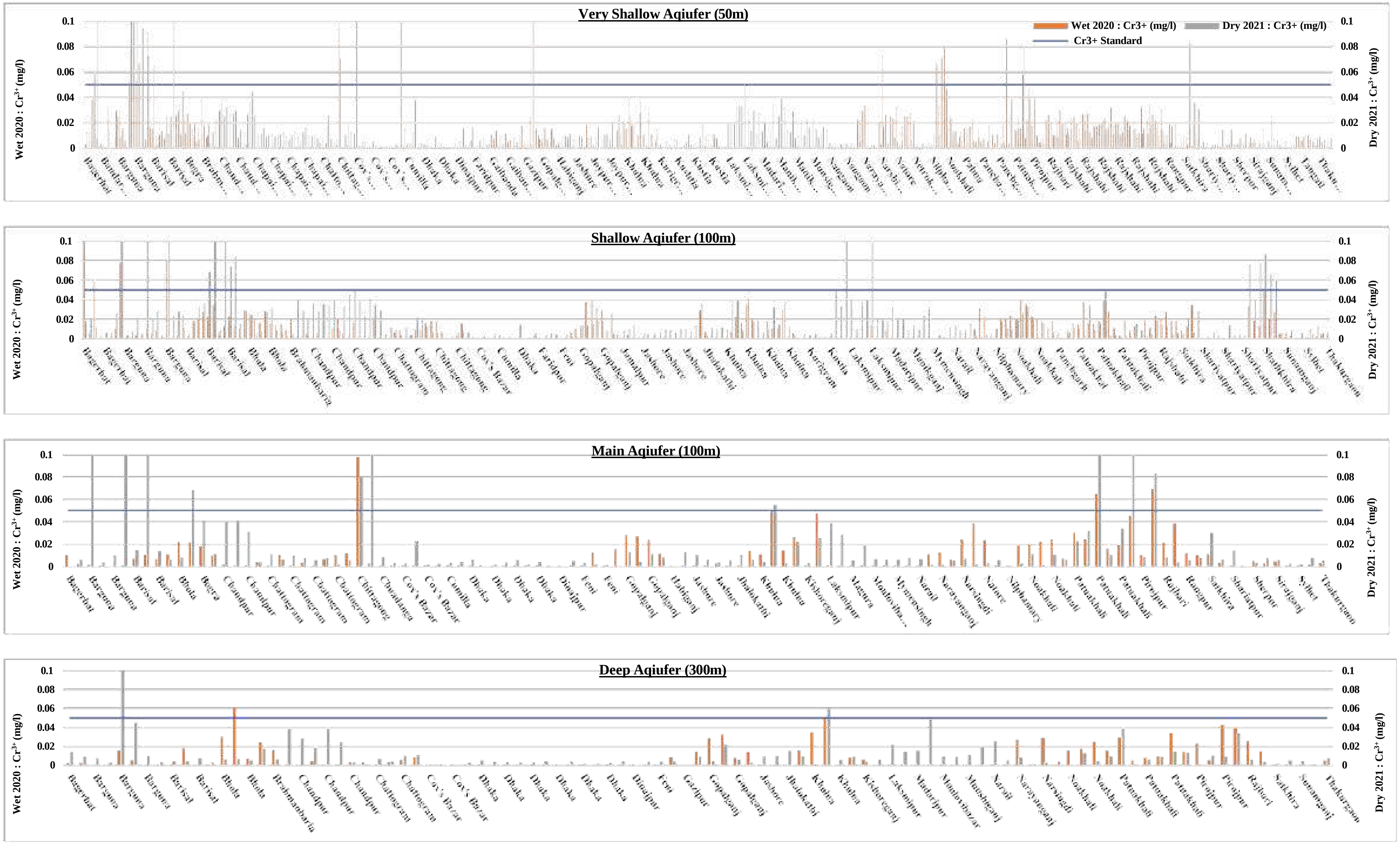


Figure 5-65: Chromium (Cr) Concentration at Different Depth levels in Bangladesh Groundwater.

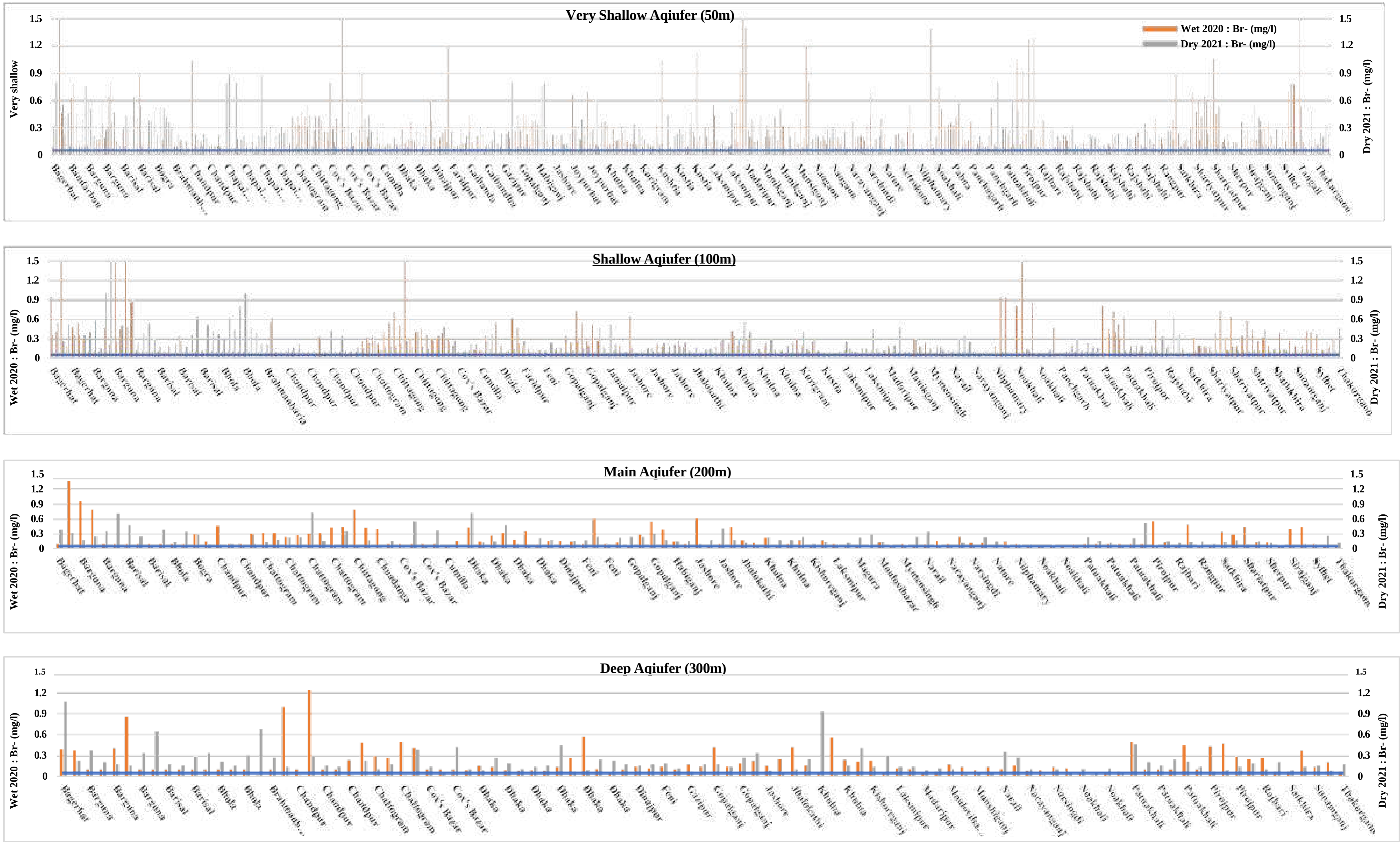


Figure 5-66: Bromine (Br) Concentration at Different Depth levels in Bangladesh Groundwater.

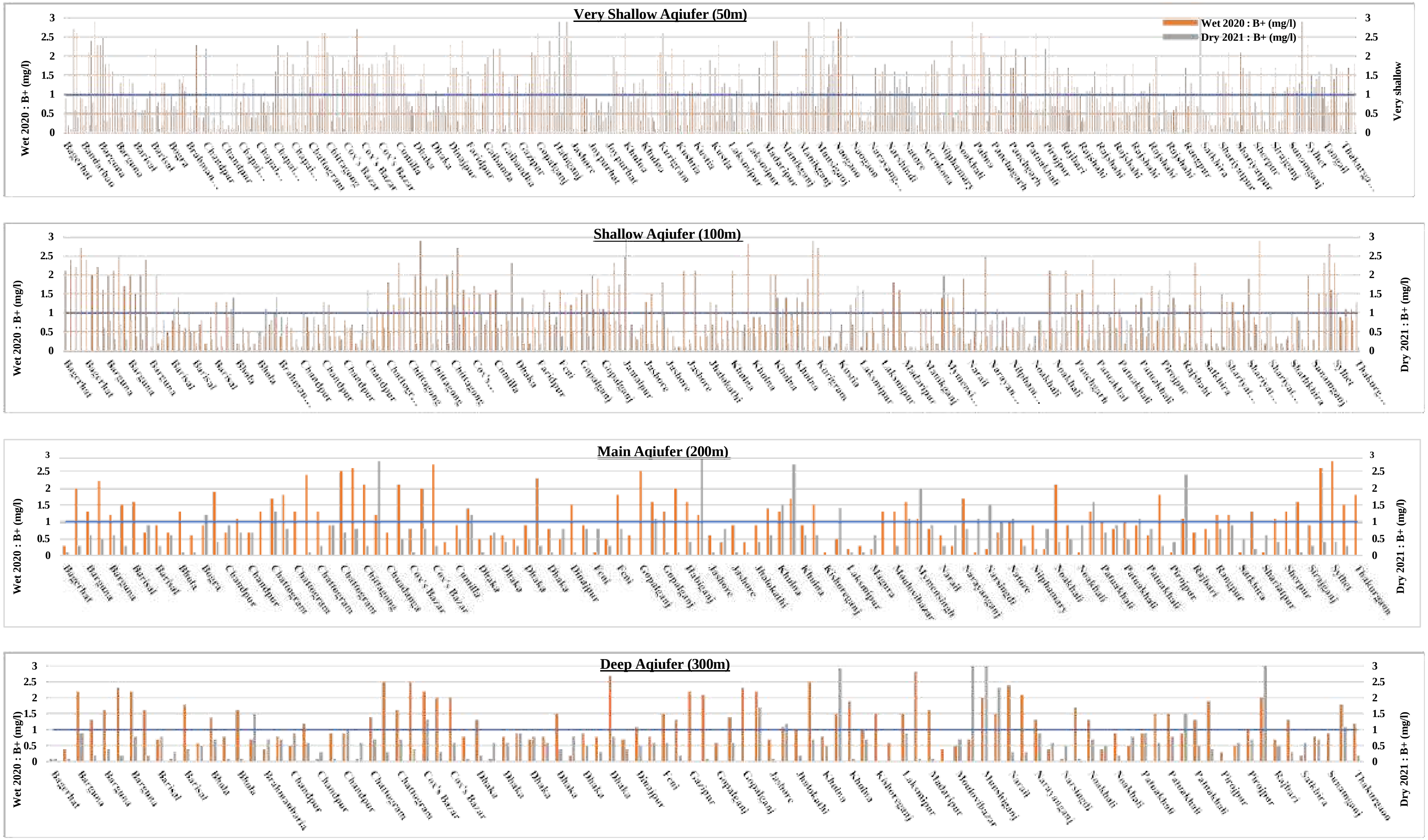
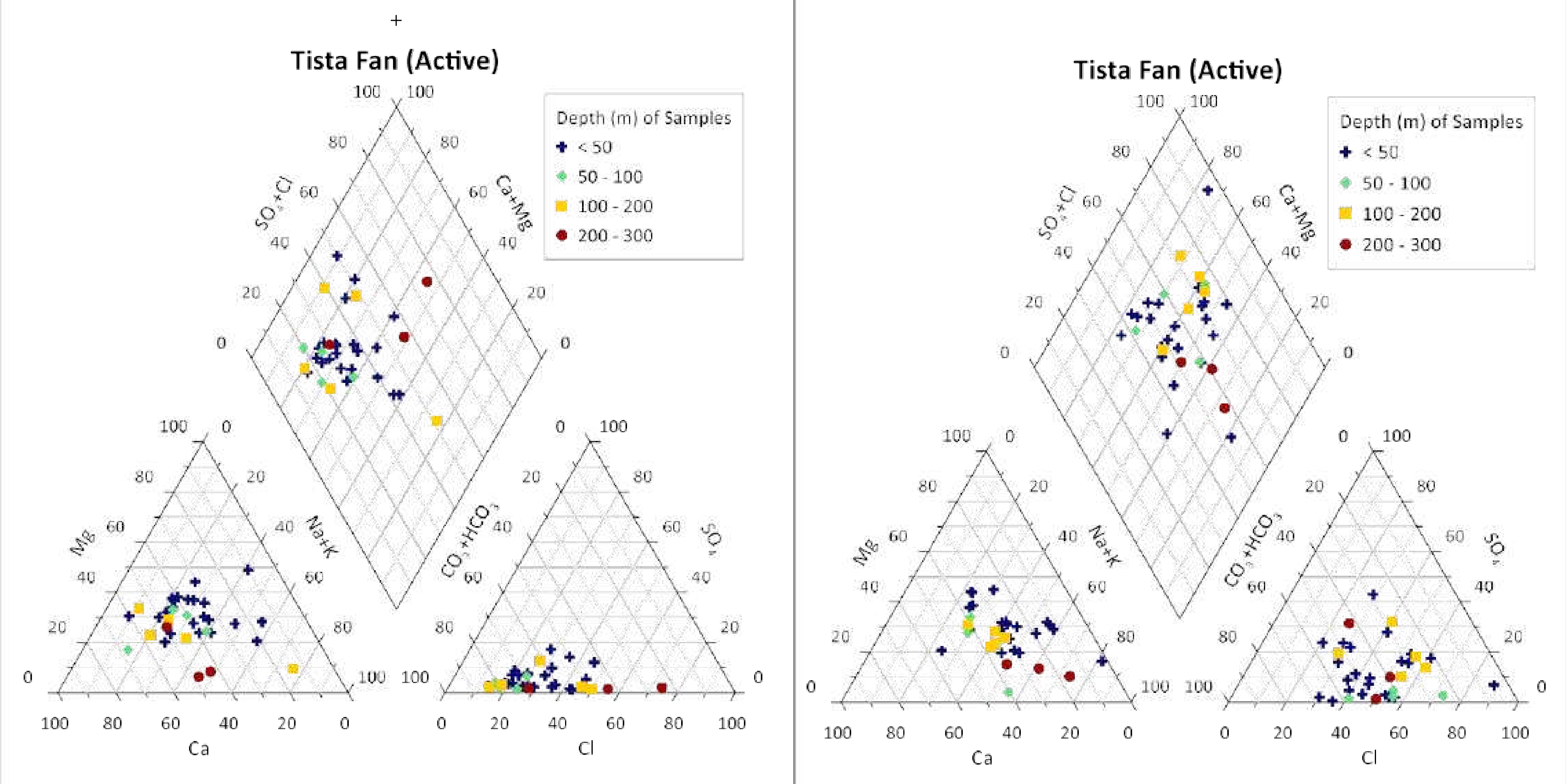


Figure 5-67: Boron (B) Concentration at Different Depth levels in Bangladesh Groundwater.

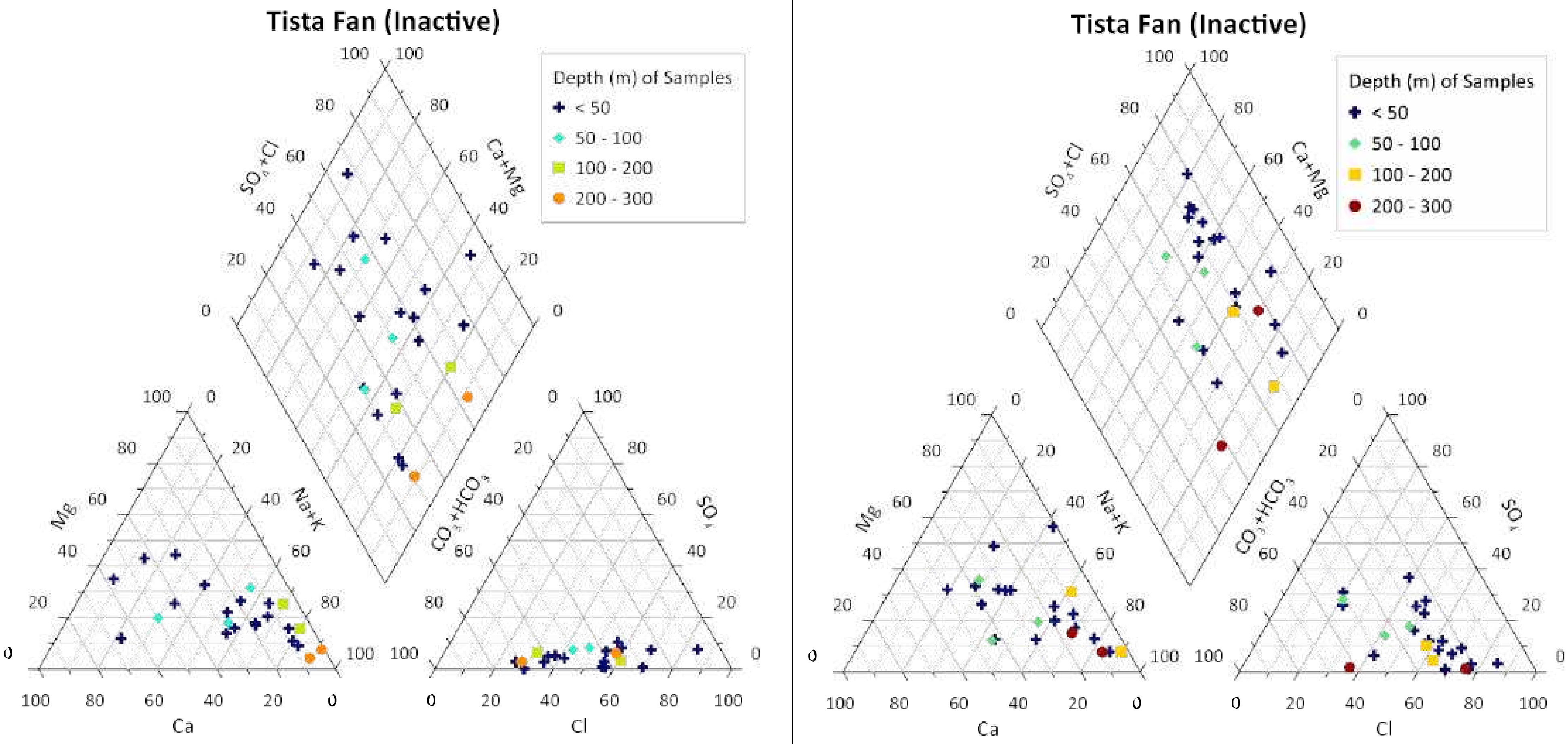
Annexure D



Wet Season 2020

Dry Season 2021

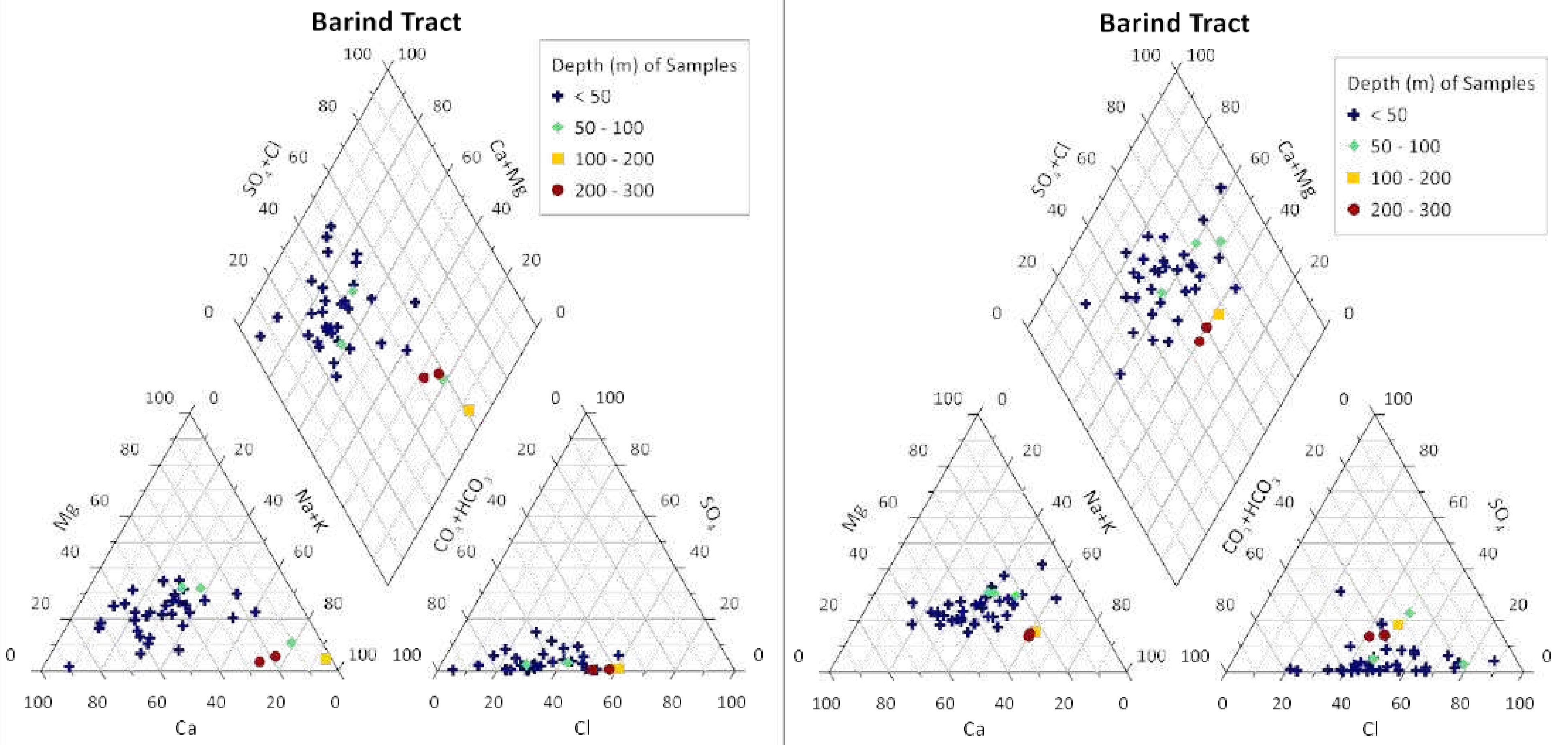
Figure 5-68: Piper Diagram of Groundwater Samples under Tista Fan (Active).



Wet Season 2020

Dry Season 2021

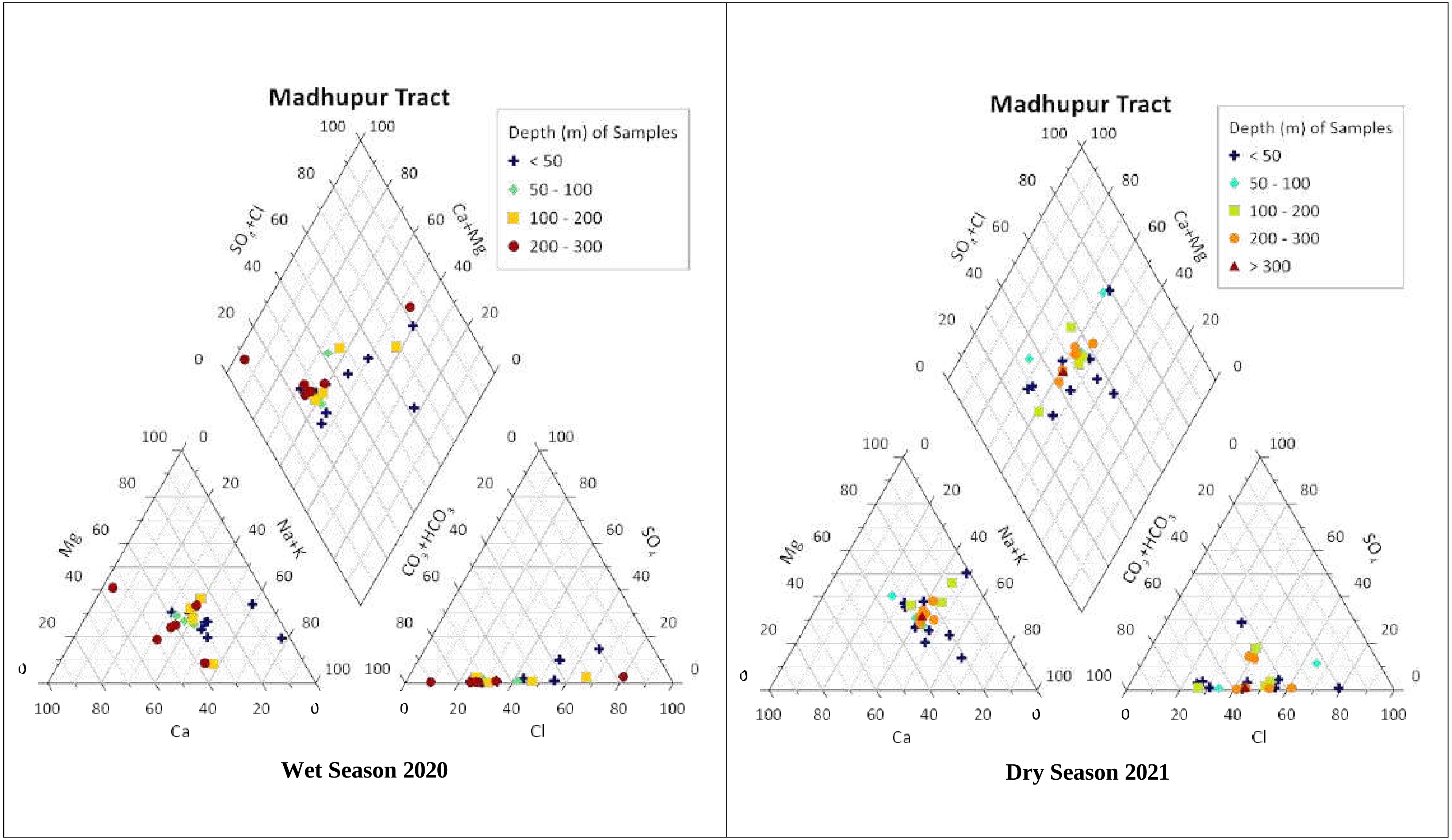
Figure 5-69: Piper Diagram of Groundwater Samples under Tista Fan (Inactive).



Wet Season 2020

Dry Season 2021

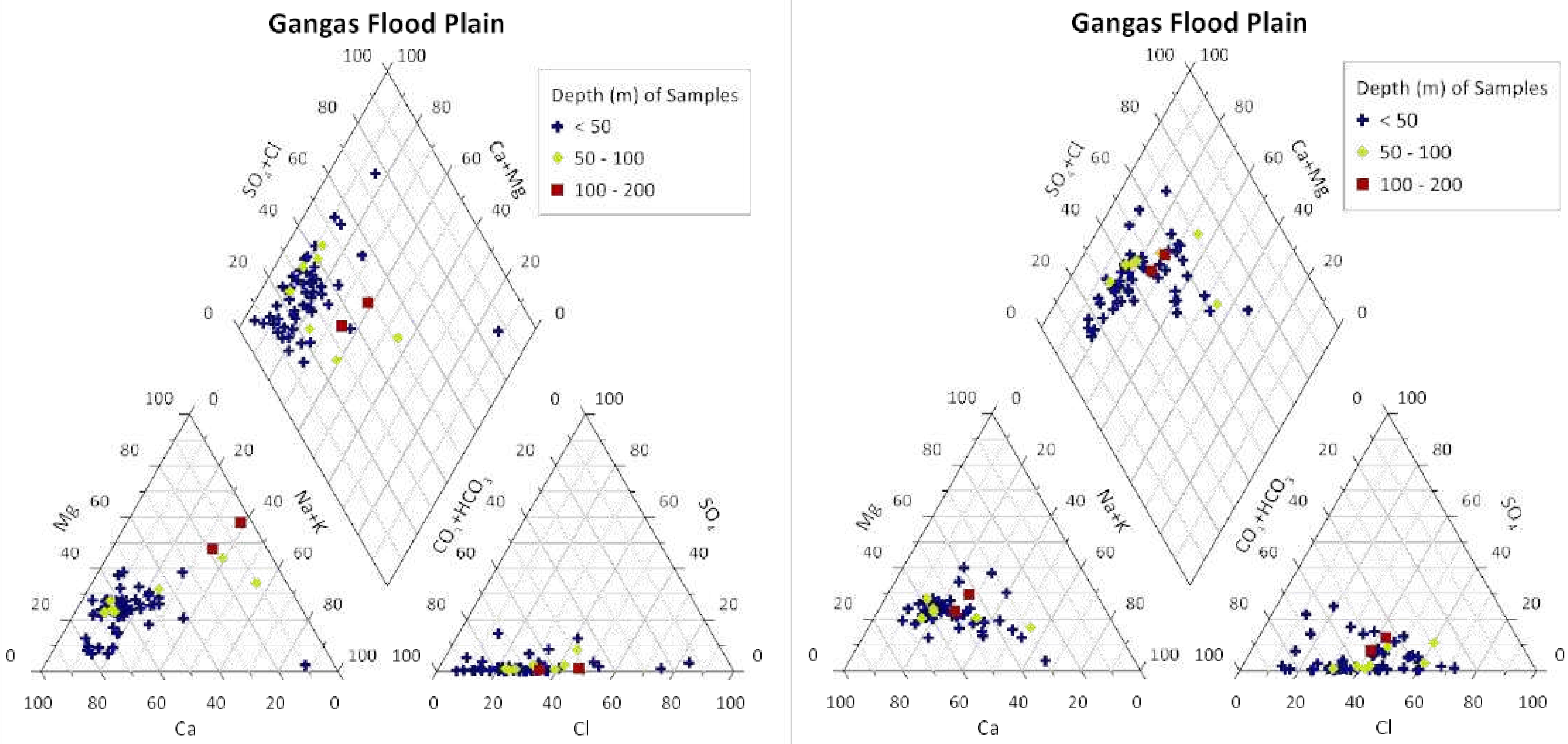
Figure 5-70: Piper Diagram of Groundwater Samples under Barind Tract.



Wet Season 2020

Dry Season 2021

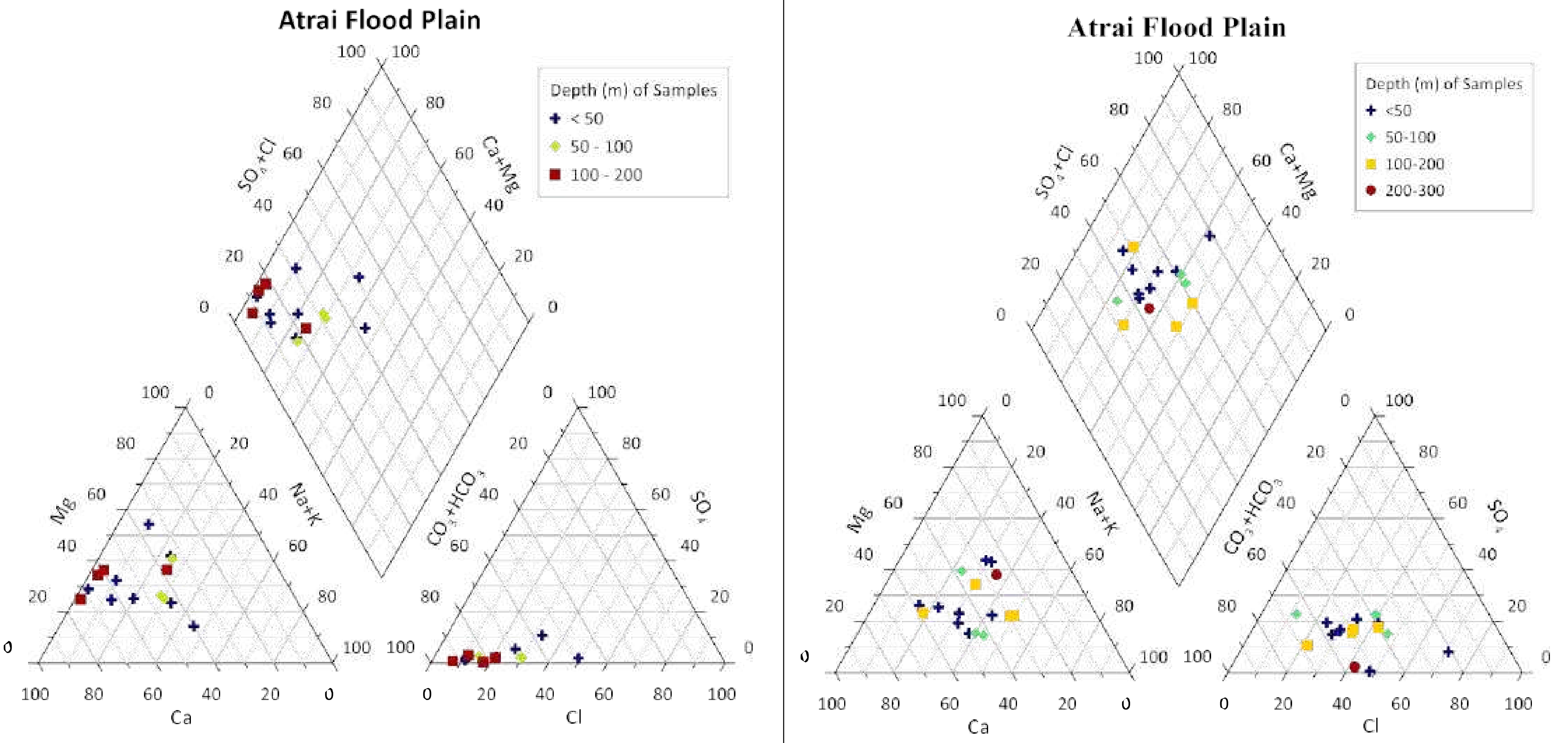
Figure 5-71: Piper Diagram of Groundwater Samples under Madhupur Tract.



Wet Season 2020

Dry Season 2021

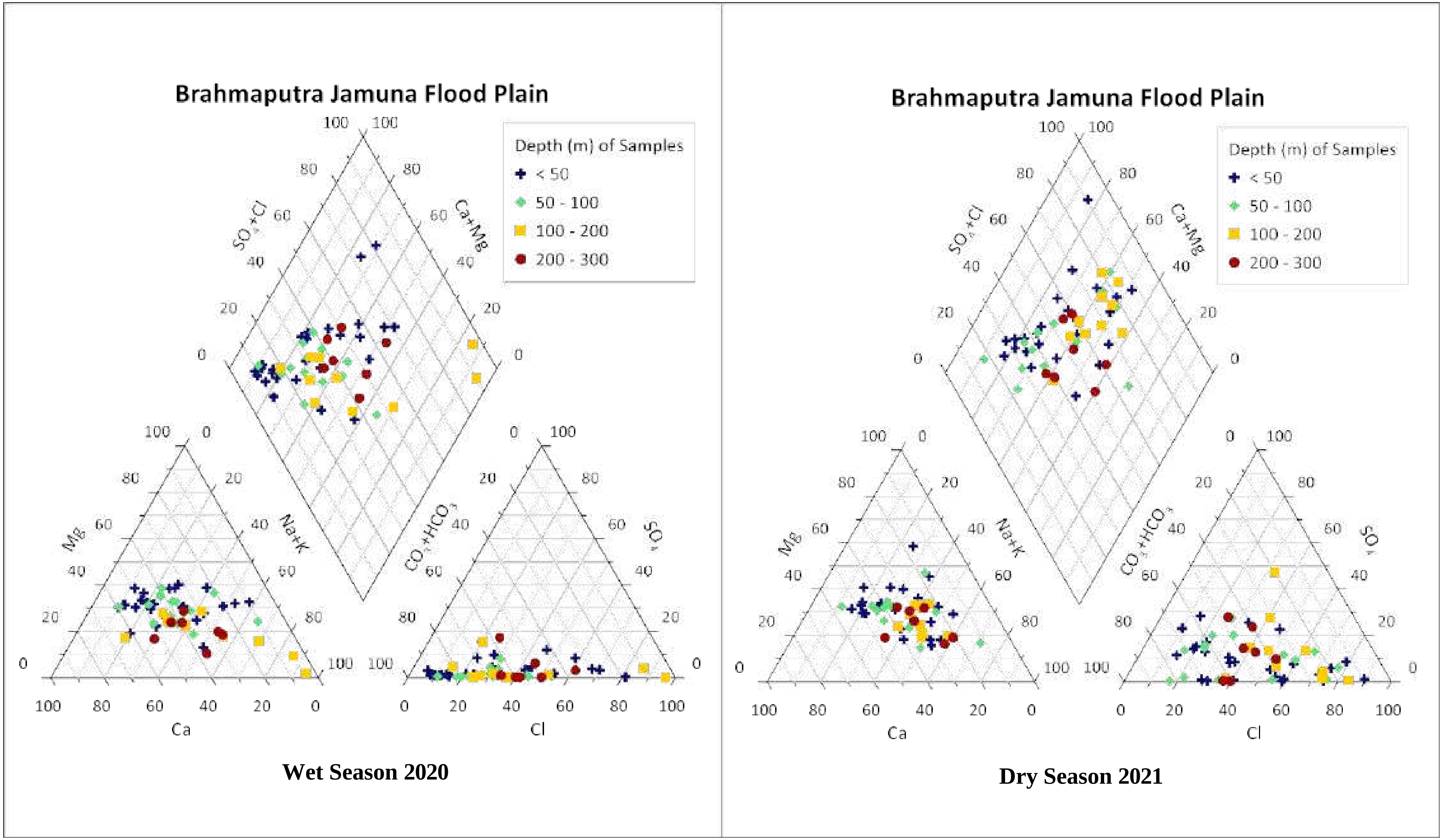
Figure 5-72: Piper Diagram of Groundwater Samples under Ganges Flood Plain.



Wet Season 2020

Dry Season 2021

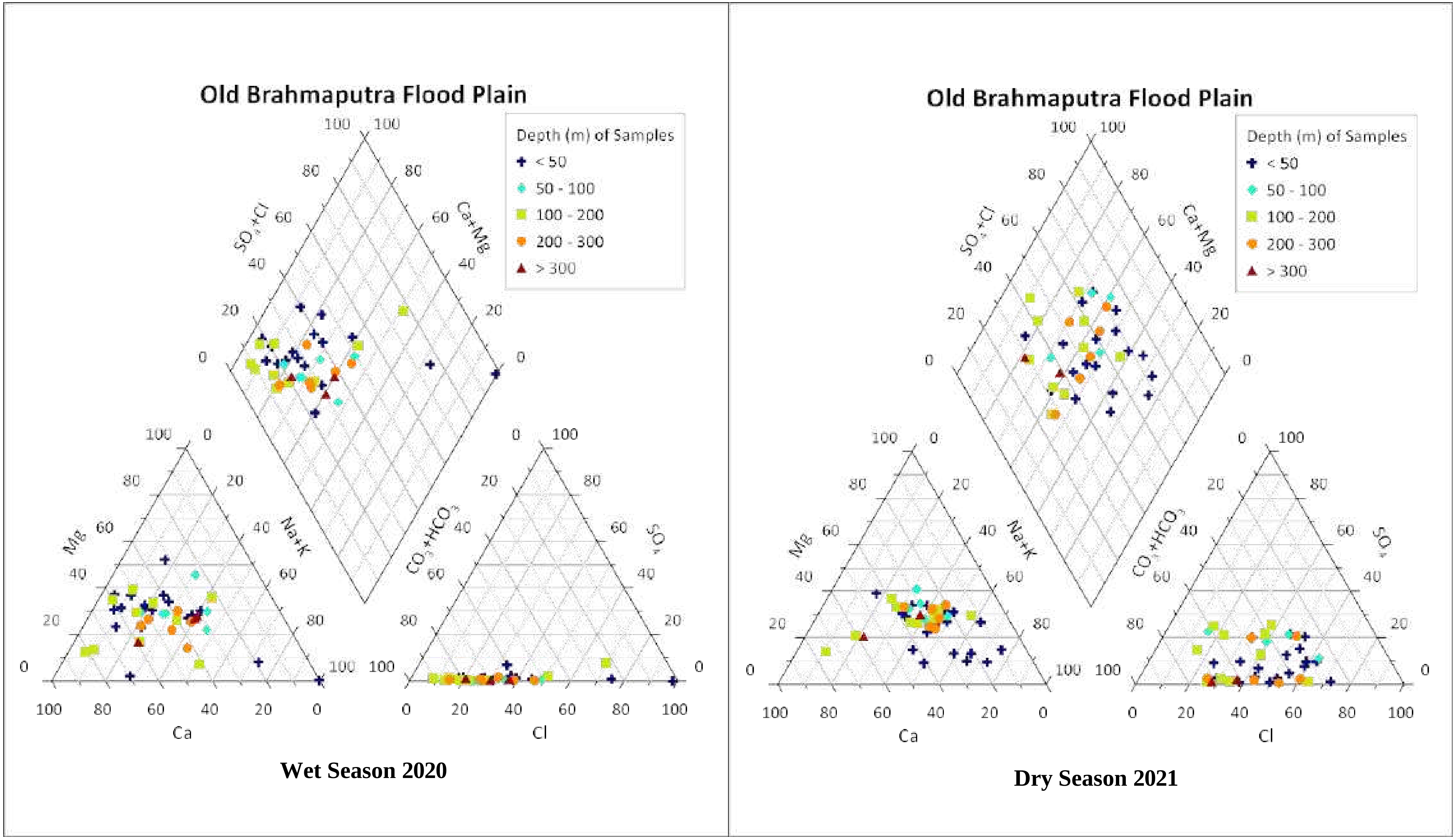
Figure 5-73: Piper Diagram of Groundwater Samples under Atrai Flood Plain.



Wet Season 2020

Dry Season 2021

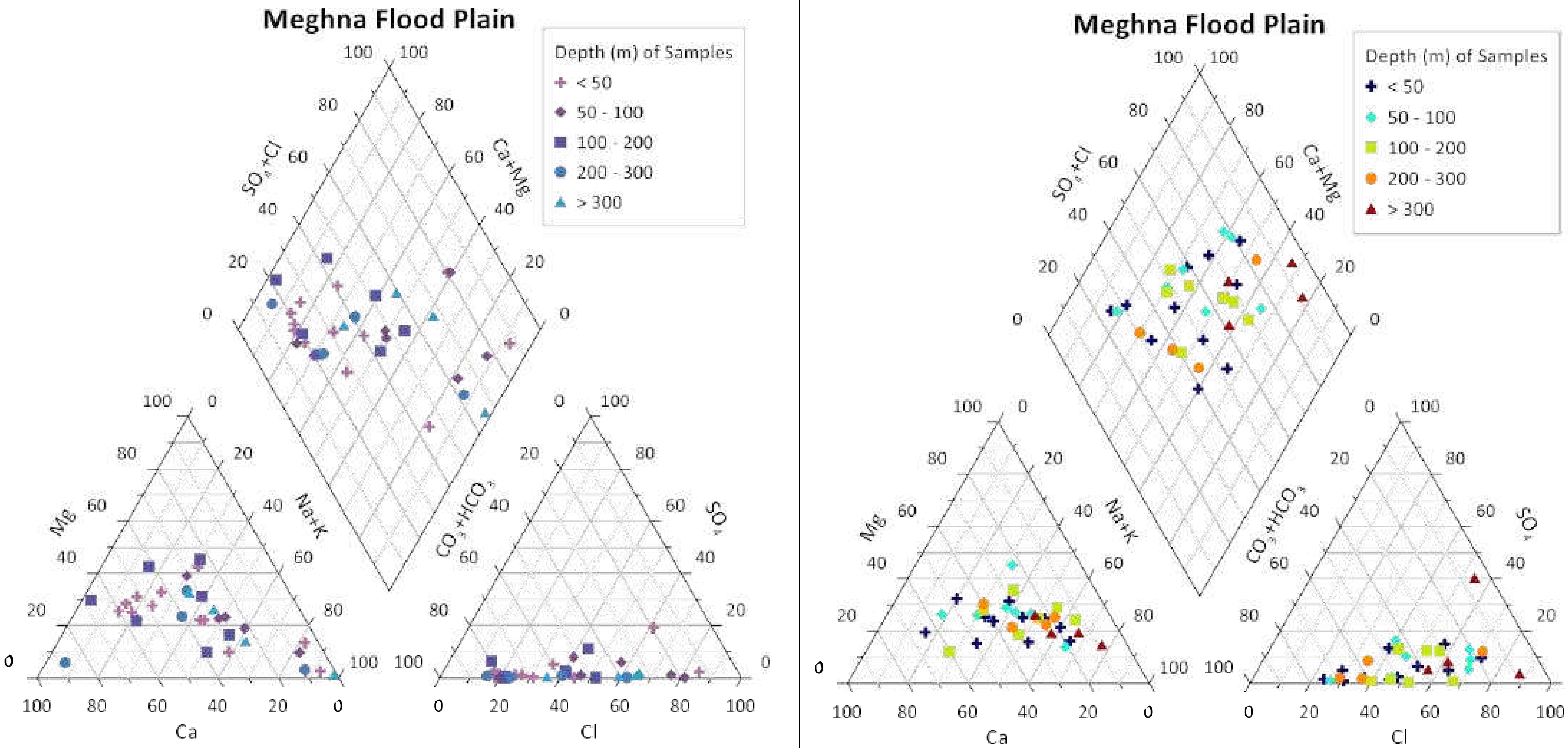
Figure 5-74: Piper Diagram of Groundwater Samples under Brahmaputra Jamuna Flood Plain.



Wet Season 2020

Dry Season 2021

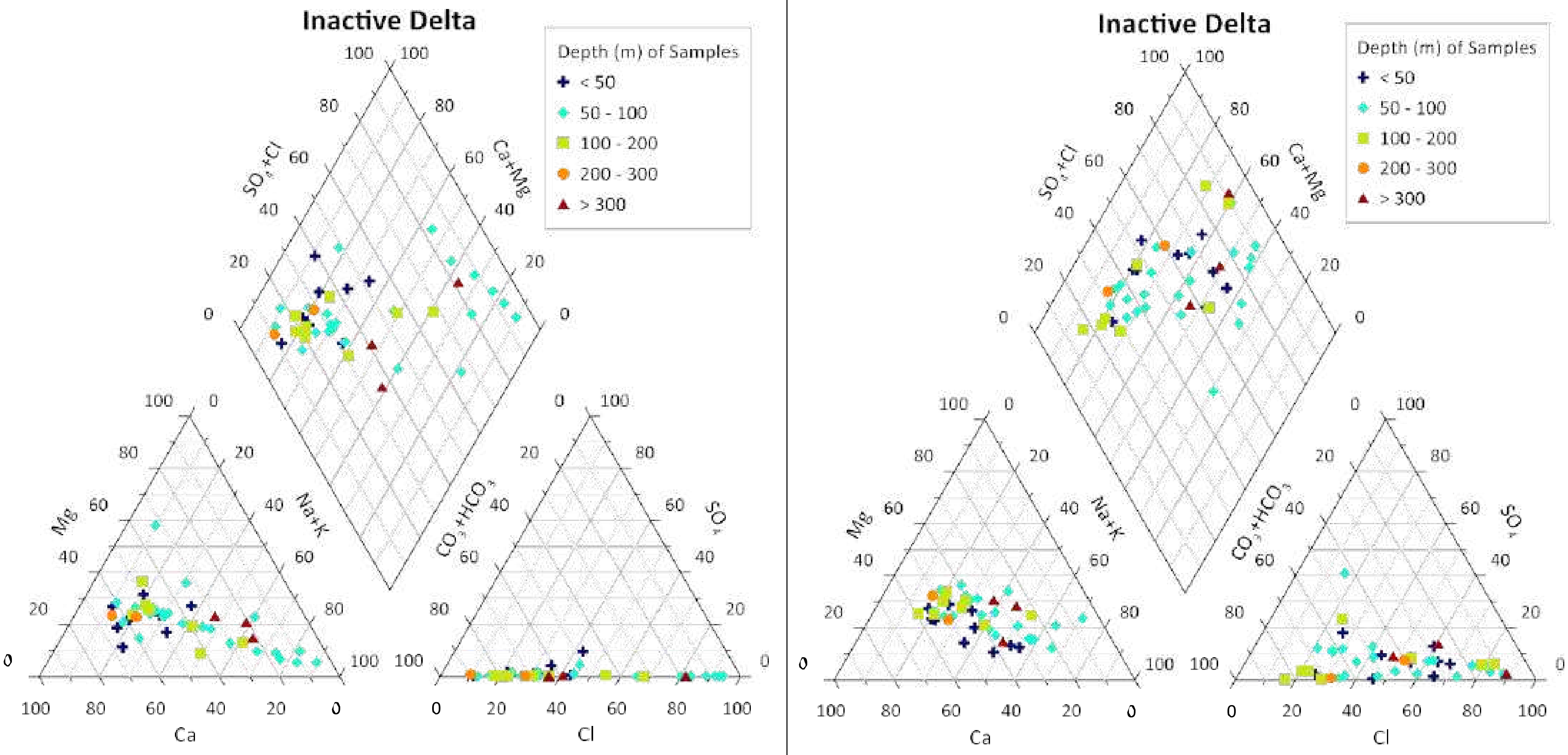
Figure 5-75: Piper Diagram of Groundwater Samples under Old Baahmaputra Flood Plain.



Wet Season 2020

Dry Season 2021

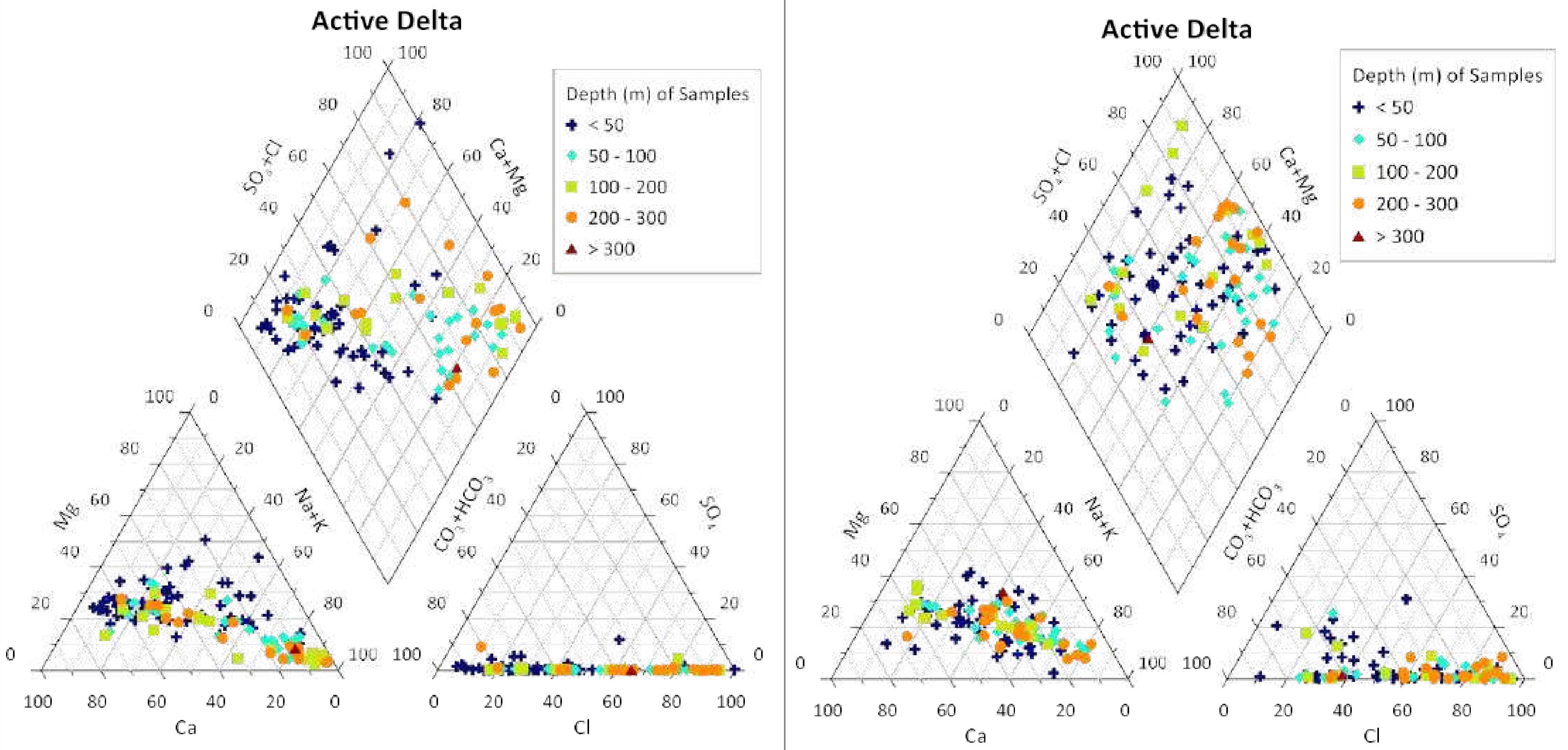
Figure 5-76: Piper Diagram of Groundwater Samples under Meghna Flood Plain.



Wet Season 2020

Dry Season 2021

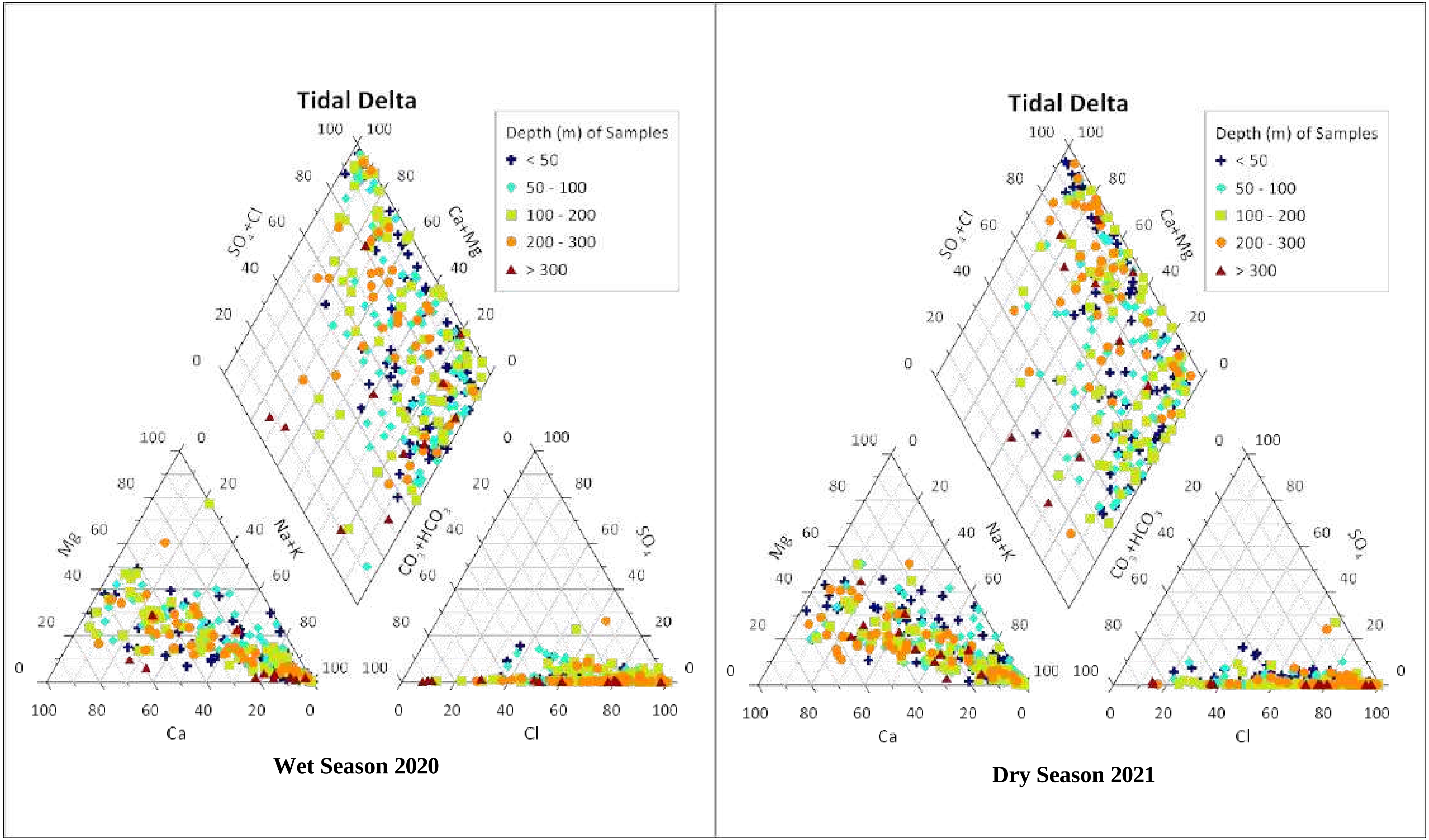
Figure 5-77: Piper Diagram of Groundwater Samples under Inactive Delta.



Wet Season 2020

Dry Season 2021

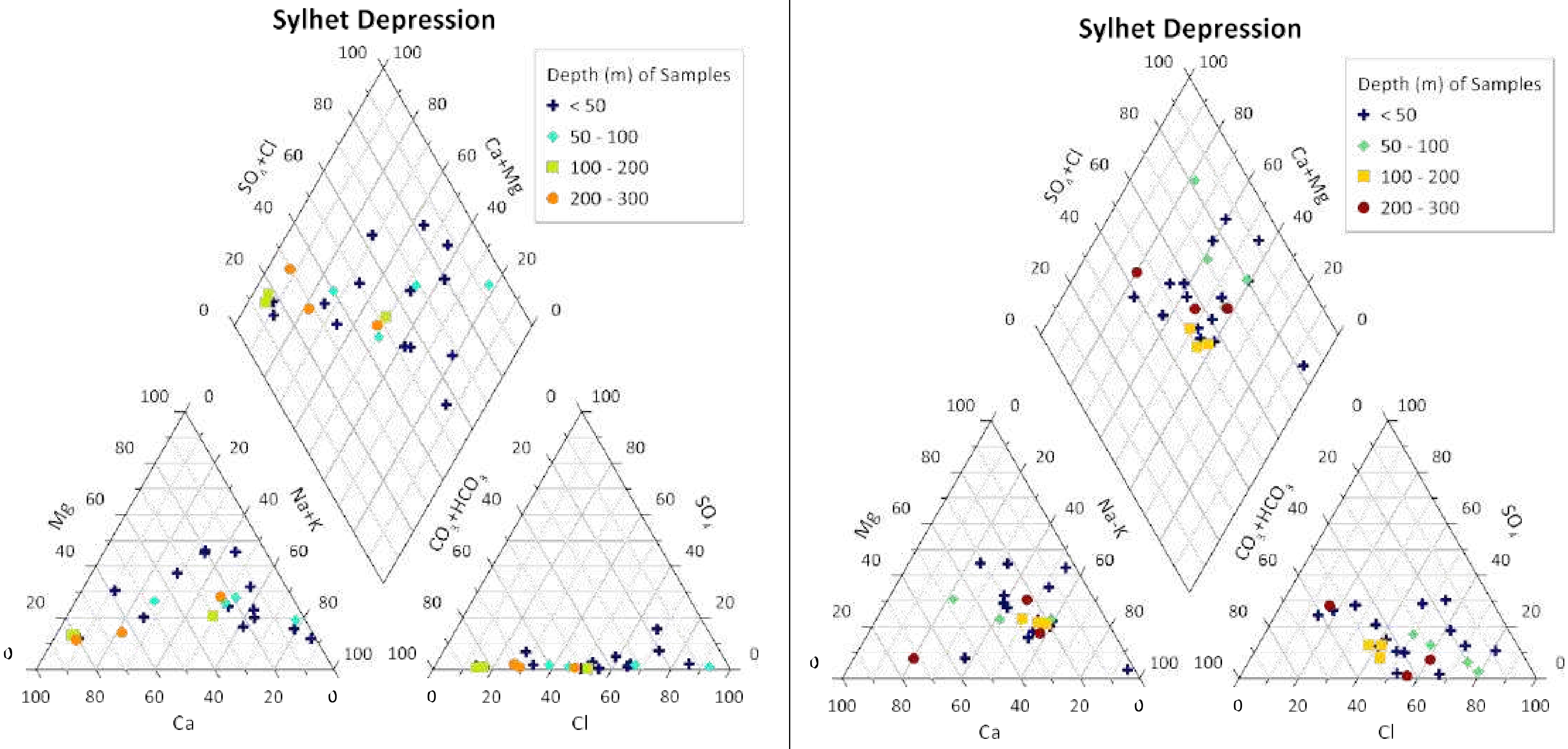
Figure 5-78: Piper Diagram of Groundwater Samples under Active Delta.



Wet Season 2020

Dry Season 2021

Figure 5-79: Piper Diagram of Groundwater Samples under Tidal Delta.

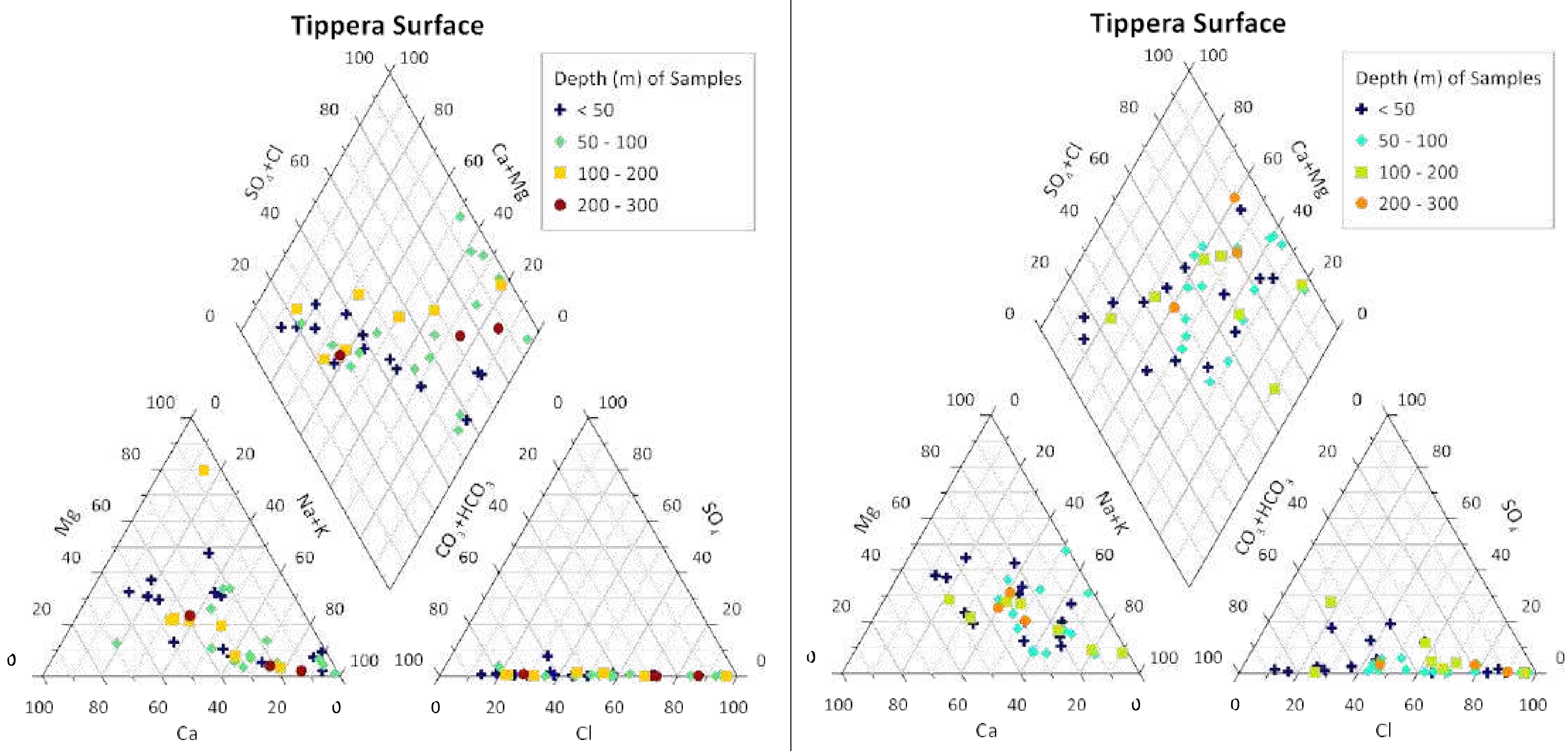

Sylhet Depression

Sylhet Depression

Wet Season 2020

Dry Season 2021

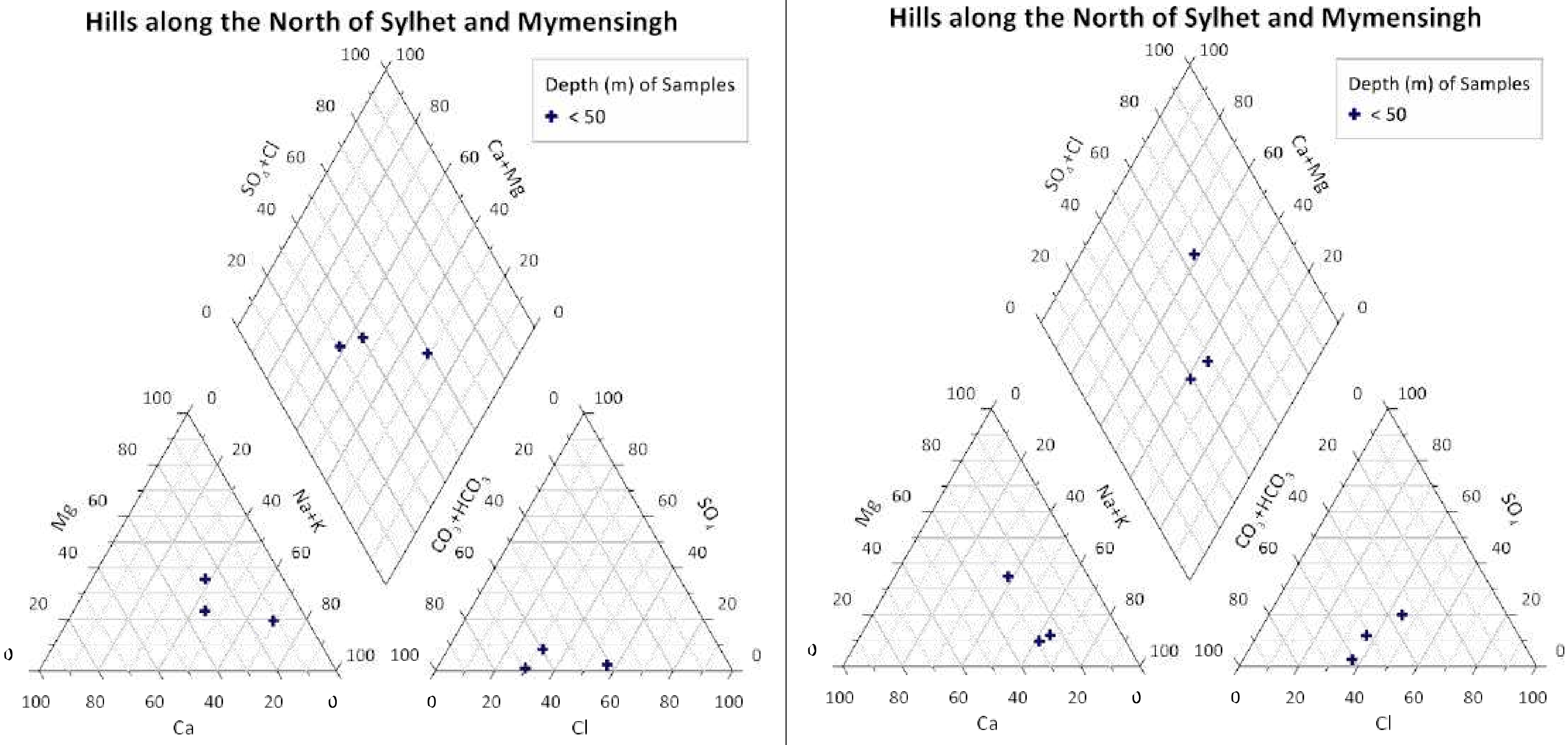
Figure 5-80: Piper Diagram of Groundwater Samples under Sylhet Depression.



Wet Season 2020

Dry Season 2021

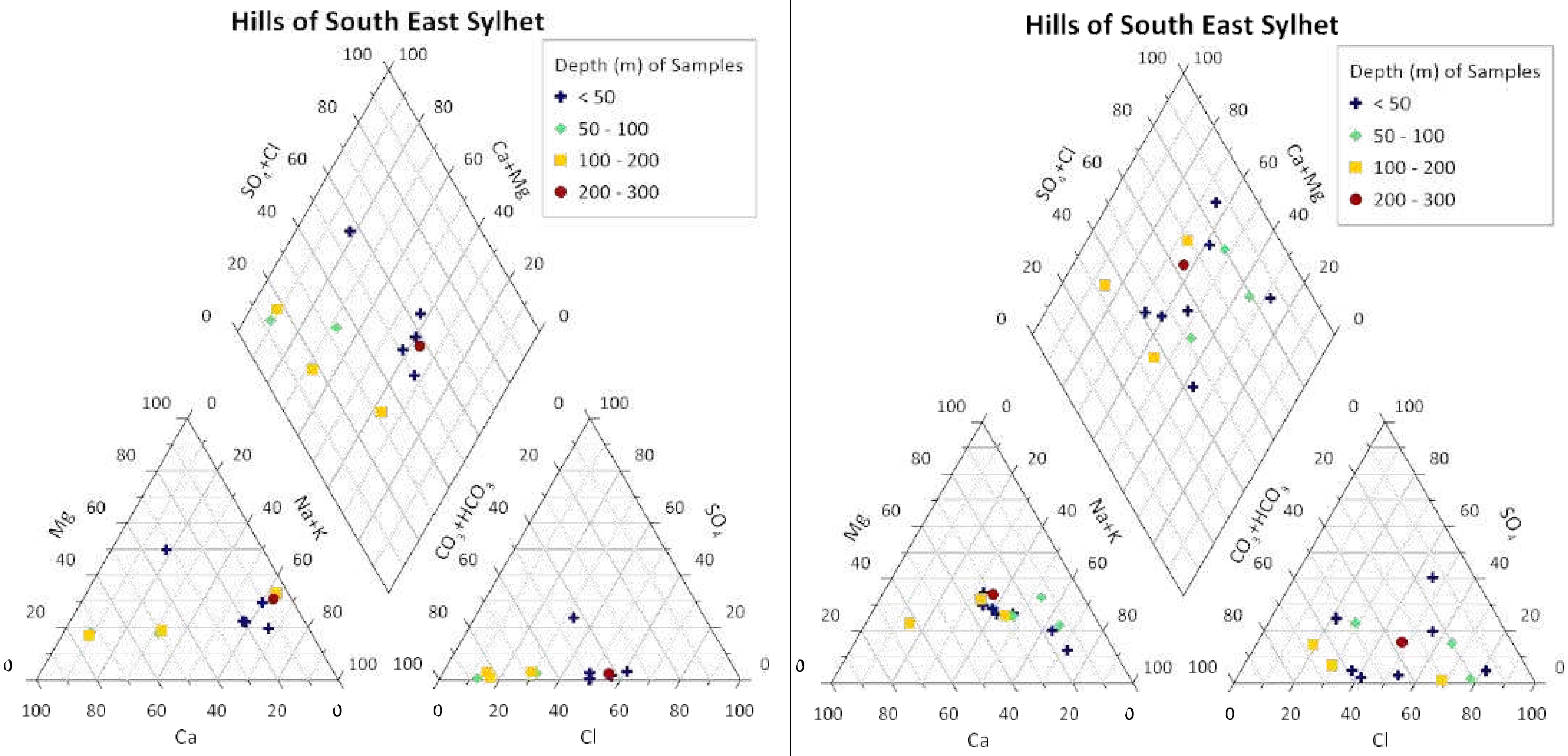
Figure 5-81: Piper Diagram of Groundwater Samples under Teppera Surface.



Wet Season 2020

Dry Season 2021

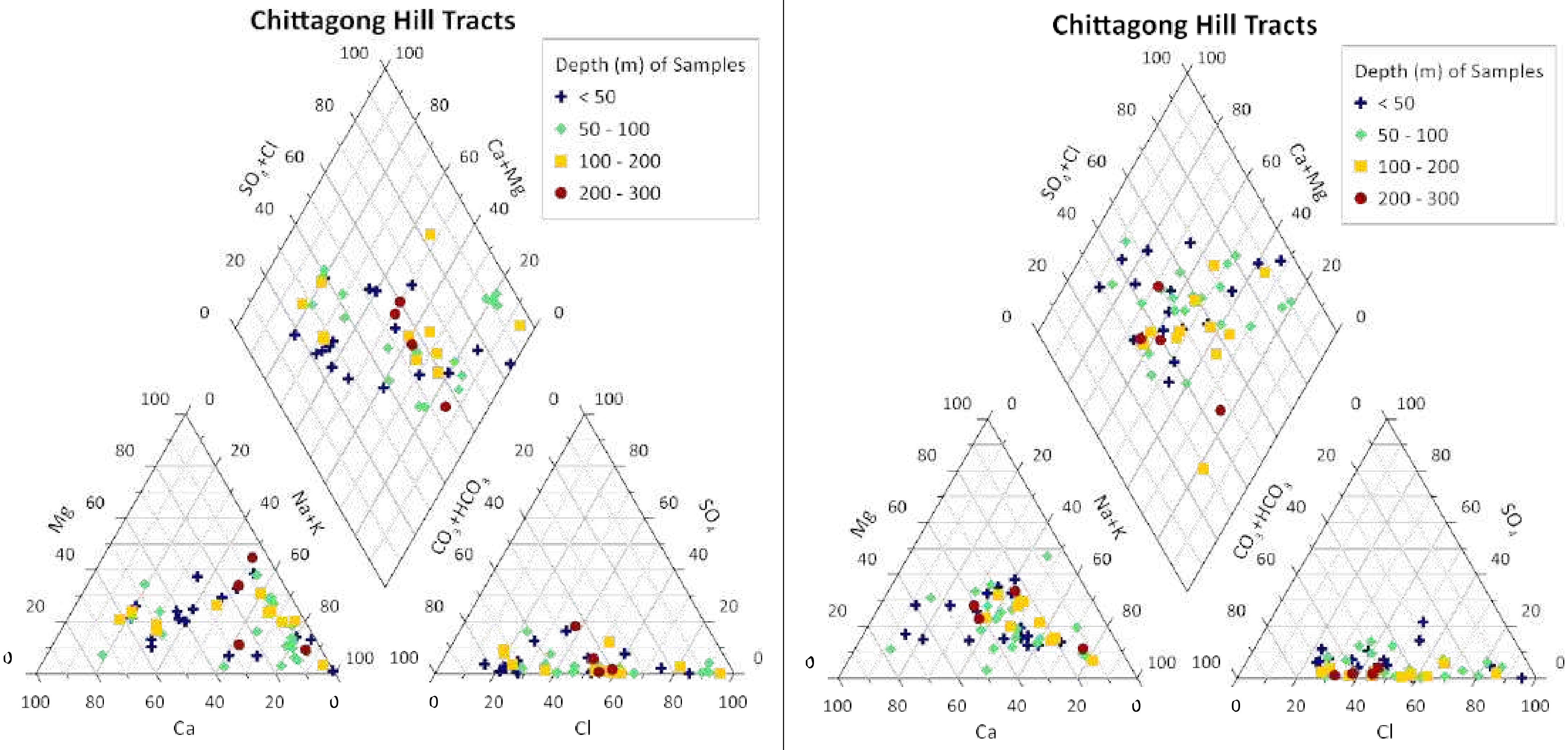
Figure 5-82: Piper Diagram of Groundwater Samples under Hills along North of Sylhet and Mymensingh.



Wet Season 2020

Dry Season 2021

Figure 5-83: Piper Diagram of Groundwater Samples under Hills of South East Sylhet.



Wet Season 2020

Dry Season 2021

Figure 5-84: Piper Diagram of Groundwater Samples under Chattogram Hill Tract.