A Dissertation on

MULTIVARIATE DATA ANALYSIS OF GROUNDWATER AND DEVELOPMENT OF SOLUTE TRANSPORT USING HYDRUS-1D IN DEEPOR BEEL AREA

Submitted in Partial Fulfillment for the Requirements for the award of the Degree of

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CANDIDATE DECLARATION

(Session: 2021-2023)

I hereby declare that the work presented in the dissertation entitled **“MULTIVARIATE DATA ANALYSIS OF GROUNDWATER AND DEVELOPMENT OF SOLUTE TRANSPORT USING HYDRUS-1D IN DEEPOR BEEL AREA”** in the partial fulfillment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in water Resources Engineering submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13, under Assam Science and Technology University, has been carried out by me under the supervision of **Dr. (Mrs.) Triptimoni Borah,** Professor, Department of Civil Engineering, Assam Engineering College, Guwahati. Whatever I have presented in this report has not been submitted by me for the award of any other degree or diploma.

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CERTIFICATE OF SUPERVISION

(Session: 2021-2023)

This is to certify that the work contained in the report entitled **“MULTIVARIATE DATA ANALYSIS OF GROUNDWATER AND DEVELOPMENT OF SOLUTE TRANSPORT USING HYDRUS-1D IN DEEPOR BEEL AREA”** has been carried out by Dibyajyoti Kalita, Roll No:210620061004, a student of M. Tech 4th semester in the Department of Civil Engineering, Assam Engineering College, Guwahati, under my guidance and supervision and submitted in the partial fulfilment of the requirement for the award of degree of Masters of Technology in Civil Engineering with specialization in Water Resources engineering under Assam Science and Technology University.

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ABSTRACT

Deepor Beel is a prominent and popular wetland located in the city of Guwahati in the state of Assam. Notably, it is the only Ramsar site present in the state. It is known for its rich biodiversity that it withholds along with its scenic beauty. But due to increasing pollution and other human activities, it has led to the deterioration of the water quality of this very wetland.

The present study was carried out to analyse the physio-chemical groundwater quality parameters of the beel and to run a multivariate data analysis in IBM SPSS software in order to check any relationship among each other. The multivariate analysis carried out for our study area includes one way ANOVA, Hierarchical Cluster Analysis (HCA), Principal Component Analysis (PCA) and K-Means Cluster Analysis available in the IBM SPSS software package. A total of twelve parameters viz. Water temperature, Dissolved Oxygen, Biological Oxygen Demand, pH, Turbidity, Total Hardness, Chloride Content, Total Dissolved Solids, Salinity, Conductivity, Iron content, Nitrate content and Lead content were tested for nine sampling locations in and around the areas of Deepor Beel. The water collected for testing were obtained from various sources like tube well, handpumps and ring wells within different ranges of availability. Standard methods were followed for the collection, sampling, and analysis of the groundwater quality parameter. Further in our report, the solute movement through the ground surface was studied using HYDRUS 1D modelling. The solute considered for our study area includes iron as it has a different concentration from the other parameters. The sampling location selected for this modelling includes site number seven near boragaon dumping area as it shows large movement of leachate from the nearby landfill zone.

Keywords- Physico-chemical groundwater quality parameters, SPSS software, one way analysis (ANOVA), HCA, PCA, K-Means cluster, HYDRUS 1D

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Wetlands are among the world's most productive environments. Deepor Beel is a permanent fresh water lake and the only Ramsar site in Assam, is a cradle of biological diversity and primary productivity upon which countless species of plants and animals depend for survival. But with increasing human interference like dumping of waste (industrial, municipal, household etc.), constructional activities, fishing, killing of migratory birds and several other ways of contamination has led to the degradation of water quality either surface water or groundwater in the beel as well as sedimentation in the lake surface, deforestation activities in and around the Beel and so on (Islam, M. *et al.* 2014**)** Ever increasing population, urbanization and modernization are posing problems of sewage disposal and contamination of water quality in the Deepor Beel. As a result of this even the groundwater near the areas of Deepor Beel are affected with various contaminants which possess a major threat to the human population residing in and around the area.

Groundwater is the water that exists in the pore spaces and fractures in rocks and sediments beneath the Earth's surface. It is an important source of water supply throughout the world. Its use in irrigation, industries, municipalities and rural homes continues to increase. It provides almost half of all drinking water worldwide. Groundwater constitutes one portion of the earths water circulatory system known as the hydrologic cycle.

Figure 1.1: Image of Deepor Beel with rail connectivity across the beel (Source: www.google.com)

1.2 ZONES OF GROUNDWATER

Water beneath the land surface occurs in two principal zones, the unsaturated zone and the saturated zone. In the unsaturated zone, the spaces between particle grains and the cracks in rocks contain both air and water. Although a considerable amount of water can be present in the unsaturated zone, this water cannot be pumped by wells because capillary forces hold it too tightly.

In contrast to the unsaturated zone, the voids in the saturated zone are completely filled with water. The approximate upper surface of the saturated zone is referred to as the water table. Water in the saturated zone below the water table is referred to as groundwater. Below the water table, the water pressure is high enough to allow water to enter a well as the water level in the well is lowered by pumping, thus permitting groundwater to be withdrawn for use.

Between the unsaturated zone and the water table is a transition zone, the capillary fringe. In this zone, the voids are saturated or almost saturated with water that is held in place by capillary forces (Yissa, J. *et al.* 2012).

1.3 GROUNDWATER CONTAMINATION AND ITS SOURCES

The quality of groundwater may be affected by a wide variety of naturally occurring situation and human activities. Saltwater encroachment associated with over drafting of aquifers or natural leaching from natural occurring deposits are natural sources of groundwater pollution.

Most concern over groundwater contamination has centred on pollution associated with human activities. Human groundwater contamination can be related to waste disposal(private sewage disposal systems, land disposal of solid waste, mine wastes, deep well disposal of liquid wastes) or not directly related to waste disposal(certain agricultural activities, mining, acid rain, improper well construction and maintenance). Groundwater pollution in most cases is a direct result of environmental pollution.

The introduction of contaminants into a groundwater system can occur through a point source or a non-point source. The groundwater pollution source whose areal extent is limited may be categorized as point source. For example, the pollution from leaky sewres, leachate from landfills ease injection wells, etc. Non-point source however, comes from many diffuse sources. It includes pollution de to use of excess fertilizers, pesticides etc in agricultural lands. Because of the diffusive nature of non-point sources, it is very difficult to assess and manage the impact.

1.4 OBJECTIVE OF THE STUDY

(1) To study the water quality of groundwater near the areas of Deepor Beel from sorces like handpump, tubewells and borewells.

(2) To monitor the status of different ground water quality parameters of the groundwater samples collected from areas near Deepor Beel through laboratory analysis.

(3) Multivariate data analysis of the ground water quality parameters using SPSS software for a period of one year.

(4) To study the solute movement in our study area near Boragaon landfill area using HYDRUS-1D modelling.

CHAPTER 2

LITERATURE REVIEW

2.1.1 Literature review for ground water quality parameters-

1. **Asari`, N.A (2017)** in his journal paper "Seasonal variations in physicochemical characteristics of ground water samples of Surajpur Wetland, NCR, India" analysed the quality of ground water and the correlations among various ground water quality parameters in the wetland. The study was carried out for 2-year period and samples were collected from 5 different locations on monthly basis. The most changeable and sensitive ground water quality parameters such as temperature, Ph, Turbidity and DO were measured in the field using field test kit. Remaining parameters like total hardness, total alkalinity, chloride content, BOD, permanent hardness was measured according to standard laboratory method. One way analysis of variance (ANOVA) was used to check the significance of difference among the results of the parameters in different months. Moreover, in order to check the relationship among various physico-chemical parameter, Pearson linear correlation was used in the investigation. It concluded that the ground water quality status of the wetland was in favourable conditions with minerals within permissible limits and was good enough to support rich biodiversity in the wetland.

2. **Bundela, P.S *et al.* (2012**) in their journal work titled "Physicochemical analysis of ground water near municipal solid waste dumping sites in Jabalpur" stated that the most usual and neglected cause of groundwater pollution are uncontrolled dumping of municipal solid waste, infiltration of water by rainfall, or ground water generated by biodegradation, cause the leachate to leave the dumping ground laterally or vertically and find its way into the groundwater thereby causing contamination. 10 groundwater samples were collected from wells, handpumps from the people near the site during the rainy season in the year of 2011 and the samples were analysed for various physical and chemical

parameters. A comparative study of groundwater i.e., borewell and handpump water carried out by taking certain important parameters like Ph, TH, TA, BOD, TDS, DO, Turbidity, Calcium hardness etc. It concluded on the basis of current investigation that the ground water near the MSW dumping areas were mostly under the permissible limits of CPCB but some of them achieve near permissible limits.

3. **Mohammadi, F. *et al.* (2017)** in their journal paper "Monitoring Groundwater and Its suitability for Drinking and Irrigation Purposes in the Sharif Abad Basin, Central Iran" analysed the data collected from 24 observation wells indicated that the mean water table has plummeted about 0.896m/year during 19 years between 1993 and 2013 due to illegal groundwater pumping, which is the main cause of groundwater quality deterioration in this area. 17 samples were collected and analysed to study physicochemical characteristics of groundwater such as Ph, Hardness, Chloride content, Fluoride content, Total Suspended solids, EC etc. The results were compared to drinking ground water quality standard published by WHO and it was concluded that none of the ground water samples were potable. Also, the water table contour is prepared using different groundwater modelling software like USGS MODFLOW.

4. **Yissa, J. *et al.* (2012)** in their journal "Underground water assessment using Water Quality Index, Niger State, Nigeria" stated that 10 well samples were randomly picked in Maikunkele District of Bosso Local Government area of Niger State. The locations of the sampling points were spread within the length and breadth of the community. All samples were collected same day and kept in two litres rubber bottles, which was previously washed with 10% HNO_3 and 1:1 HCl for 48 h. The rubber bottles were labelled and immediately few drops of HNO_3 were added in order to prevent loss of metals, bacterial and fungal growth. Temperature, turbidity, and Ph of water samples were also measured at the time of collection. The ten well water samples were analysed for nine parameters: Ph, Turbidity, temperature, Total suspended solids, phosphate, nitrates, Biochemical

oxygen demand, and 12:0. Water quality index was calculated from the point of view of suitability of the water for human consumption as seen below. The Water Quality Index (WQI) was calculated using the National Sanitation Foundation (NSF) water quality index. This index has been widely field and applied to data from a number of different geographical areas all over the world to calculate WQI for various water bodies.

5. **Islam, M. *et al.* (2014)** in their journal paper "Studies on physio-chemical properties of water in some selected sites of Deepor Beel, Assam, India" tested various water samples from 10 different locations based on factors like inlet, outlet, dumping etc. Samples were collected from the study sites during the pre-monsoon seasons and post monsoon seasons of 2009 and 2010. The water quality parameters include temperature, colour, odour, D.O, BOD, Chloride, Fluoride, Calcium and Magnesium. The parameters considered for analysis was done following the methods of American Public Health Association (APHA, 2005). One way analysis of variance (ANOVA) was done to check if any significant differences existed states Cluster analysis was performed taking water variables as parameters to evaluate similarity among the sites. Here ANOVA analysis showed F-Ratio (1.83) > 1 and p-value << 0.06, which indicated water parameters differ with location.

6. **Dash, S. *et al.* (2021)** in their paper "Heavy Metal Pollution and Potential Ecological Risk Assessment for Surficial Sediments of Deepor Beel, India" took a total of 391 (23 locations X 17 months) surficial sediment samples on a monthly basis from Oct 2017 to Feb 2019. 7 heavy metals (Cr, Cd, Fe, Mn, Cu, Pb and Mg) were chosen for analysis based on the available literature on the probable pollution sources available near the wetland. All the analysis were carried out by means of Atomic Absorption Spectrophotometer and all the measurements were taken in triplicates. The absorbance values of the standards were well within the permissible limits and the standard deviation were observed to be less than 5%. They concluded that the concentration of metals followed the trend (Mg> Fe> Mn> Cr> Pb> Cd> Cu). Most of the maximum concentrations

were obtained from the site close to the landfill i.e. to the eastern part of the wetland after analysing the results in ANOVA.

7. **Pramada, S.K. *et al.* (2020)** presented a study where surface water and groundwater interaction model is developed and applied to a case study. The surface water and groundwater are fundamentally interconnected and thus one can contaminant the other. Mathematical models have been widely used in modelling groundwater flow through an esteemed area. MODFLOW is used to model the groundwater transport flow.

8. **Kalita, Jogen Chandra. *et al.* (2011)** in their journal named "identification of estrogenic heavy metals in water bodies near Guwahati city, Assam, India" presented the work dealt with the detection and identification of Heavy metals (Pb, Cd, Cr, Ni, Hg) having estrogenic properties from three different sites around Guwahati city well known for its polluted water. Focus was emphasized on the famous wetland 'Deepor Beel'. Water samples were collected and analysed using Atomic Absorption Spectrophotometer. The estrogenic heavy metal concentration in water was in the order Pb>Cr>Ni>Hg>Cd. The results showed the presence of a number of heavy metals with estrogenic activity. It was observed that the levels of these metals in the water were higher than the permissible limits which is a serious matter of concern for the habitats in and around the designated areas.

9. **Priya, S. *et al.* (2016)** in their work on " Analysis of water quality of some selected stations along river, Tambaraparani Kanyakumari district, Tamil Nadu, India" presented the study and analysis of physiochemical parameters by collecting samples from four different locatins along the district. Sampling of water was carried out over a period of one year from February 2009 to January 2010 on a monthly basis throughout the study period in all the four stations. Water samples required for the hydro biological analyses were collected during the early hours of the morning from the selected stations. These bottles were

labelled with respect to the collecting stations, date, and time in order to avoid any error between collection and analysis. All the sample collections were immediately preserved in an icebox and brought to the laboratory for determining the specific water quality parameters. Twoway analysis of variance (ANOVA) was carried out to evaluate the variation of water quality parameters

10. **Subramaniam, S.*et al.* (2014)** in their journal titled " Assesment of physico chemical characteristics of groundwater: A case study " This study focused on the determination of various physico-chemical characteristics of groundwater and to perform a statistical analysis to determine the relationship between the measured parameters. The study was carried out during April-May 2011, in Vellore city, India. The various physico-chemical characteristics such as Ph, turbidity, chlorides, acidity, alkalinity, sulphates, dissolved oxygen, and hardness were determined by following the procedure prescribed by American Public Health Association standard methods. This study was carried out to ensure the quality of groundwater to make use of it for domestic purpose by comparing the analytical results with the Bureau of Indian Standards (BIS) and World Health Organization (WHO) drinking water quality standards. A statistical study such as correlation analysis and one-way analysis of variance (ANOVA) has been carried out using Statistical Package for the Social Science (SPSS) ver. 20 software. The correlation analysis was performed for measured parameters to determine the relationship between the variables. The One-way ANOVA was applied to estimate the uncertainty in measured values. All the measured parameters are within the permissible limit as per WHO and BIS. The statistical analysis for all the parameters has revealed a positive correlation and the F test values are significant at 95% level. From the investigation results, it can be concluded that the water quality of the study area is fit for domestic purposes. The descriptive statistics of the parameters analyzed along with correlation matrix and one-way analysis proved that there is no variation among the measured parameters.

11. **Islam, M.*et al.* (2014)** in their work named “ Studies on physiochemical properties of water in some selected sites of Deepor Beel (Ramsar site), Assam, India” deals with the study of physiochemical parameters among ten different sampling locations around Deepor Beel and one way analysis (ANOVA) was carried out to show the significant differences among the stations. Also, Bray-Curtis Cluster analysis was done to show the similarities among the sites. The results of various water quality parameters were obtained and the water variables differ with locations. Turbidity obtained was high at site 7 where DO was low at site 6. The bod ranges of water indicated that the water was moderately polluted at all the sites except site 6 and site 10. The outcome of ANOVA shown that the water variables differ with location. Results obtained from Bray-Curtis Cluster showed that site 1 and site 4 showed similarity with a percentage of 96.45%

12. **Molla Ali, M. *et al.* (2015)** in their paper titled “Surface and groundwater quality assessment based on multivariate statistical techniques in the vicinity of Mohanpur, Bangladesh” It is based on hydro chemical characteristics, surface and groundwater in the study area were, in general fresh, hard, and alkaline in nature. All chemical parameters were within the WHO water quality guidelines. Whereas, among four analysed heavy metals Pb, and Cd concentrations exceeded the WHO recommended values. Pearson correlation matrix showed a number of statistically significant associations ($P < 0.01$ and $P < 0.05$) among the examined water quality parameters. Moreover, principal component (PC) analysis (PCA) and cluster analysis (CA) were used to analyse the water quality dataset. PCA analysis identified two PCs as responsible for the data structure explaining 72.53% of the total variance in water quality. PCA indicated that the water quality variations were mainly of anthropogenic origin through agricultural and municipal discharges. Results of CA revealed three significant groups of similarity among the 10 sampling sites.

13. **Patil, V. *et. al* (2009)** in their journal with the title " Physiochemical Analysis of Selected Groundwater Samples of Amalner Town in Jalgaon District, Maharastra, India" deals with the study and analysis of physicochemical characteristics of groundwater and municipal water in Amalner town by taking water samples from five different stations. The study was carried out by collecting four groundwater samples (Two open well, two bore well) and one municipal water sample during Nov 2007-Feb 2008. Total fifteen parameters were analysed. It was found that the underground water was contaminated at few sampling sites as it has crossed the permissible limits set by IS 10500:2012. Also later Pearson Correlation matrix was plotted to identify the dependencvy among the fifteen water quality parameters.

14. **Sharma, P *et.al* (2017)** in their work titled "Seasonal Variation of Groundwater Quality in Rural Areas of Jaipur District, Rajasthan" presented a study based on the water quality parameters of the groundwater of three sites of Amber Tehsil of Jaipur, Rajasthan using statistical tools. Three samples were collected from each site and chemical analysis was conducted. With the help of one way ANOVA test, the difference between the three sites based on the parameters was calculated. This paper reveals that groundwater of these three sites shows seasonal variations in all twelve parameters using statistical methods like paired t test and ANOVA tests. Later it was concluded that the groundwater of all the site is not suitable for drinking purposes.

2.1.2 REVIEW OF LITERATURE FOR SOLUTE TRANSPORT MODEL:

1. **Naveen B.P. *et. al.* (2018)**, in their paper **"A study on contamination of ground and surface water bodies by leachate leakage from a landfill in Bangalore, India"** discussed on the effects of potential leachate leakage from municipal dump yard to the nearby water bodies. Their study area was selected to be a municipal solid waste landfill located at Mavallipura (13°50′ North, 77°36′ East), Bangalore, India. This 100 acres of area had been dumped with waste since 2005.

In their study, they focused on testing the physico-chemical parameters of the leachate from the dump yard and the quality of contaminated soil in the nearby water bodies. Samples were collected from one season in April,2012 from the MSW leachate, a open well and a pond nearby the dump yard. The various parameters that were tested for these three sites were pH, Conductivity (μS/cm), TDS (mg/l), Calcium (mg/l), Alkalinity (mg/l), Sodium (mg/l), Potassium (mg/l), Nitrate (mg/l), Heavy metals. The results showed that pH of the samples were proximate to normal standards, but alkalinity and concentrations of all the major anions like chlorides, nitrates, sulphates were considerably high in the leachate sample. Moreover, concentrations of heavy metals were found to be low in leachates samples except for Fe and Zn as compared to the other sites. A hydrochemical trilinear diagram, also known as a Piper diagram was used to plot the composition of ions in percentage for all water samples. The piper diagram reveled the dominance selected cations as Na+ and K+ in comparison to calcium and magnesium. Bicarbonates and carbonates are the dominant anion found in the leachate samples compared to sulphates and chlorides as obtained from the diagram. Furthermore, the study was carried to conduct a batch test for knowing the initial concentration of contaminant on the soil sample of landfill site. Moreover, a contaminant transport model (fluidyn-POLLUSOL model) was used to know the contaminant flow and interaction through soil. For assessing the contaminant transport parameters of metal ions through soil, the column tests were conducted based on which simulation were done in fluidyn-POLLUSOL model. Thus, they concluded that MSW in the landfill site had deteriorated the quality of soil and water in the nearby areas. The ground water model showed that zinc concentration was limited to upper soil layers and iron concentrations showing higher percolation, which in turn indicated towards pollution of nearby water bodies due to seepage of ground water.

2. **Zheng C. *et. al.* (2017)** in their paper **"Application of HYDRUS-1D model for research on irrigation infiltration characteristics in arid oasis of northwest China"** focused on the soil water infiltration in Yaoba Oasis. In their study, a field infiltration experiment was conducted to obatain various soil hydraulic

parameters and the water content data. According to the data obtained in their study in 2015, the study area had evaporation and transpiration of 429 cm and 386 cm respectively. Contrarily, due to high sand content and inappropriate irrigation regime, the amount of invalid leakage waste was up to 581 mm, accounted for 40.9% of the total infiltration. These data were then used to simulate the process of soil water infiltration in Yoaba Oasis using HYDRUS-1d model. The HYDRUS model was calibrated and validated through the measured water content. The results obtained in the study showed that average correlation coefficients of simulation results were upto .9, and relative error and root mean square error were 6.11% and >)15, indicating that HYDRUS model had a higher degree of accuracy and could be used to simulate the procedure of soil water infiltration in Yoaba Oasis. Thus, the study concluded that from simulation of different irrigation schemes, it was found that increasing the irrigation duration and controlling the single irrigation amount properly could save both water resources and improve water uptake amount.

3. **Saifadeen A. *et. al.* (2012)**, in their paper **"Modeling of solute transport in the unsaturated zone using HYDRUS-1D"** studied about the movement of water and solutes in the unsaturated zone in three different geographic locations in Sweden (Petistrask, Norrkoping and Malmo) taking into account the downward movement of the centre of mass of solutes and general patterns of concentration profiles. In each of the 3 locations, they used a soil sample of depth 250 cm, along with the other soil properties viz. soil hydraulic conductivity, types of soil, bulk density etc. They used a one-dimensional unsaturated transport model to simulate non-reactive transport of solutes. Simulations were conducted in HYDRUS-1D code from a period of 1st of March -25th of September to evaluate the effect of soil water hysteresis, and temporal variability based on precipitation and evaporation input data for the period 1996-2008. In their study, they put forwarded the relation among depth of centre of mass Vs precipitation, mass into groundwater Vs precipitation and limiting concentration with depth Vs precipitation based on two conditions i.e hysteresis and non-hysteresis. The results in their study showed that under non hysteretic water flow solute

migration is faster and with the measured precipitation input data, there were small amounts of solutes that leached into the groundwater. Moreover, it was also found that the downward migration of solutes is deeper in Petistrask and slowest in Norrkoping. The simulations showed that a lower temporal resolution of the meteorological input data increases both underestimation of the downward movement of the solutes for non-hysteretic simulations and overestimation for hysteretic ones. Thus, they concluded that the differences between hysteretic and non-hysteretic simulations are negligible when using daily input data, so disregarding the effect of hysteresis when using daily input data is recommendable.

4. **Rubio C.M. *et. al.* (2012)**, in their paper **"Applicability of Hydrus-1D in a Mediterranean Mountain Area Submitted to Land Use Changes"** evaluated the reliability and accuracy of the Hydrus-1D model to simulate the measured dynamics of water flow in a silt loam soil profile in an abandoned crop area within the Can Vila research basin (0.56 km^2), which is located in the head basin of the Llobregat River, northeast of Spain ($42^0$12' N; $1^0$49' E). In their study, their main focus was to determine the hydraulic properties of the soil profile, to parameterize the van Genuchten model and field saturated hydraulic conductivity and then calibrate Hydrus-1D model using water contents and pressure heads. The experimental data set included water potential data measured at 0.2, 0.4, and 0.6 meters of depth using SKT600 tensiometers. For the observed water contents, two-time domain reflectometry (TDR) profiles (A and B) were used between surface and 0.6 meters of depth. The field-saturated hydraulic conductivity was obtained for 3 depths (0.15, 0.25, and 0.50meters). For calibration and validation of the HYDRUS-1D model under transient conditions, field data for the period from 28th of September to 30th of November of 2003 (64 days) were used along with pressure heads were used as initial boundary conditions. The results obtained in their study showed that the profile was classified as silt loam (according to USDA), with silt content always higher than 57$g \cdot kg^{-1}$, sand content between 110$g \cdot kg^{-1}$ and 210$g \cdot kg^{-1}$, and clay content between 200 $g \cdot kg^{-1}$ and 280$g.kg^{-1}$. Moreover, using the van Genuchten equation, various soil hydraulics

properties were obtained along with the N-parameter which is less than 1.20. Despite to obtain an excellent fitted values for N-parameter, these values were solved using Hydrus-1D. Simulation using Hydrus-1D gave an acceptable fit volumetric water content using an air entry value of −2cm in the van Genuchten equation from surface to 0.6 meters of depth. Notable results were obtained during simulation of pressure heads using HYDRAS model. Initially in dry conditions, with an accumulated precipitation of about 264.4mm after a dry period, the study showed that simulations slower at deeper levels (0.4 and 0.6m depth). But, simulation for the same period starting with wet conditions indicated that the response of the model is faster, especially at the deeper levels. Thus, in research they concluded that algorithm of Hydrus-1D solved correctly the Richards equation for the concerned silt loam soil profile under natural conditions, although the model simulated the pressure head data with smaller differences**.**

5. **Simunek J. *et. al.* (2012)** in their paper **“HYDRUS: Model use, Calibration and validation”** put forwarded a brief overview on application of HYDRAS software for simulating water flow and solute transport in variably saturated soils and groundwater. Applications involve a broad range of steady-state or transient water flow, solute transport, and/or heat transfer problems. In their article, the objective was laid on the history of development of the HYDRUS-1D and HYDRUS (2D/3D) software packages along with summarizing the theory behind the models and the key parameters needed to run the codes as well as discussed how these parameters can be obtained by model calibration. They stated in their paper the HYDRUS software package may be used to simulate movement of water, heat, and multiple solutes in unsaturated, partially saturated, or fully saturated homogeneous or layered media in single or multiple dimensions.

CHAPTER 3

GROUND WATER QUALITY PARAMETERS

3.1 INTRODUCTION

Ground water quality refers to the physical, chemical and biological characteristics of ground water in relationship to a set of standards (Wikipedia). For utilization of ground water for various purposes, the used ground water should meet certain requirements in its standard. Thus, the suitability of ground water to support and sustain the requirements as well as various processes is termed as ground water quality. Quality analysis of ground water is a very important tool or monitoring and updating of the limits of ground water parameters for proper maintenance of environmental balance, for example limits on the concentrations of toxic substances for drinking ground water use, or restrictions on temperature and pH ranges for ground water supporting invertebrate communities. Generally, surface ground water and ground water sums up the available ground water resources. The ground water quality of different location available on earth may not be same. The deterioration or variation in limits of the quality of ground water may occur due to natural factor as well as human influences.

Human activities are the worst factor affecting the ground water quality. Human activities contaminate both surface ground water and ground water through widespread interference in all aspects of nature without takin proper preventive measures to maintain the quality of available ground water resources. Examples of human activities worsening the ground water quality involves dumping of industrial and municipal wastes frequently, agricultural and residential activities which involves fertilizers, pesticides and animal wastes, leaking of fuel storage tanks, landfills road salt and more.

3.2 GROUND WATER QUALITY STANDARDS

In the setting of standards, agencies make political and technical/scientific decisions about how ground water will be used. In case of natural ground water bodies, they also make some reasonable estimate of original and fresh conditions. Ground water quality in this project is used with reference to a set of guidelines values and standards set by World Health Organization (WHO) and Bureau of Indian Standards (BIS).

3.3 GROUND WATER QUALITY PARAMETERS

The parameters defining, he quality of ground water can be sectioned into different categories or types. A brief explanation about their characteristics and measurement techniques is put forwarded as follows: -

1) Physical parameters.

2) Chemical parameters.

3) Biological parameters.

3.3.1 PHYSICAL PARAMETERS

The important physical parameters of ground water include turbidity, colour, odour, temperature, electrical conductivity (EC), total dissolved solids (TDS), viscosity, specific weight and vapour pressure.

3.3.1.1 Temperature:

Temperature measurement in ground water does not directly imply to whether ground water is polluted or not. But, temperature of ground water affects some of the important properties and characteristics of ground water such as density, specific weight, viscosity, surface tension, solubility of dissolved gases and etc. Chemical and biological reaction rates increase with increasing temperature. Reaction rates usually assumed to double for an increase in temperature of 10 °C. Dissolved oxygen is indirectly related to temperature, as temperature increases D.O of ground water decreases. Increase in temperature increases the growth rate of aquatic microorganism which leads to higher consumption of consume dissolved O_2 and level of dissolved O_2 decreases. Moreover, temperature also affects disinfection process because efficiency of disinfection is lower at lower temperature.

3.3.1.2 Colour:

Pure ground water is colourless. Appearance of any colour in ground water points towards presence of polluted materials in ground water. Natural ground water system is often colored by foreign material. Colour in ground water is imparted mainly due to dissolved materials and suspended materials. If the colour is due to suspended material, it is called as apparent colour. Colour given by dissolved material that remains even after removal of suspended material is called true colour or real colour. The maximum acceptable level of colour in ground water is 15 TCU (True Colour Unit). Objections to high colour are generally on aesthetic grounds rather than on the basis of a health hazard.

3.3.1.3 Total Dissolved Solids (TDS):

Total Dissolved Solids is the measure of the mass of solid material dissolved in a give volume of ground water. TDS is measured in grams per litre. Total dissolved solids include inorganic salts (mainly salts of calcium, magnesium, sodium, bicarbonates, chlorides ad sulfates) ad dome small amounts of organic matter that are dissolved in ground water. The sources of TDS comprise of natural sources, urban run off, industrial waste ground water, sewage, chemicals in ground water treatment process etc. TDS test provides a qualitative measure of the amount of dissolved solids present in the ground water sample. The presence of TDS is not a health hazard but concerned with the aesthetics of ground water. The limit for drinking ground water standards of TDS is set for not greater than 500 mg per litre.

TDS test is done generally through two methods: Gravimetric analysis and Electrical conductivity.

Gravimetric analysis is the most accurate methods and involve evaporating the liquid solvent ad measuring the mass of residues left. Although, this method is very time consuming, but it provides more reliable results. This method is applicable for measurement of total dissolved solids I all natural ground waters, in raw, process and treated agricultural, municipal and industrial wasteground waters and in treated drinking ground water.

Electrical conductivity is a measure of the capacity of ground water to conduct electrical current. Conductivity is directly related to the concentration of salts dissolved in ground water and thereby directly linking to the Total Dissolved Solids. The measure of TDS I the field directly is difficult, so its measurement is done through the conductivity method. Electrical conductivity is a fast method which ca be measured using a conventional conductivity meter or TDS meter

3.3.2 CHEMICAL PARAMETERS

Ground water quality is most affected by the chemical matters preset in it. Chemical parameters may include organic and inorganic matters. Some of the concerned chemical parameters include ground water pH, Total Hardness, Calcium Hardness, Magnesium Hardness, Alkalinity, presence of Chloride, Fluoride, Iron, Arsenic, Lead, Nitrate etc. The chemical parameters those are investigated in this study are listed below:

3.3.2.1 Hydrogen-Ion Concentration (pH):

The pH is a quantitative measure of the hydrogen ion concertation of ground water indicating the measurement of the acidity or alkalinity of a solution. The pH scale generally rages from 0 to 14. The pH scale indicates:

ground water is acidic if pH is less than 7

ground water is neutral if pH is equal to 7

ground water is alkaline if pH is greater than 7

pH is calculated as the negative logarithm of the hydrogen ion concertation, i.e. $pH=-\log_{10}[H]$. It is measured in units of moles per litre, of hydrogen ions. The normal rage for pH in drinking ground water is between 6.5 to 8.5 (as per IS 10500:2012). The pH of pure ground water is considered to be 7. The effect of pH is not direct o to our health. When pH level is less than 6.5 it increases acidity resulting in metallic or sour taste of drinking ground water, blue-green staining of sinks and other household fixtures. Moreover, with increase of pH indicates alkaline ground water which results in scale buildup in household plumbing.

3.3.2.2 Total Hardness (TH):

The characteristics of ground water that prevents formation of lather or foam with soap is termed as the harness of ground water. Ground water which has high dissolved minerals in it, generally calcium and magnesium is considered hard. As ground water moves through soil and rock, it dissolves very small amounts of minerals and holds them in solution. The degree of hardness becomes greater as the calcium and magnesium content increases in the ground water. Hardness of ground water is generally of two types:

(i) Carbonate or temporary hardness: The bicarbonates and carbonates of calcium and magnesium usually causes this type of hardness. Temporary hardness can be removed to some extent by boiling or removed fully by addition of lime.

(ii) Non-carbonate or permanent hardness: Permanent hardness is primarily caused by presence of calcium chloride, calcium sulphate, magnesium chloride or magnesium sulphate. It cannot be removed by boiling, and some special treatment is required for its removal. Non- carbonaceous hardness can be removed by ground water softening methods such as lime soda process, demineralization process and zeolite process.

Total hardness is the sum of the carbonate harness and non-carbonate hardness. It is measured in terms of parts per million(ppm) or mg/litre of $CaCO_3$.Ground water is considered soft when the concentration of $CaCO_3$ is below 60 mg/l; moderately hard when between 60-120 mg/l; hard when between 120-180 mg/l and very hard when more than 180 mg/l. Hard ground water is not a health hazard but it has serious impacts on household items. Ground water hardness causes damages to boilers, cooling towers and other equipment that handles ground water. Hard ground water can cause mineral build-up in ground water pipes and eventually clog them. Total hardness is measured by EDTA (Ethylene Diamine Tetra-acetic Acid test).

3.3.2.3 Alkalinity:

The alkalinity refers to the measure of the capacity of the ground water to neutralize the acids. Alkalinity of ground water may be due to the presence of one or more of a number of ions. These include hydroxides, carbonates and bicarbonates. Most alkalinity in surface ground water comes from calcium carbonate (CaCO3) that come from rocks and soil. Limestone contains high level of calcium carbonate. The process is enhanced if the rocks and soil have already been broken up before entering the ground water. The dissolved minerals get into the ground water through construction and other processes. In simple terms, the pH of a solution is a measure of how strong the bases are in a solution, whereas the alkalinity measures the amount of chemical bases present in the solution.

Alkalinity is determined through titration. It is usually measured in unit of mEq/L (milliequivalent per litre).

3.3.2.4 Chloride (Cl):

Chlorides are salts resulting from the combination of the gas chlorine with a metal. Some common chlorides include sodium chloride (NaCl) and magnesium chloride ($MgCl_2$). Chloride exists in all natural ground waters, the concentrations varying very widely and reaching a maximum in sea ground water (up to 35,000 mg/l Cl). In fresh ground waters the sources include soil and rock formations, sea spray and waste discharges. Chloride contents are very high in sewage and industrial effluents. Chloride does not pose a health hazard to humans under standard limits. Public Drinking Ground water Standards require chloride levels not to exceed 250 mg/L. Ground water will begin to taste salty and will become increasingly objectionable as the concentration level rises further above 250 mg/L. Chlorine alone as Cl_2 is highly toxic and it is often used as a disinfectant. In combination with a metal such as sodium it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plant and animal life. Criteria for protection of aquatic life require levels of less than 600 mg/L for chronic (long-term) exposure and 1200 mg/L for short-term exposure.

Concentration of chloride is measured by titration by Mohr’s method.

3.3.2.5 Dissolved Oxygen (D.O):

Dissolved oxygen is the amount of oxygen that is dissolved in ground water. D.O is one of the most important factor that determines the survivality of the aquatic organisms. Dissolved oxygen is different from the oxygen that is present in ground water molecules. Only bout ten molecules of oxygen per millions of ground water is actually dissolved in ground water. This dissolved oxygen is breathed by fish and zooplankton and is needed by them to survive. Oxygen is dissolved in ground water from atmosphere through direct absorption, from areas where ground water discharges into streams or as a waste product of plant photosynthesis. Temperature affects the formation of dissolved oxygen. Dissolved oxygen decreases in ground water with increases of temperature. Moreover, dissolved oxygen is also affected by movement of ground water. Rapidly moving ground water, such as in a mountain stream or large river, tends to contain a lot of dissolved oxygen, whereas stagnant ground water contains less. The standard level of dissolved oxygen in ground water is 4 mg/L. Dissolved oxygen level is important ground water quality indicator. Measurement of level of D.O in ground water samples in done through Wrinkler's Iodemetric method (titration).

3.3.2.6 Biological Oxygen Demand (B.O.D):

Biochemical oxygen demand (BOD) represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic conditions at a specified temperature. Biological oxygen demand (BOD) generally represents how much oxygen is needed to break down organic matter in ground water. Measurement of BOD is used as an index of the degree of organic pollution in ground water. BOD directly affects the amount of dissolved oxygen in rivers and streams. The greater the BOD, the more rapidly oxygen is depleted in the stream. This means less oxygen is available to higher forms of aquatic life. The consequences of high BOD are the same as those for low dissolved oxygen: aquatic organisms become stressed, suffocate, and die. Sources of BOD include leaves and woody debris; dead plants and animals; animal manure; effluents from pulp and paper mills, wasteground water treatment plants, feedlots, and food-processing plants; failing septic systems; and urban storm ground water runoff.

B.O.D is measured by a test in which amount of oxygen consumption is determined from a sample at 5 days period at a temperature of 20^0C. Light must be excluded from the incubator where the sample will be placed for 5 days, to prevent algal growth that may produce oxygen in the bottle.

B.O.D in mg/L = $(D.O_i - D.O_f) \times D.F$

Where, DO_i and DO_f are the initial and final concentrations of dissolved oxygen in mg/l.

D.F is the dilution factor.

3.3.3 BIOLOGICAL PARAMETERS

Biological parameters of ground water are important ground water quality testing factors. Biological parameters of ground water indicate the presence of microbiological organisms and pathogens in ground water. From, health prospective, biological parameters are more important to test for, then physical and chemical parameters. Presence of these micro-organisms in ground water can cause deterioration of health when consume directly. These organisms that affect the quality status of ground water generally includes bacteria, protozoa, virus and algae.

3.4 DRINKING GROUND WATER QUALITY STANDARDS

TABLE 3.1: IS 10500-2012 SPECIFIED LIMITS

Sl. No.	Ground water quality parameter	Desirable limit	Maximum permissible limit
1	Hydrogen-ion concentration (Ph)	6.5 – 8.5	6.5 – 8.5
2	Turbidity (NTU)	1.0	5.0
3	Alkalinity (mg/l)	200	600
4	Total Hardness (mg/l)	200	600
5	Total Dissolved Solids (mg/l)	500	2000
6	Nitrate (mg/l)	<4.5	4.5
7	Chloride(mg/l)	250	1000
8	Fluoride (mg/l)	1.0	1.5
9	Total Suspended Solids (mg/l)	500	2000
10	Arsenic (mg/l)	0.01	0.05
11	Lead (mg/l)	< 0.01	0.01

CHAPTER 4

STUDY AREA

4.1 INTRODUCTION

Deepor Beel is situated in the Kamrup (M) district and it is the only Ramsar site in Assam. In Ramsar Convention on wetlands, 1971, Deepor Beel was declared as “Wetlands of International Importance”. Deepor Beel was declared Ramsar site in 2002.(Wikipedia). Its basin is drained by a system of rivulets and hill streams that connect the neighbouring hills and the forests to the river Brahmaputra through an outlet called the Khanajan.

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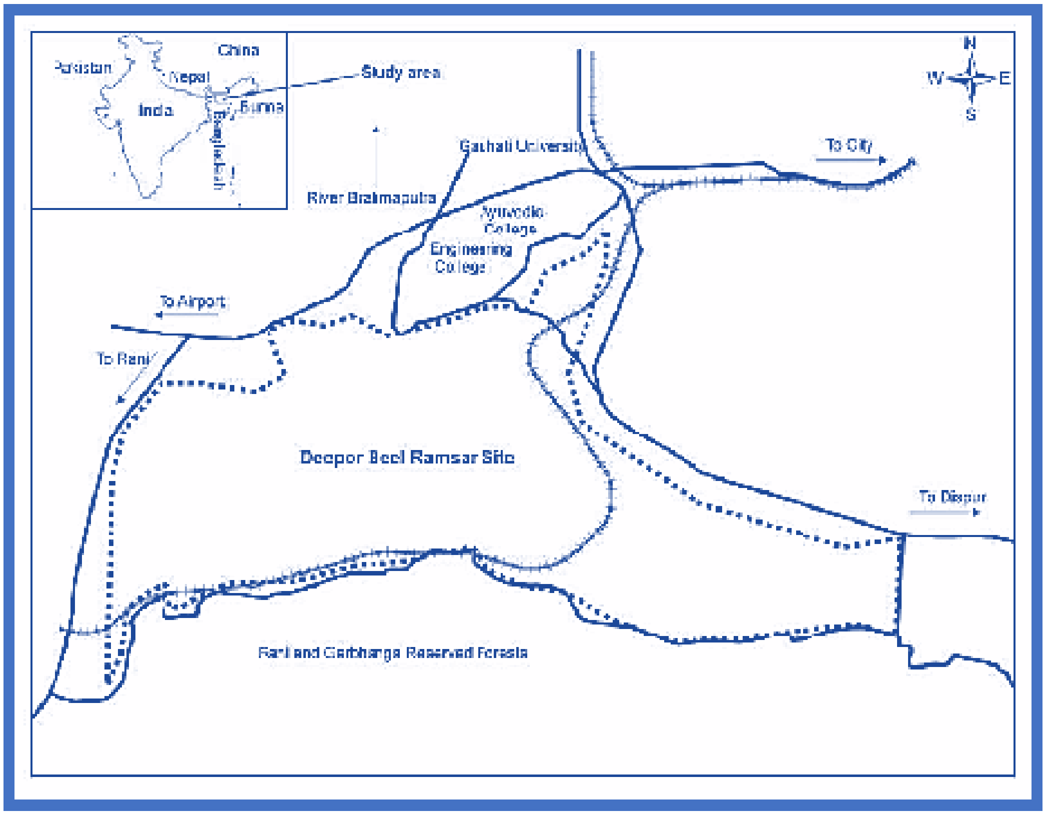


Figure 4.1 MAP OF DEEPOR BEEL

The above figure (Fig 4.1) shows the mapping of the boundary of our study area of Deepor Beel.

4.2 LOCATION AND BOUNDARIES

The beel is located between latitude: 26° 05’- 26°11’ N and longitude: 91°35’ - 91°43’ E, it covers an area of 40.14 sq.km. The northern-eastern side of the beel is thickly populated and is encircled by various government institutions like Gauhati University, Assam Engineering College, Assam Ayurvedic College, and Forest School. The national highway 37 (NH-37) is located in the northern and north-western side of the Beel and touches its periphery at different places like Dharapur, Azara etc. It is bounded by the PWD road, northern fringe of the Rani and Garbhanga Reserve Forests on the south.

4.3 PHYSIOGRAPHY

The Deepor Beel is located in a U-shaped valley bounded by steep highlands in the north and south side of the beel. The Deepor Beel and its fringe areas are made up of recent alluvium consisting of clay, silt, sand and pebbles whereas the hills in the north and south side of the Beel’s are of Archaean age. The wetland receives most of the surface runoff from the nearby hills which is one of the reasons of sedimentation of the wetland. Deposited soil in the bed of the wetland is the cause of lowering the depth of the Beel. It is commonly stated that the beel together with those adjoining it are an abandoned channel of the Brahmaputra system.

4.4 CLIMATE

Deepor Beel has a meso-thermal climate, characterized by high humidity and moderate temperature (Singh & Dutta 1960). The temperature ranges between 10.6°C to 30°C. The annual average precipitation is 3000 to 4000 mm. Most of the rainfall occurs during monsoon period (May-September). The monsoon season (May -September) has a maximum temperature of 32°C and minimum of 27.3°C. The pre-monsoon season (March-May) has a maximum temperature of 27° C and minimum of 24° C, and relative humidity between 50.5-76.8%. The relative humidity is 82.5%. Warm humid and cloudy weather is characteristics for this season. The retreating monsoon covers the period from September to October with maximum and minimum temperatures of 27° and 25° C respectively. The relative humidity is 82% and the rainfall gradually decreases to average as the season advances, when the morning mist and fogs start appearing. The winter season begins in November and continues until January. The average field temperature during this period remains at 20 ± 2°C and the relative humidity

4.5 HYDROLOGY

Basistha and Kalmani rivers and monsoon run off are the major sources of ground water for the wetland. In the rainy season the depth of the Beel increases up to four meter while in the dry season the depth drops to one meter. Khonajan channel drains the beel into the Brahmaputra river, 5 km to the north. for the Guwahati city.

CHAPTER 5

METHODOLOGY

5.1 SELECTION OF SITES

With increasing growth in population, there will be more waste generated in the city of Guwahati. As of this, there will be more waste generated and most of the waste being collected by Municipal Board will be dumped into the vicinity of Deepor Beel. This has already resulted in deterioration of the ground water quality standards as well the sediment quality of the wetland. Also this activities lead to the deterioration of groundwater near the areas of Deepor Beel. The surface ground water pollution of Deepor Beel is directly or indirectly related to the ground water pollution. Due to large amount of infiltration from precipitation, even ground water is getting affected vigorously. So, a study has been carried out selecting 9 areas around the beel. The sites for sample testing have been selected based on garbage dumping, the industrial effluents deposition, agricultural field’s wash off, etc.

Table 5.1: **Geographical description and G.P.S. location of study sites.**

Sl. No.	Site No.	Sampling Areas	G.P.S Point	
			Latitude	Longitude
1	Site 1	Near ASTU	26^{0}08’20.85” N	91^{0} 39’56.62” E
2	Site 2	Near MCA building, AEC	26^{0}08’32” N	91^{0}39’43.56” E
3	Site 3	Near Tetelia	26^{0}08’24” N	91˚40’5.63” E
4	Site 4	Chakardeo village	26^{0}06’31.04” N	91^{0}38’29.32” E
5	Site 5	Mikir Para, Rani	26^{0}06’36.14” N	91^{0}38’38.49” E
6	Site 6	Boragaon dumping site(i)	26^{0}07’21.62” N	91^{0}38’48.69” E
7	Site 7	Boragaon dumping site(ii)	26˚08’54’’N	91˚39’ 51’’ E
8	Site 8	Near GIMT	26˚ 07’ 33’’ N	91˚ 36’ 45’’ E
9	Site 9	Azara	26˚07’59.6’’ N	91˚37’27.44’’E

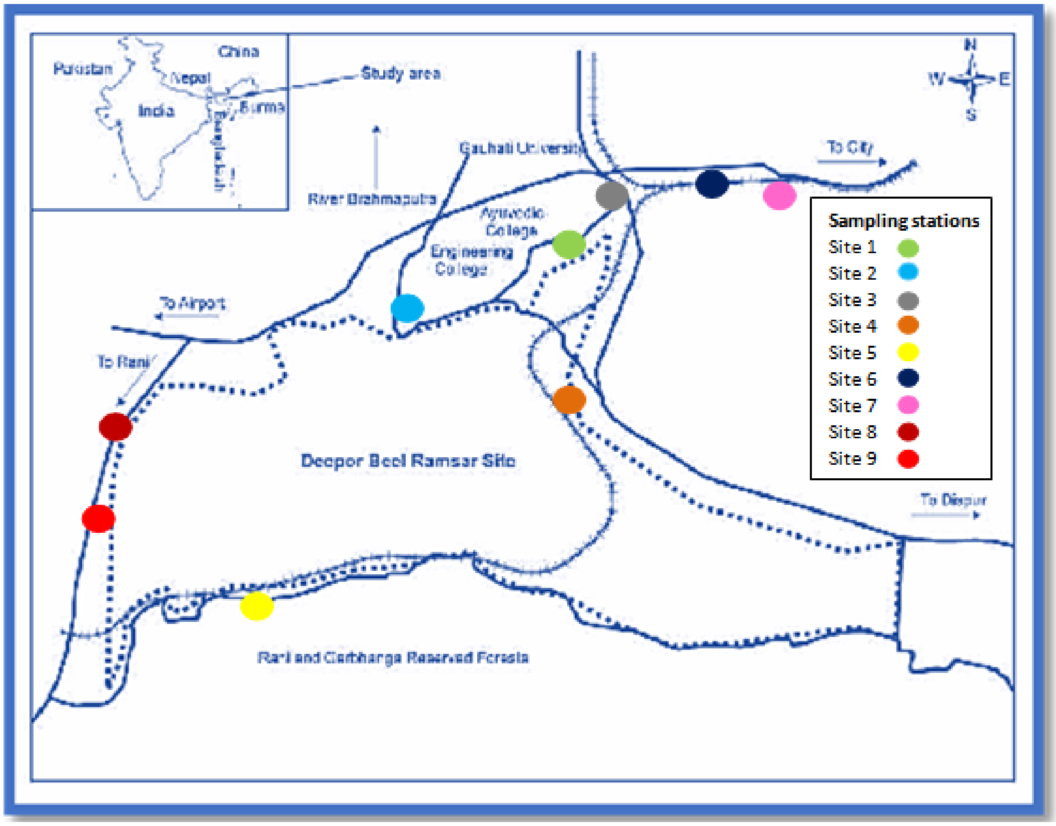


Figure 5.1 Map of Deepor Beel locating the sampling stations

5.2 COLLECTION AND PRE TREATMENT OF SAMPLES

Samples of ground water were collected from the study sites during morning hours following Standard methods as per *Islam et. al* (2014). Collection of ground water samples were done two times during the period from October 2022 to January 2023 after a suitable interval between each sampling at the sites. Ground water were collected from ground water sources like ring wells, tubewells and handpumps from 9 different locations within the vicinity of Deepor Beel. The ground water samples were collected in a plastic ground water bottles and BOD bottles from the respective study sites and brought to laboratory for further analysis.. The temperature was measured for each sample on the spot at the time of collection. Whereas the other parameters like Total Alkalinity (TA), pH, Total Dissolved Solids (TDS), turbidity (T), chloride etc. were estimated within 24 hours of collection by applying suitable analytical methods. For Dissolved oxygen (DO) and Biological Oxygen Demand (BOD), the samples were collected in 300 ml BOD bottles very carefully, for BOD analysis samples were collected and preserved for 5 days.

5.3 ANALYTICAL METHODS OF TESTING

5.3.1 Determination of temperature:

Measuring of temperature is important because of its effect on other testing parameters.

Procedure:

Measured with the help of mercury thermometer, graduated between 0º - 100º C at the time of collection of the samples.

5.3.2 Determination of pH:

Procedure:

(i) 50 ml sample was taken in a glass test tube.

(ii) pH was determined by inserting the pH-meter into the test tube.

5.3.3 Determination of Total Hardness by Titration:

Methodology as per IS:3025 (Part 21)- Reaffirmed 2007

Apparatus:

1. Measuring cylinder
2. Burette
3. Pipette
4. Glass rod
5. Conical flask

Reagents:

1. Ammonium buffer solution
2. Erichrome black-T indicator
3. Standard Ethylene Di-amine Tetra Acetic Acid (EDTA) titrant.

Procedure:

(i) 25 ml of sample is taken in the conical flask and another 25 ml of ground water is pipetted to the flask to make a solution of 50 ml.

(ii) 2 ml of Ammonium buffer solution is added to the solution.

(iii) 1 to 2 ml of erichrome Black-T indicator is added and the colour of the solution turns to light red/pink

(iv) Now, the burette is filled with EDTA.

(v) EDTA is added to the solution in the flask, titrated until the pink colour changes to sky blue.

Calculation:

Total hardness (mg/L) = (Burette reading x 1000)/ ml of sample.

5.3.4 Determination of Chloride by titration (Argentometric method):

Methodology as per IS:3025 (Part 32)- Reaffirmed 2007

Apparatus:

1. Measuring cylinder
2. Burette
3. Conical flask
4. Pipette

Reagents:

1. Silver nitrate ($AgNO_3$), 0.02 N

2. Potassium chromate (K_2CrO_4), 5%

Procedure:

(i) 50 ml of sample is taken in

a conical flask.

(ii) 2 ml of K_2CrO_4 solution is added the sample and the solution will turn to yellow colour.

(iii) Now, the burette is filled with $AgNO_3$ solution.

(iv) $AgNO_3$ solution from burette is allowed to fall in to the conical flask, titration is continued till the yellow colour of the solution turns to brick colour.

Calculation:

Chloride (mg/L) = ((ml x N) of $AgNO_3$ x 1000 x 35.5)/ ml of sample.

5.3.5 Determination of Biological Oxygen Demand (B.O.D):

Methodology as per IS: 3025 (Part 44)- 1993.

Apparatus:

1. Burette
2. Measuring cylinder
3. B.O.D bottle
4. Conical flask
5. Pipette

Reagents:

1. Phosphate buffer solution

2. Magnesium sulphate solution

3. Calcium chloride solution

4. Ferric Chloride solution

Procedure:

(i) One BOD bottle is filled with the sample to determine the initial D.O of the ground water sample.

(ii) Another BOD bottle of the sample is kept for incubation for 5-day period at a temperature of 20^0C.

(iii) Prepare four blanks by siphoning out dilution ground water directly into the bottles.

(iv) Initial D.O of two bottles is determined and remaining two bottles are kept for Incubation at 20^0C for 5 days.

(v) After 5 days, final D.O of the incubated bottles is determined.

Calculation:

$\text{B.O. D (mg/L)} = (\text{D.O}_i - \text{D.O}_f) \times \text{D.F}$

Some physicochemical parameters like Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Electrical conductivity (EC) and salinity were recorded in situ with the use of Multiparameter Ground water Quality Analyzing device.

5.3.6 Determination of Iron Content using UV-VIS Spectrophotometer:

Apparatus:

1. UV-VIS Spectrophotometer
2. Plastic cuvette
3. Volumetric flask
4. Pipettes

Reagents:

1) Hydroxylamine hydrochloride ($NH_2OH.HCI$)

2) 10-phenanthroline
3) sodium acetate
4) H_2SO_4
5) Standard iron solution

Procedure:

(i) 50 ml of the sample is taken on an aliquot, containing not more than 4 mg/l of iron in a 150 ml conical flask.

(ii) To the solution, 2 ml conc. HCl and 1 ml of hydroxylamine hydrochloride Solution.

(iii) Boiled the contents to half of the volume for dissolution of all iron

(iv) The solution is cooled and 10 ml of ammonium acetate buffer and 10 ml phenonthroline solution is added. An orange red colour appears.

(v) The solution is made to 100 ml and allowed to stand for 10 minutes.

(vi) In order to measure the blank, rinse the cuvette several times with tap ground water followed by deionized ground water, fill it with deionized ground water, place it the holder, and blank the spectrometer.

(vii) Now, the cuvette is filled with the solution and placed in the spectrophotometer and readings are noted at 510 nm.

(viii) A standard curve of Absorbance spectrum curve is prepared using various dilutions of standard iron solutions (0, 0.5, 1.0, 1.5, 2.0, and 2.5 mL of the standard iron solution).

(ix) The concentration of iron is calculated directly from the standard curve.

5.3.7 Determination of Nitrate concentration using UV-VIS Spectrophotometer:

Apparatus:

1. UV-VIS Spectrophotometer
2. Plastic cuvette
3. Volumetric flask
4. Pipettes

Reagents:

1. Stock solution: Preparation of stock solution is done by mixing 721.8 mg of KNO_3 made up to 1000 ml of using distilled water.
2. Intermediate solution: 100 ml stock solution is made up to 1000 ml using distilled water.
3. Phenoldisulphonic Acid (PDA): PDA was prepared by dissolving 25 g of white phenol in 235 ml of conc. H_2SO_4 by constant stirring and heated for 2 hrs on a water bath.

Procedure:

(i) 0, 5, 15, 25 and 35 ml of intermediate solution is taken in different volumetric flask of 50 ml and is filled up to the mark with distilled water.

(ii) 1 ml of 1 N HCL is added to the standards.

(iii) Distilled water is taken in cuvette as blank solution.

(iv) The calibration curves of standard nitrate and blank solution are obtained using the spectrophotometer.

(v) 10 ml of an aliquot of the sample was taken and evaporated to dryness.

(vi) To the dry residue, 2 ml of phenoldisulphonic acid (PDA) reagent was added.

(vii) Then 10 ml of concentrated NH_4OH was added carefully in a fume hood.

(viii) The content was made up to 100 ml by using distilled water, placed in a spectrophotometer and readings are taken at 410 nm wavelength.

(ix) The standard Absorbance spectrum curve is used to obtain the nitrate concentration of the water sample.

5.3.8 Determination of lead content by Atomic Absorption Spectrophotometer

Apparatus:

Atomic absorption spectrophotometer provided with background corrector and having following parameters:

a) Lamp current - depending on the lamp and instrument used

b) Support - air

c) Fuel – acetylene

d) Flame stoichiometry – oxidising

Reagents:

i) Pure Lead Metal - 99.9%.

ii) Concentrated Nitric Acid –

iii) Concentrated Hydrochloric Acid

iv) Standard Lead Solution - Dissolve 1.0 g of lead in 1 : 1 nitric acid, dilute to one litre with distilled water to give 1 mg/ml of lead.

Sample Preparation

i) Metals and Alloys - A suitable quantity of sample is dissolved in hydrochloric acid or a mixture of hydrochloric acid and nitric acid, evaporated to dryness, again dissolved in hydrochloric acid, diluted, filtered and made up to known volume. A suitable dilution is made for determination of lead before aspirating in the flame. Concentration of solution by ion exchange or by solvent extraction should he done where lead is expected to be present in very low quantities.

ii) Water and Effluents - Lead content in ground water is usually at very low level. Concentration technique is required before feeding to flame.

Concentration may be done by evaporation of solvent extraction or by ion exchange method.

iii) Minerals and Ores-Finely divided particles are dissolved in hydrochloric-nitric acid mixture and evaporated to dryness. It is again taken in hydrochloric acid, diluted and filtered to remove siliceous matter.

Procedure:

Optimize the response of instrument by adjustment of burner height and flame. Aspirate ground water to get zero absorption, when stable response is observed, aspirate standards. (at least 4) and note down absorption. Aspirate sample to get absorption of the sample. Prepare calibration curve by plotting the net absorption value of the standard against concentration in Vg/ml of lead. Locate the point of the sample absorption and calculate the concentration of lead in the sample.

Calculation:

Lead percent by mass = (C x V)/100 x 100/M

Where, C - concentration of lead in µg/ml in final solution, V = volume in ml of final solution, and M = mass in gram of the sample in final solution.

5.4 MULTIVARIATE DATA ANALYSIS (MVDA):

Multivariate data analysis (MVDA) is a Statistical procedure for analysis of data involving more than one type of measurement or observation. It may also mean solving problems where more than one dependent variable is analyzed simultaneously with other variables. The main advantage of multivariate analysis is that since it considers more than one factor of independent variables that influence the variability of dependent variables, the conclusion drawn is more accurate. The main disadvantage of MVDA includes that it requires rather complex computations to arrive at a satisfactory conclusion. Many observations for a large number of variables need to be collected and tabulated; it is a rather time-consuming process.

There are many different techniques for multivariate analysis, and they can be divided into two categories. The various type of multivariate analysis techniques available in IBM SPSS Statistics are:

- Multiple linear regression
- Multivariate analysis of variance (MANOVA)
- Factor analysis
- Cluster analysis
- K-Means cluster analysis
- Cluster silhouettes
- Discriminant analysis

In this report, the multivariate data analysis techniques used are One-Way Analysis of Variance (ANOVA), Hierarchical Cluster Analysis (HCA), Factor analysis or Principal Component Analysis (PCA) and K-Means Cluster Analysis.

It was carried out in the IBM SPSS Statistics software package downloaded from the official website of IBM. The results for this various analysis were obtained from the input data that were inserted to run this cluster analysis in SPSS statistics software. A separate chapter is dedicated for these four different analyses of our study area.

5.5 DEVELOPMENT OF SOLUTE TRANSPORT MODEL:

Solute transport modelling has become a very reliable and important tool for understanding the solute movement through the soil layers and investigating the ground water quality problems in the ground water. For a complete ground water quality analysis of an area, modelling software provides so much valuable information in predicting the sub-surface soil-water interaction, in addition to physico-chemical quality analysis for surface water. In this project, the multivariate analysis using SPSS software of the Deepor Beel is followed up with the development of a solute transport model using HYDRUS-1D software. HYDRUS-1D model used in this study will show the movement of iron through the soil profile in the area selected near the Municipal dumping yard at Boragaon which is site number 7. A separate chapter is dedicated to solute movement model which will come later, presenting both theory and detailed simulation process of the model.

CHAPTER 6

GROUNDWATER PARAMETERS CONCENTRATION

6.1 RESULT

The different ground water quality parameters were tested as per the methodology that were described in the previous chapter. The results obtained in this testing have presented in both tabular form in this chapter. The variation in the parameters in different months has been noted and discussed in details. With the results obtained from the test, the ground water quality status of the study area will be known.

6.1.1 Tabular output of results:

The different parameters that were analyzed along with their results for the specified month are presented in a tabular form below:

6.1.1.1 Results of October-December 2022-

Table 6.1: Concentrations of ground water quality parameters of the sampling sites in the month of October-December 2022:

Ground water quality parameters	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9
Temperature (˚)	26	27.2	26.2	27	26.5	27.2	25.6	26.5	26
pH	7.2	7.35	7.42	6.25	6.45	6.92	6.97	6.78	6.59
Dissolved Oxygen (mg/l)	3.6	5.4	3.5	4.1	5.6	3	4	4.8	3.8
Total Dissolved Solids (mg/l)	190	187.5	196.2	180	88.2	155.6	156.2	70	122.7
Salinity (ppt)	0.271	0.295	0.289	0.152	0.130	0.232	0.231	0.140	0.180
Electrical	0.365	0.234	0.387	0.165	0.175	0.309	0.312	0.155	0.238

Conductivity (ms/cm)									
Biological Oxygen Demand (mg/l)	1.1	1.9	1.6	2.1	1.3	3.6	2.8	1.2	1.3
Total Hardness (mg/l)	70	65	95	70	55	100	105	80	75
Chloride (mg/l)	100	105	60	95	50	30	35	75	80
Iron (mg/l)	1.17	0.65	0,69	1.22	1.67	2.72	2.95	1.03	1.2
Nitrate (mg/l)	0.009	0.01	0.008	0.045	0.07	0.15	0.22	0.04	0.05
Lead (mg/l)	0.01	0.008	0.008	0.04	0.047	0.095	0.098	0.015	0.017

The above table is a demonstration of the concentration of the nine different ground water parameters for the nine different sampling locations. The values listed are based on laboratory analysis of the ground water samples for the first period of our study.

6.1.1.2 Results of January (2023)-February (2023)-

Table 6.2: Concentrations of ground water quality parameters of the sampling sites in the month of January- February 2023:

Ground water quality parameters	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9
Temperature (˚)	24.5	25	25.2	23	22.5	24	23	23.8	22.5
pH	6.94	7.15	7.25	6.5	6.85	7.2	6.75	7.05	6.83
Dissolved oxygen (mg/l)	4.2	3.7	4.2	4.4	6	5.4	4.7	4.7	3.9
Total Dissolved Solids (mg/l)	210	196.5	203.2	199	130.2	149.5	136.4	82.6	147.2

Salinity (ppt)	0.294	0.350	0.275	0.220	0.142	0.200	0.365	0.155	0.128
Electrical Conductivity (ms/cm)	0.405	0.245	0.355	0.205	0.178	0.292	0.325	0.207	0.250
Biological Oxygen Demand (mg/l)	1.4	2.8	1.7	2	1.25	4	3.7	2.9	2.1
Total Hardness (mg/l)	85	70	105	80	45	90	110	100	70
Chloride (mg/l)	90	110	75	70	45	35	50	70	65

The above table is a demonstration of the concentration of the nine different ground water parameters for the nine different sampling locations. The values listed are based on laboratory analysis of the ground water samples for the next period of our study i.e., from Jan- Feb 2023.

6.1.1.3 Results of April -June (2023)-

Table 6.3: Concentrations of ground water quality parameters of the sampling sites in the month of April- June 2023

Ground water quality parameters	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9
Temperature (˚)	29	28.4	29	30.5	31	29.4	28	29.2	28.6
pH	7.01	7.18	7.2	6.75	6.92	7..24	7.33	7	6.91
Dissolved oxygen (mg/l)	3.25	3.62	4.15	4.38	5.65	3.8	3.76	4.65	3.79

Total Dissolved Solids (mg/l)	228	207.25	211	224.5	152.8	153.5	168.3	98.5	152.9
Salinity (ppt)	0.304	0.275	0.32	0.386	0.182	0.204	0.372	0.164	0.130
Electrical Conductivity (ms/cm)	0.397	0.284	0.350	0.216	0.198	0.297	0.365	0.208	0.257
Biological Oxygen Demand (mg/l)	1.63	2.82	1.84	2.6	1.32	4.6	4.75	2.92	2.35
Total Hardness (mg/l)	90	80	115	85	65	125	170	95	85
Chloride (mg/l)	95	105	80	70	45	40	80	75	75
Iron (mg/l)	1.21	0.65	0.55	1.35	1.69	2.65	2.7	1.02	1.20
Nitrate (mg/l)	0.0072	0.008	0.012	0.036	0.045	0.12	0.18	0.039	0.018
Lead (mg/l)	0.007	0.0074	0.0072	0.041	0.04	0.092	0.096	0.014	0.01

The above table is a demonstration of the concentration of the nine different ground water parameters for the nine different sampling locations. The values listed are based on laboratory analysis of the ground water samples for the next period of our study i.e from April- June 2023

6.1.1.4 Results of July -September (2023)-

Table 6.4: Concentrations of ground water quality parameters of the sampling sites in the month of July- September 2023

Ground water quality parameters	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9
Temperature (˚)	31	31.4	28	28.5	27.5	29	30	29	29.6
pH	6.98	7.07	7.25	6.83	6.96	7..2	7.35	6.98	6.9
Dissolved oxygen (mg/l)	3.22	3.6	4.12	4.36	5.68	3.66	3.58	4.52	3.8
Total Dissolved Solids (mg/l)	230	210	212.5	229.5	160.8	159	182.3	100	150.9
Salinity (ppt)	0.308	0.29	0.325	0.402	0.196	0.215	0.405	0.174	0.149
Electrical Conductivity (ms/cm)	0.4	0.283	0.350	0.218	0.199	0.292	0.368	0.200	0.260
Biological Oxygen Demand (mg/l)	1.65	3	2.06	2.65	2.5	4.9	5.2	3.15	2.6
Total Hardness (mg/l)	85	85	110	85	70	120	165	95	80
Chloride (mg/l)	98	100	84	75	48	65	90	82	70
Iron (mg/l)	1.2	0.62	0.54	1.38	1.75	2.68	2.84	1.05	1.18
Nitrate (mg/l)	0.007	0.0075	0.01	0.037	0.048	0.122	0.185	0.036	0.018
Lead (mg/l)	0.0065	0.0072	0.007	0.042	0.045	0.096	0.098	0.01	0.012

The above table is a demonstration of the concentration of the nine different ground water parameters for the nine different sampling locations. The values listed are based on laboratory analysis of the ground water samples for the next period of our study i.e. from July- September 2023.

CHAPTER 7

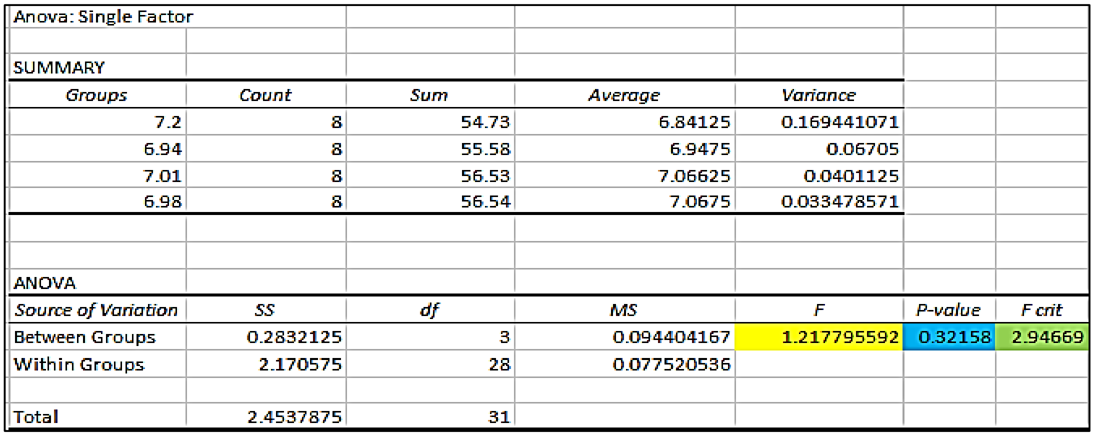
MULTIVARIATE DATA ANALYSIS

7.1 ONE-WAY ANOVA

The results obtained from the test were subjected to basic statistical analysis (One-Way ANOVA) . One-Way Analysis of Variance (ANOVA) of the various the parameters of the ground water samples are done to determine whether there are any statistically significant differences between the means of two or more independent groups. In this case study, the One-Way ANOVA is performed using the data analysis tool pack in MS Excel. This analysis tests the validity of null hypothesis that the ground water variables concentrations did not differ with different seasons. The analysis computes the results based on two statements. One is null hypothesis which says that there is no significant difference between the means of the selected groups and the other hypothesis i.e alternative hypothesis says that there is a significant difference between the means of the selected groups. This significance is based on the F-ratio and the p-value, obtained from the software during the analysis. If the F-ratio > F-critical and the p-value ≤ 0.05, then it is concluded as the null hypothesis is not valid and the differences are quite significant. If F-ratio< F-critical and the p-value ≥ 0.05, then it is concluded that the null hypothesis is accepted and the differences observed are less significant. For the null hypothesis to hold good, the value of F must be approximately equal to 1. The One-Way ANOVA values obtained for each parameter is shown below.

7.1.1 RESULTS OF ONE-WAY ANOVA:

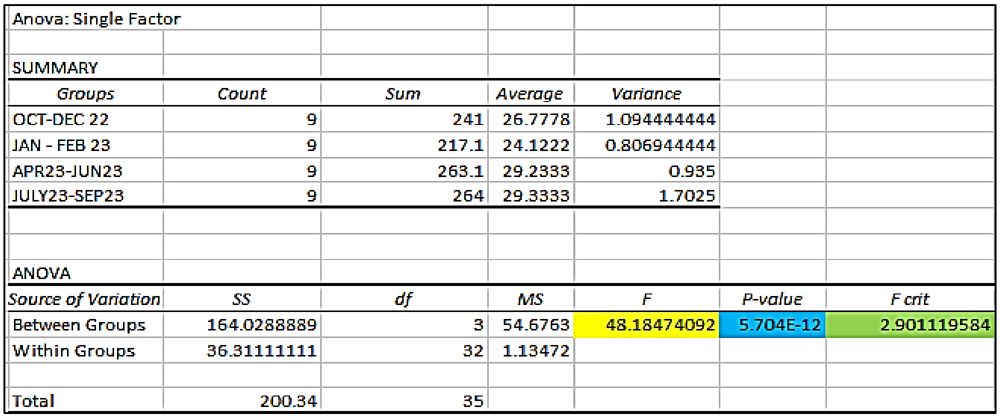
Table 7.1: pH



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
7.2	8	54.73	6.84125	0.169441071		
6.94	8	55.58	6.9475	0.06705		
7.01	8	56.53	7.06625	0.0401125		
6.98	8	56.54	7.0675	0.033478571		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.2832125	3	0.094404167	1.217795592	0.32158	2.94669
Within Groups	2.170575	28	0.077520536			
Total	2.4537875	31				

The table 7.1 shows the ANOVA results for pH parameter. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus it concludes less significant differences of pH content for one year period.

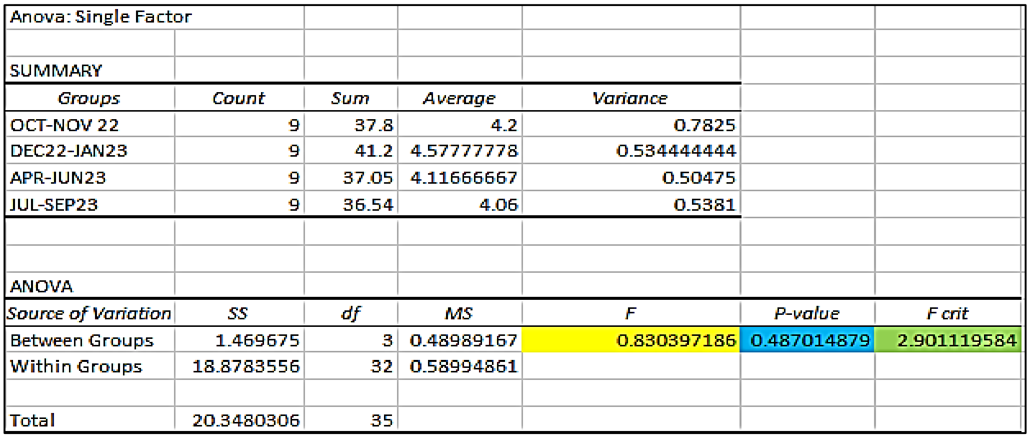
Table 7.2 : Temperature:



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-DEC 22	9	241	26.7778	1.094444444		
JAN - FEB 23	9	217.1	24.1222	0.806944444		
APR23-JUN23	9	263.1	29.2333	0.935		
JULY23-SEP23	9	264	29.3333	1.7025		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	164.0288889	3	54.6763	48.18474092	5.704E-12	2.901119584
Within Groups	36.31111111	32	1.13472			
Total	200.34	35				

The table above shows the ANOVA results for surface temperature of various time periods. It can be seen that F-ratio > F-critical and the p-value ≤ 0.05. Thus, it concludes a significant difference for the surface temperatures.

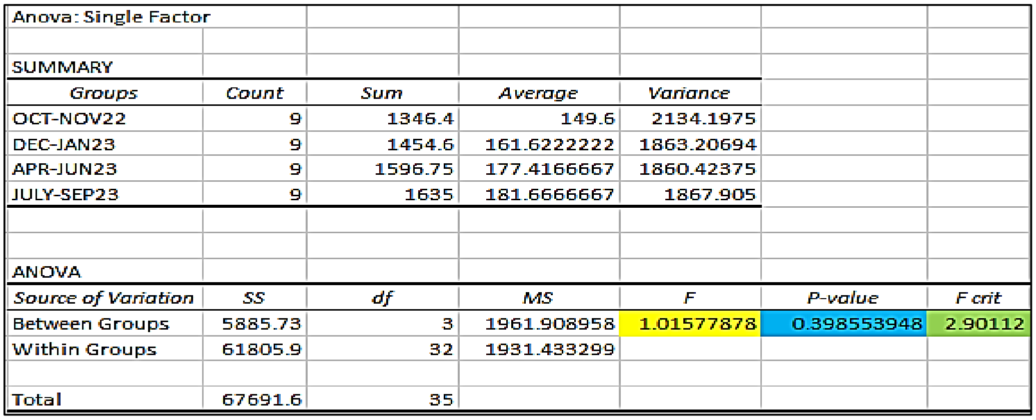
Table 7.3 : Dissolved Oxygen :



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV 22	9	37.8	4.2	0.7825		
DEC22-JAN23	9	41.2	4.57777778	0.534444444		
APR-JUN23	9	37.05	4.11666667	0.50475		
JUL-SEP23	9	36.54	4.06	0.5381		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.469675	3	0.48989167	0.830397186	0.487014879	2.901119584
Within Groups	18.8783556	32	0.58994861			
Total	20.3480306	35				

The table above shows the one way ANOVA results for dissolved oxygen parameter of various time periods. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes a significant differences for the surface temperatures.

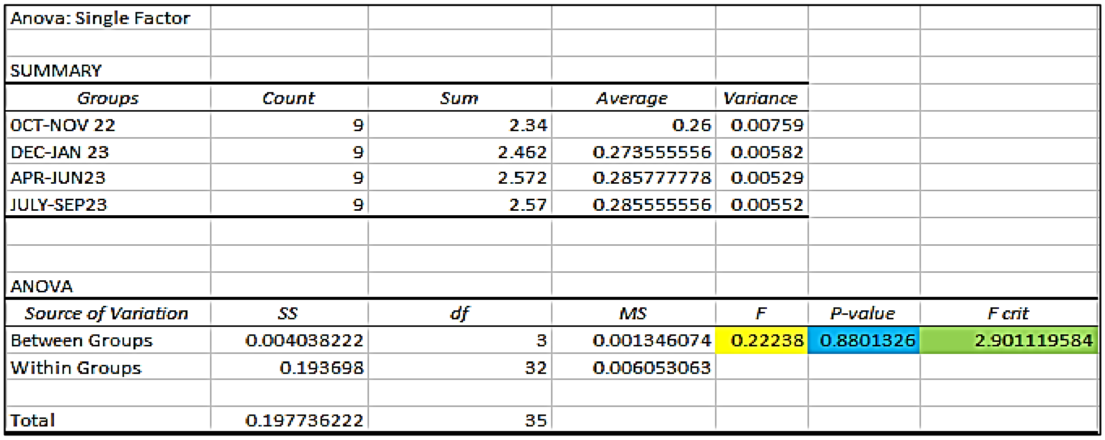
Table 7.4 : Total Dissolved Solids:



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV22	9	1346.4	149.6	2134.1975		
DEC-JAN23	9	1454.6	161.6222222	1863.20694		
APR-JUN23	9	1596.75	177.4166667	1860.42375		
JULY-SEP23	9	1635	181.6666667	1867.905		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5885.73	3	1961.908958	1.01577878	0.398553948	2.90112
Within Groups	61805.9	32	1931.433299			
Total	67691.6	35				

The table 7.4 above shows the one way ANOVA results for dissolved oxygen parameter of various time periods. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes a less significant differences as the null hypothesis assumed was accepted.

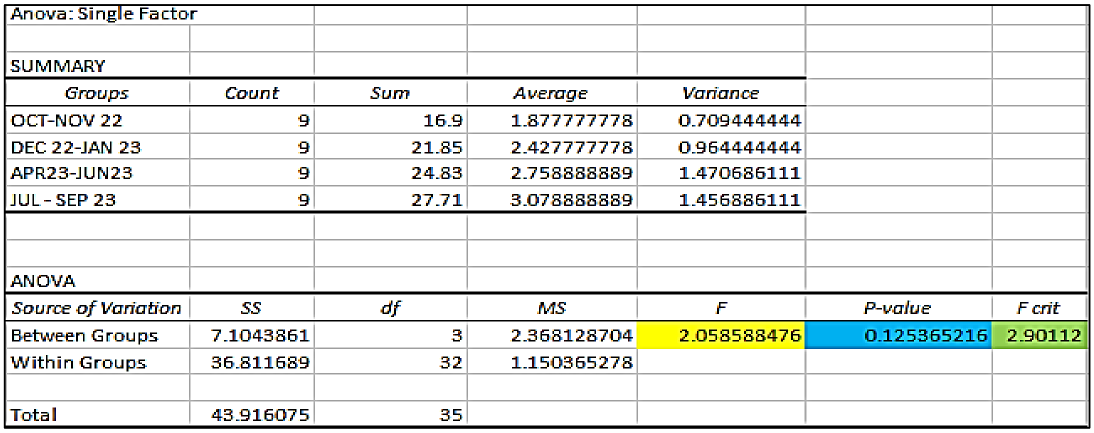
Table 7.5 : Electrical Conductivity:



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV 22	9	2.34	0.26	0.00759		
DEC-JAN 23	9	2.462	0.273555556	0.00582		
APR-JUN23	9	2.572	0.285777778	0.00529		
JULY-SEP23	9	2.57	0.285555556	0.00552		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004038222	3	0.001346074	0.22238	0.8801326	2.901119584
Within Groups	0.193698	32	0.006053063			
Total	0.197736222	35				

The table above shows the ANOVA results for electrical conductivity of various time periods. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. It concludes a less significant differences as the null hypothesis assumed was accepted.

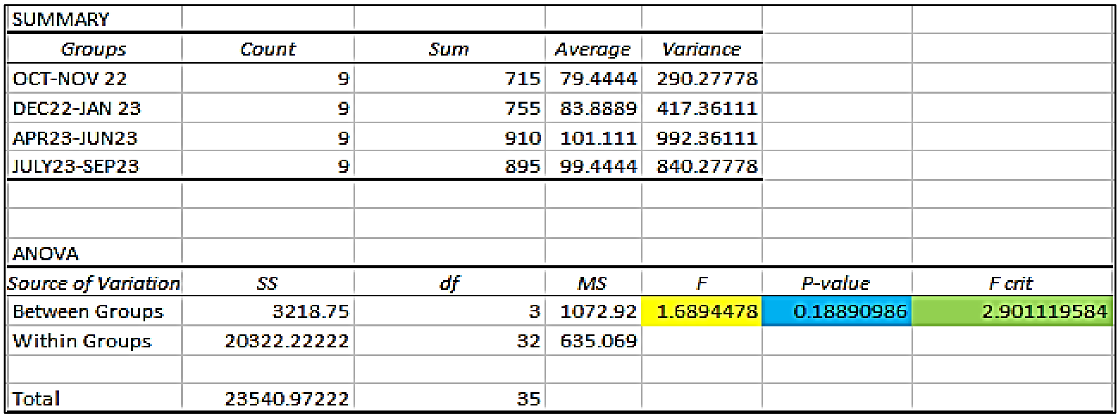
Table 7.6 : Biological Oxygen Demand:



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV 22	9	16.9	1.877777778	0.709444444		
DEC 22-JAN 23	9	21.85	2.427777778	0.964444444		
APR23-JUN23	9	24.83	2.758888889	1.470686111		
JUL - SEP 23	9	27.71	3.078888889	1.456886111		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.1043861	3	2.368128704	2.058588476	0.125365216	2.90112
Within Groups	36.811689	32	1.150365278			
Total	43.916075	35				

The table shows the ANOVA results for BOD parameter. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes less significant differences for BOD content for one year period.

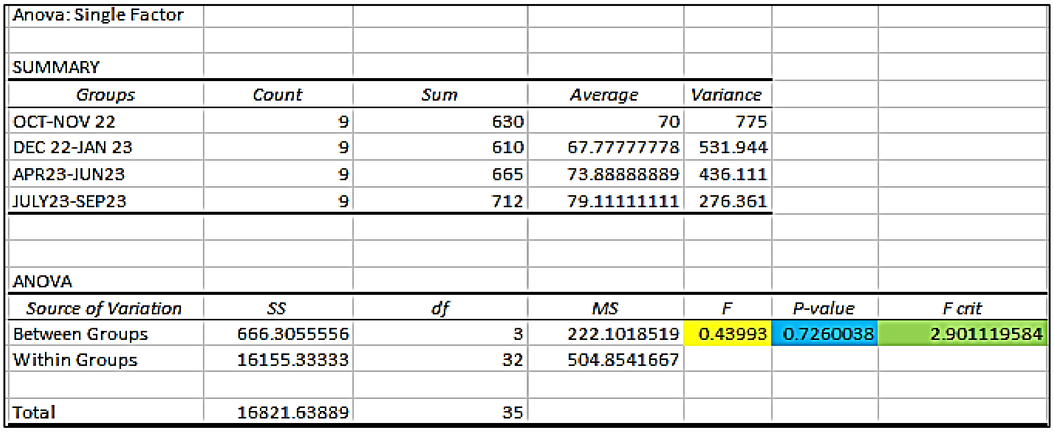
Table 7.7: Total Hardness



SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV 22	9	715	79.4444	290.27778		
DEC22-JAN 23	9	755	83.8889	417.36111		
APR23-JUN23	9	910	101.111	992.36111		
JULY23-SEP23	9	895	99.4444	840.27778		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3218.75	3	1072.92	1.6894478	0.18890986	2.901119584
Within Groups	20322.22222	32	635.069			
Total	23540.97222	35				

The table 7.7 above shows the one way ANOVA results for total hardness parameter of various time periods. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes a less significant differences among this specific parameter as the null hypothesis assumed was accepted.

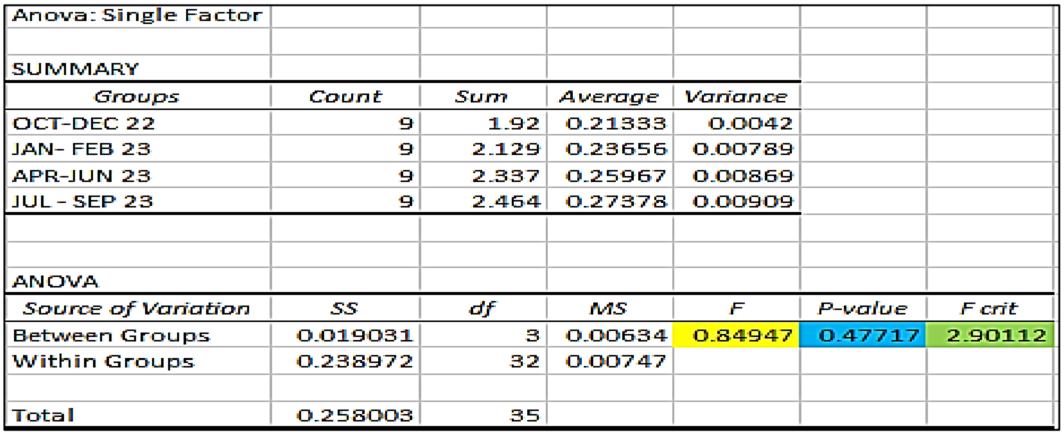
Table 7.8: Total Chloride Concentration:



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV 22	9	630	70	775		
DEC 22-JAN 23	9	610	67.77777778	531.944		
APR23-JUN23	9	665	73.88888889	436.111		
JULY23-SEP23	9	712	79.11111111	276.361		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	666.3055556	3	222.1018519	0.43993	0.7260038	2.901119584
Within Groups	16155.33333	32	504.8541667			
Total	16821.63889	35				

The table 7.8 above shows the one way ANOVA results for the total chloride concentration of various time periods. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes a less significant differences among this specific parameter as the null hypothesis assumed was accepted.

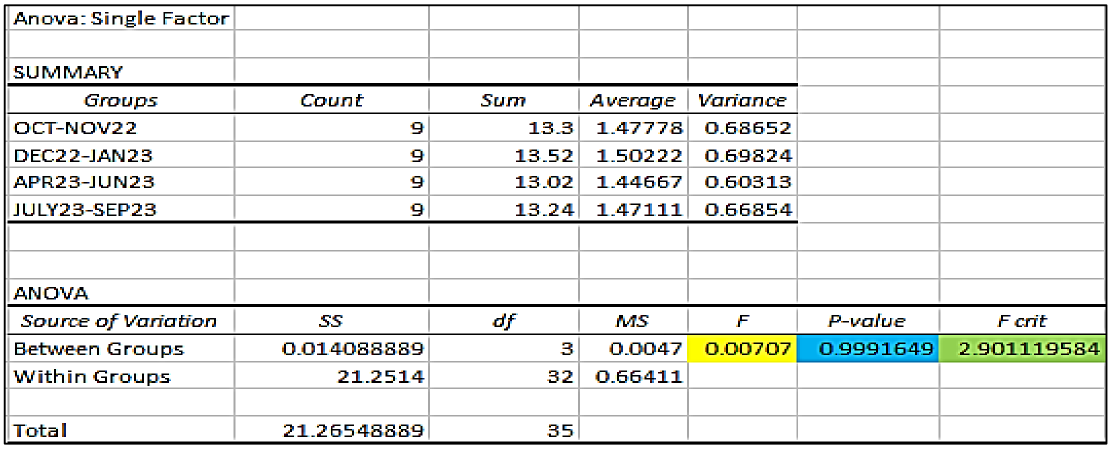
Table 7.9 : Salinity:



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-DEC 22	9	1.92	0.21333	0.0042		
JAN- FEB 23	9	2.129	0.23656	0.00789		
APR-JUN 23	9	2.337	0.25967	0.00869		
JUL - SEP 23	9	2.464	0.27378	0.00909		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.019031	3	0.00634	0.84947	0.47717	2.90112
Within Groups	0.238972	32	0.00747			
Total	0.258003	35				

The table shows the ANOVA results for salinity parameter. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes less significant differences for salinity content for one year period.

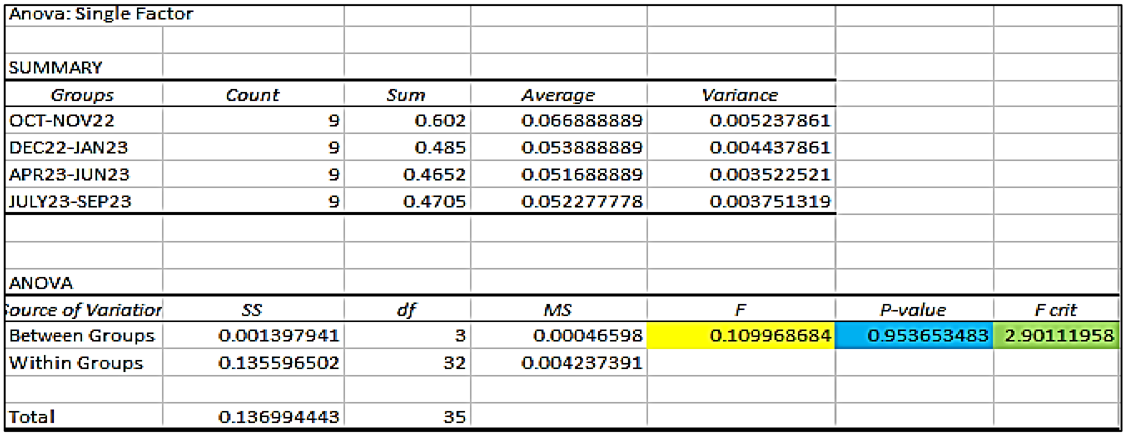
Table 7.10 : Iron



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV22	9	13.3	1.47778	0.68652		
DEC22-JAN23	9	13.52	1.50222	0.69824		
APR23-JUN23	9	13.02	1.44667	0.60313		
JULY23-SEP23	9	13.24	1.47111	0.66854		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.014088889	3	0.0047	0.00707	0.9991649	2.901119584
Within Groups	21.2514	32	0.66411			
Total	21.26548889	35				

The table 7.10 above shows the one way ANOVA results for the iron concentration of various time periods. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes a less significant differences among this specific parameter for one year time period as the null hypothesis assumed was accepted.

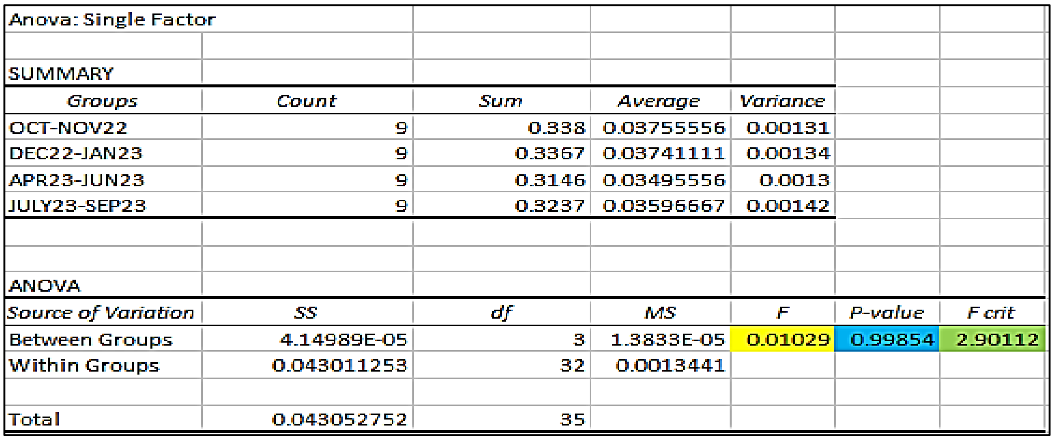
Table 7.11: Nitrate



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV22	9	0.602	0.066888889	0.005237861		
DEC22-JAN23	9	0.485	0.053888889	0.004437861		
APR23-JUN23	9	0.4652	0.051688889	0.003522521		
JULY23-SEP23	9	0.4705	0.052277778	0.003751319		
ANOVA						
ource of Variatior	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001397941	3	0.00046598	0.109968684	0.953653483	2.90111958
Within Groups	0.135596502	32	0.004237391			
Total	0.136994443	35				

The table shows the ANOVA results for nitrate parameter. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes less significant differences for nitrate content for one year period.

Table 7.12: Lead



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
OCT-NOV22	9	0.338	0.03755556	0.00131		
DEC22-JAN23	9	0.3367	0.03741111	0.00134		
APR23-JUN23	9	0.3146	0.03495556	0.0013		
JULY23-SEP23	9	0.3237	0.03596667	0.00142		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.14989E-05	3	1.3833E-05	0.01029	0.99854	2.90112
Within Groups	0.043011253	32	0.0013441			
Total	0.043052752	35				

The table 7.12 above shows the one way ANOVA results for the lead concentration of various time periods. It can be seen that F-ratio < F-critical and the p-value ≥ 0.05. Thus, it concludes a less significant differences among this specific parameter for one year time period as the null hypothesis assumed was accepted.

The above demonstrated table is the output results obtained from the statistical analysis carried out for the nine different ground water parameters using one way analysis variance (ANOVA). One way analysis of variance (ANOVA) is interpreted using the data analysis toolpack present in MS Excel selecting two sets of group for the period of study. This table presents the results obtained after running the analysis.

Analysis were done for the nine different ground water quality parameters for a period of one year (October 2022- September 2023) using the one way ANOVA present in the data analysis tool pack in MS Excel. It was carried out to check the differences in variations between the parameters for a time period of one year. ANOVA involves mathematical formulas and programming approach which gives us an image of the significant differences obtained for the selected groups within the different months. ANOVA analysis for all the twelve parameters are listed in the above respective tables.. According to ANOVA, the null hypothesis is rejected if F-ratio>F-critical and $p \leq 0.05$ I.e., the parameters show a significant difference. Otherwise, the null hypothesis is accepted that concludes that there is no significant differences within or between the groups. In our study area, all the parameters show values of F-ratio < F-critical and $p \geq 0.05$ which results in no significant differences among the parameters for a span of one year within our prescribed time period. Only the on-field temperature showed a significant difference for the selected time period.

7.2 HIERARCHICAL CLUSTER ANALYSIS (HCA)-

Hierarchical Cluster Analysis (HCA) is a procedure that attempts to identify relatively homogeneous groups of cases (or variables) based on selected characteristics, using an algorithm that starts with each case (or variable) in a separate cluster and combines clusters until only one is left. It is an unsupervised pattern recognition technique, and its algorithms produce a sequence of nested partitions including similar groups. Clusters in HCA are formed sequentially, starting with the most similar pair of variables and forming higher clusters step by step. Cluster process formation is repeated until a single cluster containing all the variables are obtained. The result of the clustering can be displayed in a tree like structure, called a dendrogram. The dendrogram can be broken at different levels to yield different clusters of the data set. However, it should be noted that the decision of the final cluster is rather arbitrary.

The hierarchical agglomerative clustering methods differ in the way they calculate the similarity between two clusters i.e single link, complete link, group average and Wards method. The former methods depend on calculating the similarity between two patterns using a distance measure. The most popular distance method is the Euclidean distance (Abu-Khalaf et.al, 2013).

The Ward's method is distinct from the other methods, because it uses an analysis of variance approach to evaluate the distance between the clusters. Cluster membership in this method is assessed by calculating the total sum of squared deviations from the mean of a cluster. The criteria for fusion is that it should produce the smallest possible increase in the error sum of squares. The Wards method with squared Euclidean distance is used as a dissimilarity measure has been found to provide meaningful dendrogram of clusters with the proximity or similarity of clusters measured with a rescaled distance.

7.2.1 CONSIDERATIONS FOR HCA

Statistics. Agglomeration schedule, distance (or similarity) matrix, and cluster membership for a single solution or a range of solutions.

Plots: Dendrograms and icicle plots.

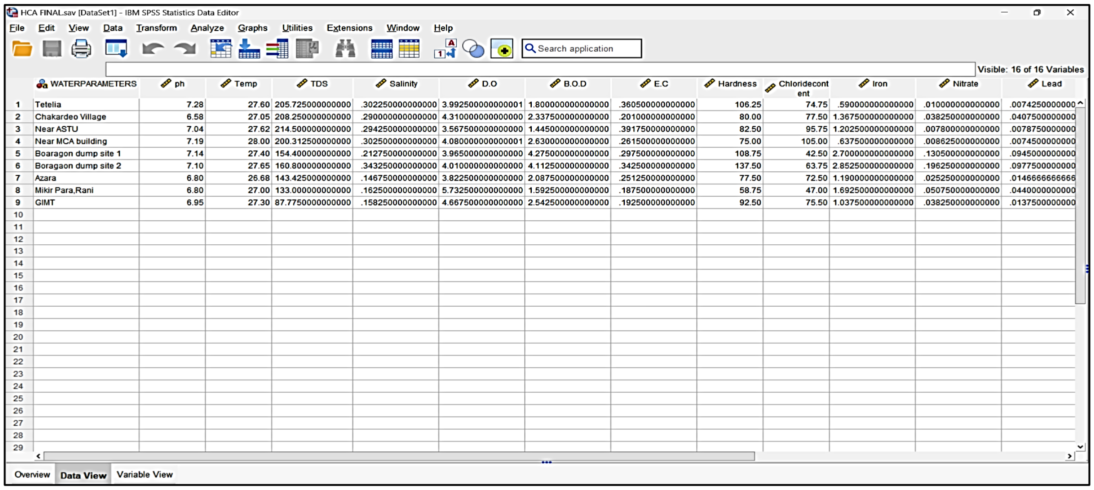
Data. The variables can be quantitative, binary, or count data. Scaling of variables is an important issue--differences in scaling may affect our cluster solution(s). If the variables have large differences in scaling (for example, one variable is measured in dollars and the other is measured in years), one should consider standardizing them (this can be done automatically by the Hierarchical Cluster Analysis procedure).

Case order. If tied distances or similarities exist in the input data or occur among updated clusters during joining, the resulting cluster solution may depend on the order of cases in the file. You may want to obtain several different solutions with cases sorted in different random orders to verify the stability of a given solution.

Assumptions. The distance or similarity measures used should be appropriate for the data analyzed (see the Proximities procedure for more information on choices of distance and similarity measures). Also, you should include all relevant variables in your analysis.

Omission of influential variables can result in a misleading solution. Because hierarchical cluster analysis is an exploratory method, results should be treated as tentative until they are confirmed with an independent sample.

7.2.2 INPUT DATA FOR HCA

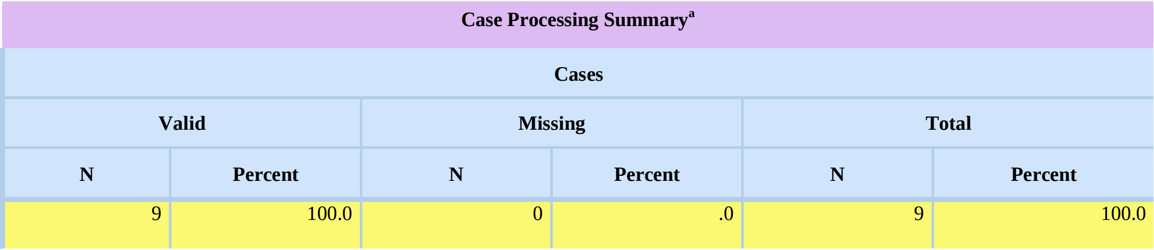


	WATERPARAMETERS	ph	Temp	TDS	Salinity	D.O	B.O.D	E.C	Hardness	Chloridecontent	Iron	Nitrate	Lead
1	Tetelia	7.28	27.60	205.725000000000	.302250000000000	3.992500000000001	1.800000000000000	.360500000000000	106.25	74.75	.590000000000000	.010000000000000	.0074250000000
2	Chakardeo Village	6.58	27.05	208.250000000000	.290000000000000	4.310000000000000	2.337500000000000	.201000000000000	80.00	77.50	1.367500000000000	.038250000000000	.0407500000000
3	Near ASTU	7.04	27.62	214.500000000000	.294250000000000	3.567500000000000	1.445000000000000	.391750000000000	82.50	95.75	1.202500000000000	.007800000000000	.0078750000000
4	Near MCA building	7.19	28.00	200.312500000000	.302500000000000	4.080000000000001	2.630000000000000	.261500000000000	75.00	105.00	.637500000000000	.008625000000000	.0074500000000
5	Boaragon dump site 1	7.14	27.40	154.400000000000	.212750000000000	3.965000000000000	4.275000000000000	.297500000000000	108.75	42.50	2.700000000000000	.130500000000000	.0945000000000
6	Boragaon dump site 2	7.10	27.65	160.800000000000	.343250000000000	4.010000000000000	4.112500000000000	.342500000000000	137.50	63.75	2.852500000000000	.196250000000000	.0977500000000
7	Azara	6.80	26.68	143.425000000000	.146750000000000	3.822500000000000	2.087500000000000	.251250000000000	77.50	72.50	1.190000000000000	.025250000000000	.0146666666666
8	Mikir Para,Rani	6.80	27.00	133.000000000000	.162500000000000	5.732500000000000	1.592500000000000	.187500000000000	58.75	47.00	1.692500000000000	.050750000000000	.0440000000000
9	GIMT	6.95	27.30	87.7750000000000	.158250000000000	4.667500000000000	2.542500000000000	.192500000000000	92.50	75.50	1.037500000000000	.038250000000000	.0137500000000

Figure 7.1: Data view dialog window in SPSS

The figure above shows the input parameters to run HCA for our study area. The variables considered for this analysis are the ground water parameters present in the x axis and the cases (represented by ‘N’) considered here are represented by the sites present in the y-axis. This Hierarchical cluster analysis were allowed to run in the software available in IBM SPSS Statistics website.

7.3.3 OUTPUT FOR HEIRARCHICAL CLUSTER ANALYSIS



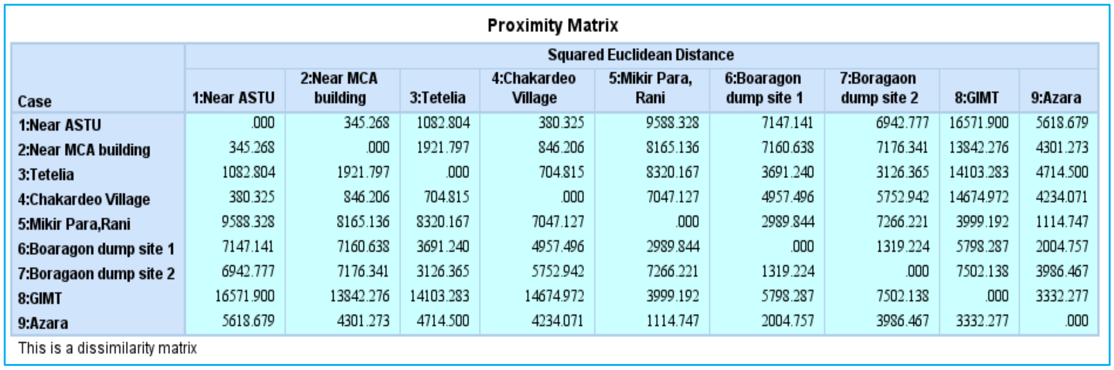
Case Processing Summary[a]

Cases					
Valid		Missing		Total	
N	Percent	N	Percent	N	Percent
9	100.0	0	.0	9	100.0

a. Ward Linkage

Figure 7.2 : Case processing summary dialog (SPSS)

It represents the first output result in the form of a summary which were obtained from the input datas available. It shows the number of cases for which it was run and all the nine cases available (site names) are valid to run the cluster analysis.



Proximity Matrix

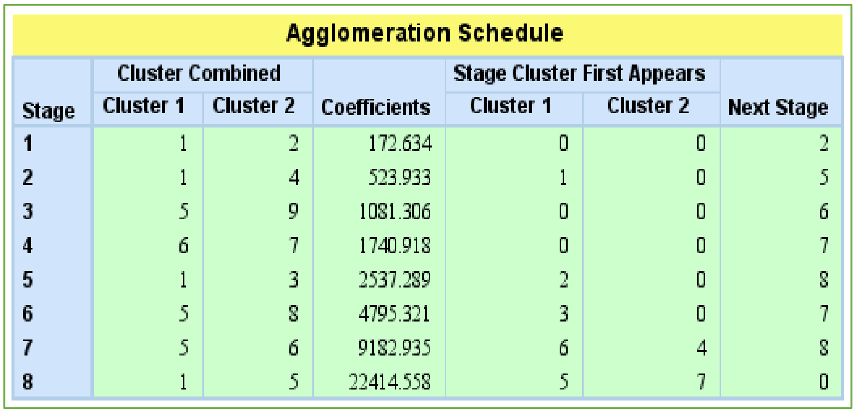
Case	Squared Euclidean Distance								
	1:Near ASTU	2:Near MCA building	3:Tetelia	4:Chakardeo Village	5:Mikir Para, Rani	6:Boaragon dump site 1	7:Boragaon dump site 2	8:GIMT	9:Azara
1:Near ASTU	.000	345.268	1082.804	380.325	9588.328	7147.141	6942.777	16571.900	5618.679
2:Near MCA building	345.268	.000	1921.797	846.206	8165.136	7160.638	7176.341	13842.276	4301.273
3:Tetelia	1082.804	1921.797	.000	704.815	8320.167	3691.240	3126.365	14103.283	4714.500
4:Chakardeo Village	380.325	846.206	704.815	.000	7047.127	4957.496	5752.942	14674.972	4234.071
5:Mikir Para,Rani	9588.328	8165.136	8320.167	7047.127	.000	2989.844	7266.221	3999.192	1114.747
6:Boaragon dump site 1	7147.141	7160.638	3691.240	4957.496	2989.844	.000	1319.224	5798.287	2004.757
7:Boragaon dump site 2	6942.777	7176.341	3126.365	5752.942	7266.221	1319.224	.000	7502.138	3986.467
8:GIMT	16571.900	13842.276	14103.283	14674.972	3999.192	5798.287	7502.138	.000	3332.277
9:Azara	5618.679	4301.273	4714.500	4234.071	1114.747	2004.757	3986.467	3332.277	.000

This is a dissimilarity matrix

Figure 7.3 : Proximity matrix dialog window in SPSS

The above figure shows the similarity between the cases(here sites are taken as case number) based on the scuared Euclidean Distance. It was done with the WARD'S method. The squared Euclidean distance shown here is not a metric, but it is useful for comparing distances (Abu Khalaf et.al 2013). The values of Euclidean distances which are of larger weights depicts that the cases (sites) are far apart that is they show characters of dissimilarity in terms of the variables (ground water parameters) and vice versa.

7.3.4 WARD LINKAGE-



Agglomeration Schedule

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	1	2	172.634	0	0	2
2	1	4	523.933	1	0	5
3	5	9	1081.306	0	0	6
4	6	7	1740.918	0	0	7
5	1	3	2537.289	2	0	8
6	5	8	4795.321	3	0	7
7	5	6	9182.935	6	4	8
8	1	5	22414.558	5	7	0

Figure 7.4: Agglomeration schedule

The figure above represents the numerical summary of the cluster solution in the form of agglomeration schedule obtained from the cluster analysis. The agglomeration schedule shows the step-by step clustering process. It shows which clusters were combined on that step and also the resulting total "error" in the clustering solution. The agglomeration schedule will help us decide how many clusters to be included in our solution.

At first stage cases 1 and 2 are combined because they have smallest euclidean. From the agglomeration schedule, we obtained that the main clusters combined in our solution comprises of two numbers.

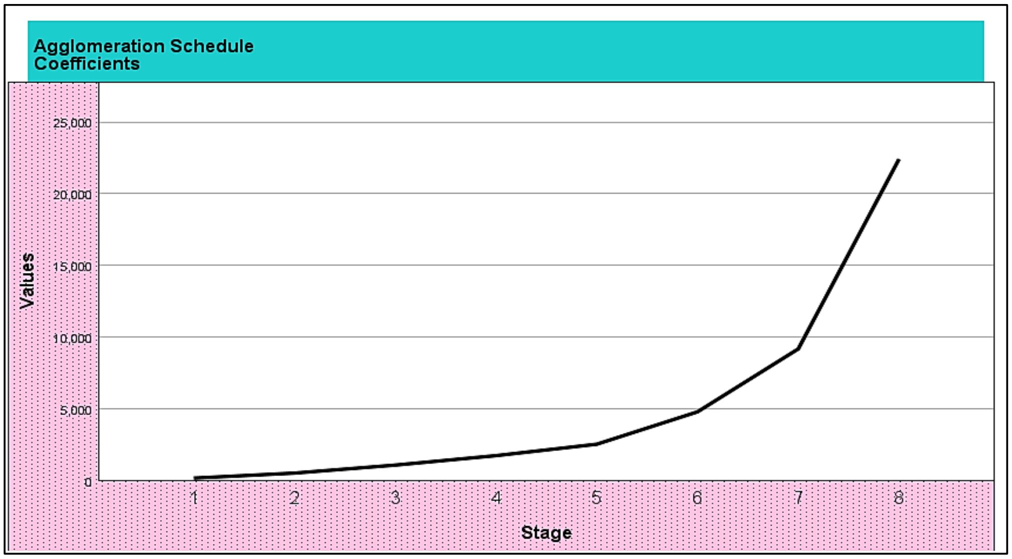


Figure 7.5: Graphical representation of agglomeration schedule coefficients.

The above figure shows the plot between the agglomeration coefficients and the different stages. From this, we see a giant leap of the values of the agglomeration coefficients from stage 7 to stage 8. It depicts a large difference between the coefficients as also can be seen from figure 7.4.

7.3.5 CLUSTER MEMBERSHIP-

Cluster Membership

Case	5 Clusters
1:Near ASTU	1
2:Near MCA building	1
3:Tetelia	2
4:Chakardeo Village	1
5:Mikir Para,Rani	3
6:Boaragon dump site 1	4
7:Boragaon dump site 2	4
8:GIMT	5
9:Azara	3

Figure 7.6: Cluster membership window in SPSS

The sub clusters obtained from the agglomeration schedule are summarised in the above figure and shows which site falls under which subclusters in a more refined way.

In our study area, from the above figure we can say that site 6 and site 7 belong to the same sub cluster member ‘four’ as these two sites belong close to each other as figured out in the squared Euclidean matrix above. Similarly site 1 ,site 2 and site 4 belongs to the same subcluster with respect to the various physical, chemical and heavy metal parameters within our study area.

7.3.6 DENDROGRAM PLOT:

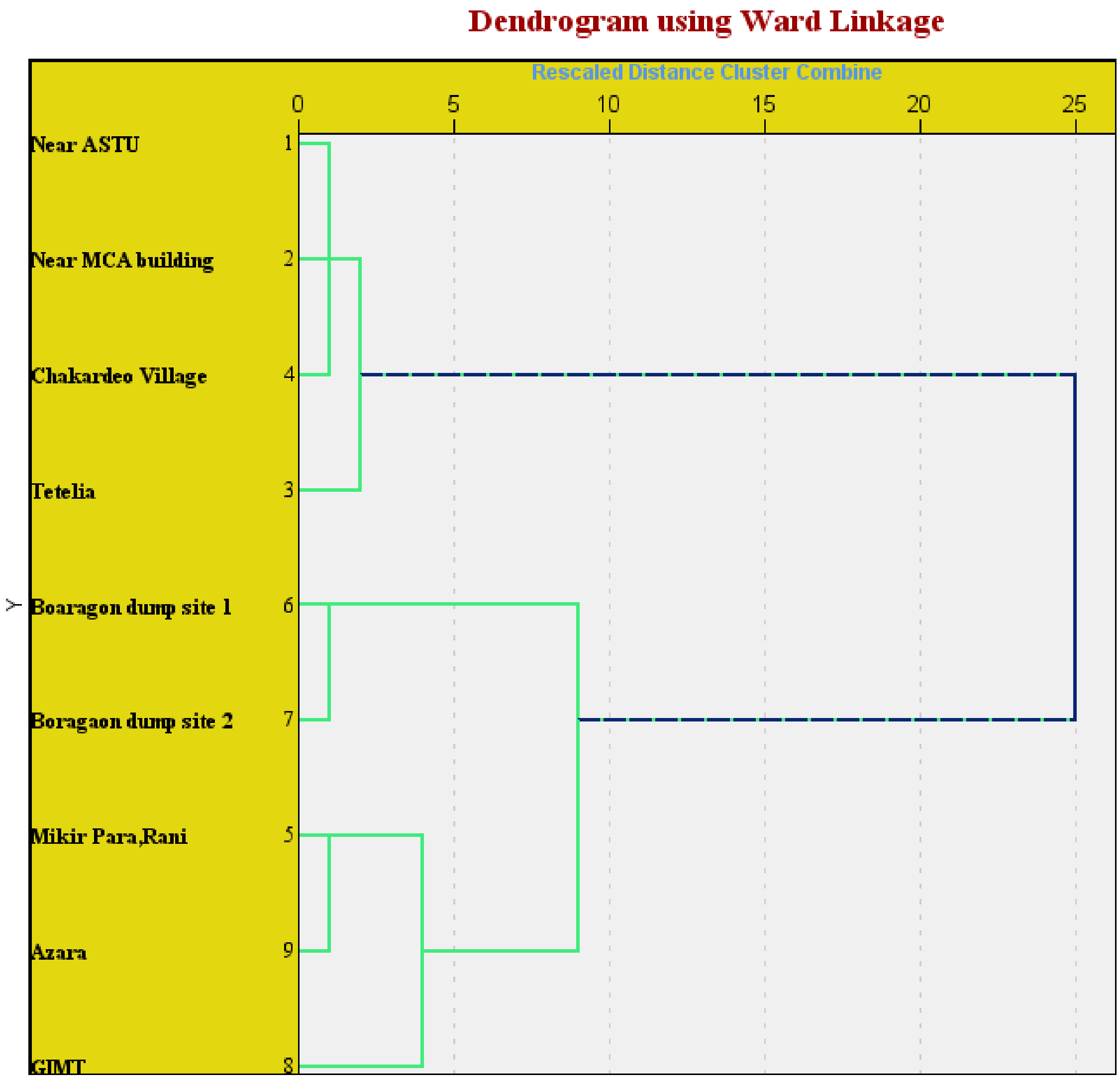


Figure 7.7: Plot of dendrogram showing different clusters.

The above plot is a tree-like structure called dendrogram plot which depicts clusters between the sites and the rescaled Euclidean distance. This plot is obtained by analysing between the ground water parameters which are considered as variables and the sites that are considered as cases.

The blue dotted lines in the dendrogram represent the two main set of clusters among the study area. The green lines depicts the sub clusters within the study area which totals to five number of cluster formations. It shows the similarity among the sites with respect to the ground water parameters within our study for a period of one year from October 2022 to September 2023.

7.4 PRINCIPAL COMPONENT ANALYSIS (PCA):

Principal Component Analysis is an unsupervised learning algorithm that is used for the dimensionality reduction in machine learning. It is a statistical process that converts the observations of correlated features into a set of linearly uncorrelated features with the help of orthogonal transformation. These new transformed features are called the Principal Components. It is one of the popular tools that is used for exploratory data analysis and predictive modelling. It is a technique to draw strong patterns from the given dataset by reducing the variances (O’ Rourke et. al, 2005)

PCA generally tries to find the lower-dimensional surface to project the high-dimensional data.

PCA works by considering the variance of each attribute because the high attribute shows the good split between the classes, and hence it reduces the dimensionality. Some real-world applications of PCA are image processing, movie recommendation system, optimizing the power allocation in various communication channels**.** It is a feature extraction technique, so it contains the important variables and drops the least important variable.

The central idea of principal component analysis (PCA) is to reduce the dimensionality of a data set consisting of a large number of interrelated variables while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, *the* principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables.

The PCA algorithm is based on some mathematical concepts such as:

- Variance and Covariance
- Eigenvalues and Eigen factors

7.4.1 SOME COMMON TERMS USED IN PCA ALGORITHM:

- **Dimensionality:** It is the number of features or variables present in the given dataset. More easily, it is the number of columns present in the dataset.
- **Correlation:** It signifies that how strongly two variables are related to each other. Such as if one changes, the other variable also gets changed. The correlation value ranges from -1 to +1. Here, -1 occurs if variables are inversely proportional to each other, and +1 indicates that variables are directly proportional to each other.
- **Orthogonal:** It defines that variables are not correlated to each other, and hence the correlation between the pair of variables is zero.
- **Eigenvectors:** If there is a square matrix M, and a non-zero vector v is given. Then v will be eigenvector if Av is the scalar multiple of v.
- **Covariance Matrix:** A matrix containing the covariance between the pair of variables is called the Covariance Matrix.

7.4.2 INPUT DATA FOR PRINCIPAL COMPONENT ANALYSIS:

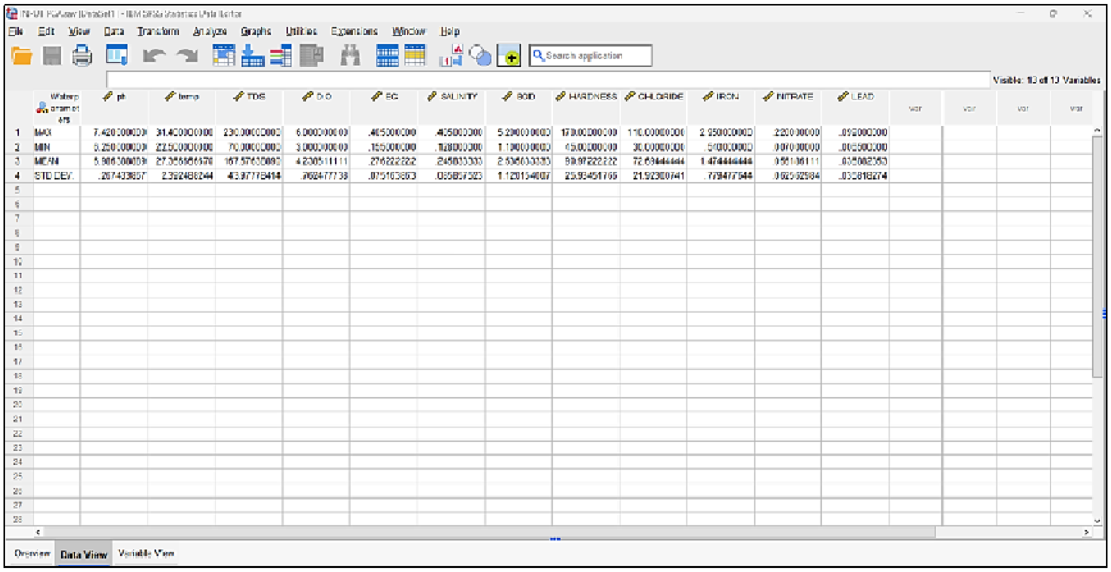


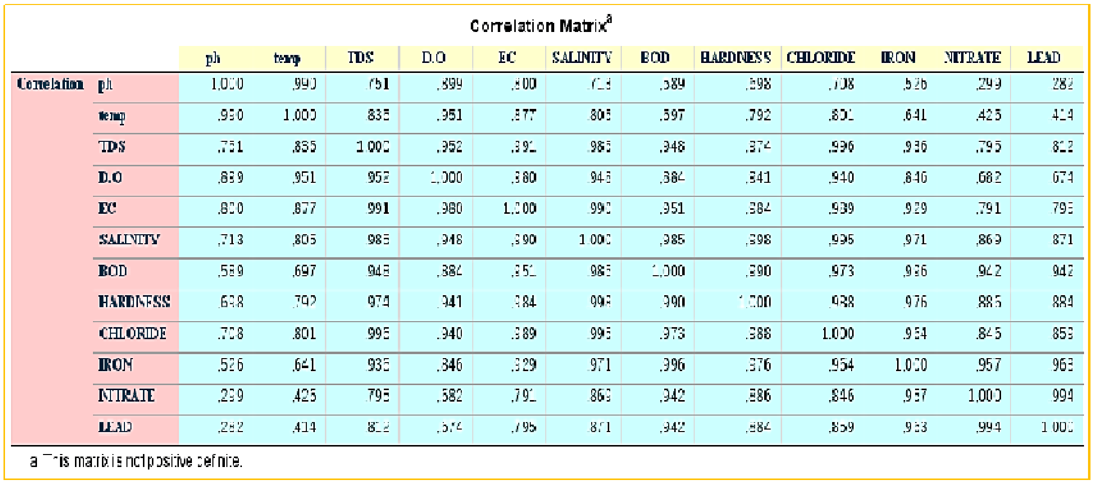
Figure 7.8: Data view dialog window in SPSS.

The pictorial representation figure 7.7 shows the representation of input parameters for Principal component analysis in IBM SPSS Statistics software.

The variables considered for principal component analysis in the form of the ground water parameters are aligned horizontally while the mean, median, mode and standard deviation for the parameters for a period of one year from October 2022 to September 2023 are aligned vertically.

7.4.3 OUTPUT FOR PCA:

7.4.3.1 CORRELATION MATRIX:



Correlation Matrix[a]

		ph	temp	TDS	D.O	EC	SALINITY	BOD	HARDNESS	CHLORIDE	IRON	NITRATE	LEAD
Correlation	ph	1.000	.990	.751	.899	.800	.713	.589	.698	.708	.526	.299	.282
	temp	.990	1.000	.835	.951	.877	.805	.697	.792	.801	.641	.425	.414
	TDS	.751	.835	1.000	.952	.991	.985	.948	.974	.996	.936	.795	.812
	D.O	.899	.951	.952	1.000	.980	.948	.884	.941	.940	.846	.682	.674
	EC	.800	.877	.991	.980	1.000	.990	.951	.884	.939	.929	.791	.795
	SALINITY	.713	.805	.985	.948	.990	1.000	.985	.998	.995	.971	.869	.871
	BOD	.589	.697	.948	.884	.951	.985	1.000	.990	.973	.936	.942	.942
	HARDNESS	.698	.792	.974	.941	.884	.998	.990	1.000	.988	.976	.885	.884
	CHLORIDE	.708	.801	.995	.940	.939	.995	.973	.988	1.000	.954	.845	.859
	IRON	.526	.641	.935	.846	.929	.971	.936	.976	.954	1.000	.957	.963
	NITRATE	.299	.425	.795	.682	.791	.869	.942	.886	.846	.957	1.000	.994
	LEAD	.282	.414	.812	.674	.795	.871	.942	.884	.859	.963	.994	1.000

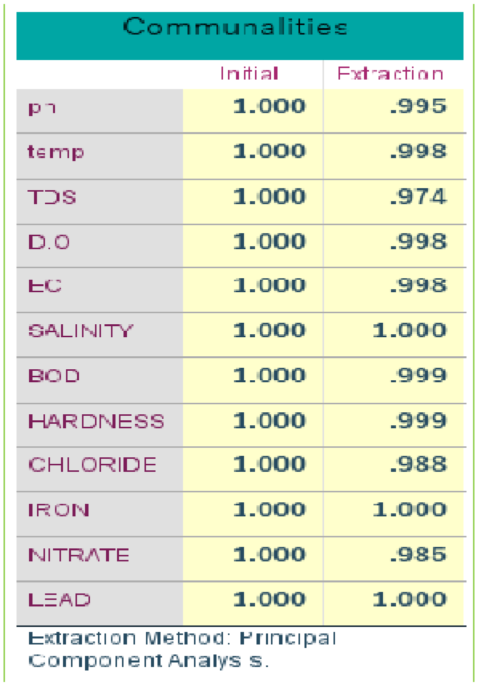
a. This matrix is not positive definite.

Figure 7.9: Correlation matrix of ground water parameters.

The figure above shows the correlation among the variables (ground water parameters) which forms a base for running factor analysis. This matrix is prepared by the software since the input data available has different scales like temperature, conductivity , dissolved oxygen etc. So principal component analysis prepare this correlation matrix in order to standardize by their standard deviation so the total variance is equal to one

7.4.3.2 COMMUNALITIES:

This is the proportion of each variable’s variance that can be explained by the factors It is also noted as h^2 and can be defined as the sum of squared factor loadings for the variables. It is generally the sum of the squared component loadings up to the number of components that is to be extracted by the extraction method available in principal component analysis (Vogt, 1999).



Communalities

	Initial	Extraction
pH	1.000	.995
temp	1.000	.998
TDS	1.000	.974
D.O	1.000	.998
EC	1.000	.998
SALINITY	1.000	1.000
BOD	1.000	.999
HARDNESS	1.000	.999
CHLORIDE	1.000	.988
IRON	1.000	1.000
NITRATE	1.000	.985
LEAD	1.000	1.000

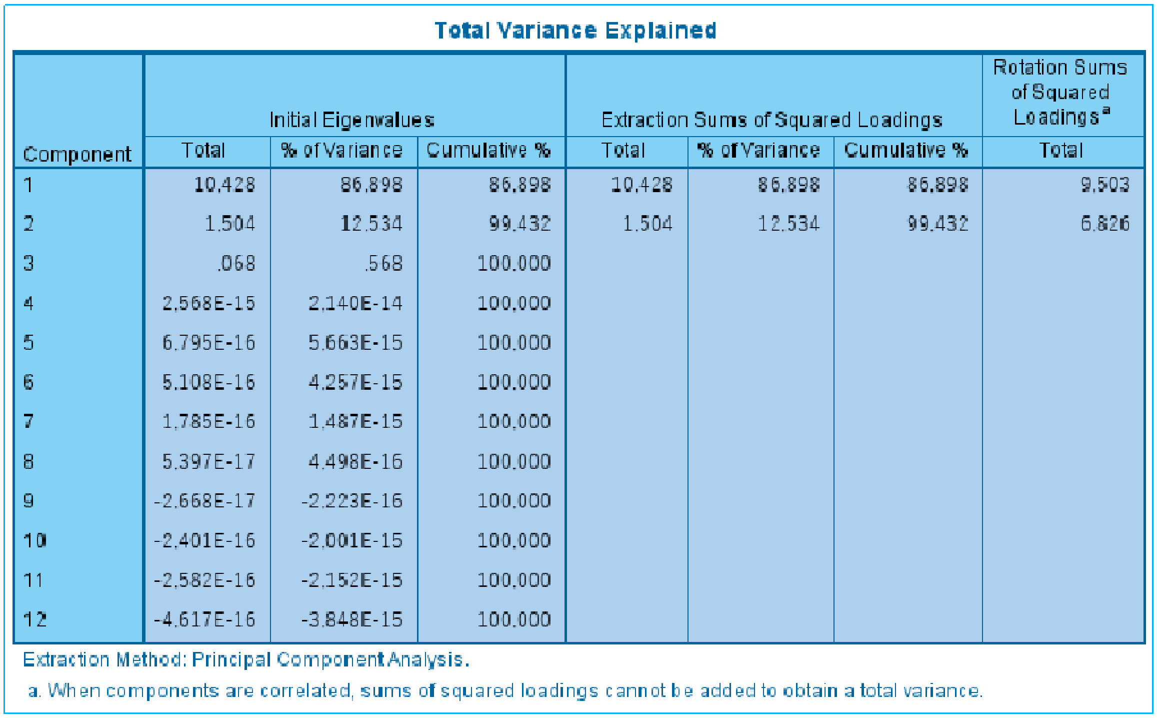
Extraction Method: Principal Component Analysis.

Figure 7.10: Extraction method of Principal Component Analysis

It represents the communalities for the various ground water parameters. The closer the communality is to 1, the better the variable is explained by the factors .Since the extraction values show positive 1.0 for Salinity, Iron content and Lead, it concludes that this parameters show some significant importance in our ground water samples for a period of one year and this parameters are properly explained by the factors during PCA

7.4.3.3 TOTAL VARIANCE SET:

Total variance in factor analysis is the amount of variation in the original variables that can be explained by the factors. The sum of all eigen values, which are the squared factor loadings, equals the total number of variables. Factor analysis seeks to find linear combinations of factors that account for the covariances in the data, while principal components seeks to find linear combinations of variables that explain the total variance.



Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	10.428	86.898	86.898	10.428	86.898	86.898	9.503
2	1.504	12.534	99.432	1.504	12.534	99.432	6.826
3	.068	.568	100.000				
4	2.568E-15	2.140E-14	100.000				
5	6.795E-16	5.663E-15	100.000				
6	5.108E-16	4.257E-15	100.000				
7	1.785E-16	1.487E-15	100.000				
8	5.397E-17	4.498E-16	100.000				
9	-2.668E-17	-2.223E-16	100.000				
10	-2.401E-16	-2.001E-15	100.000				
11	-2.582E-16	-2.152E-15	100.000				
12	-4.617E-16	-3.848E-15	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Figure 7.11: Summary of Total Variance Data.

It depicts the number of components the data variables are grouped in. From this we interpret it to have two number of principal components that govern the ground water quality in the study area. The components having initial eigen values greater than one are considered for the analysis.

7.4.3.4 SCREE PLOT:

Scree plot is a graphical that shows the explained variance per newly defined component (principal component). The measure of the plot can be the percentage or the absolute value of the explained variance (eigenvalues). It is common in practice that the first few principal components explain the major amount of variance.

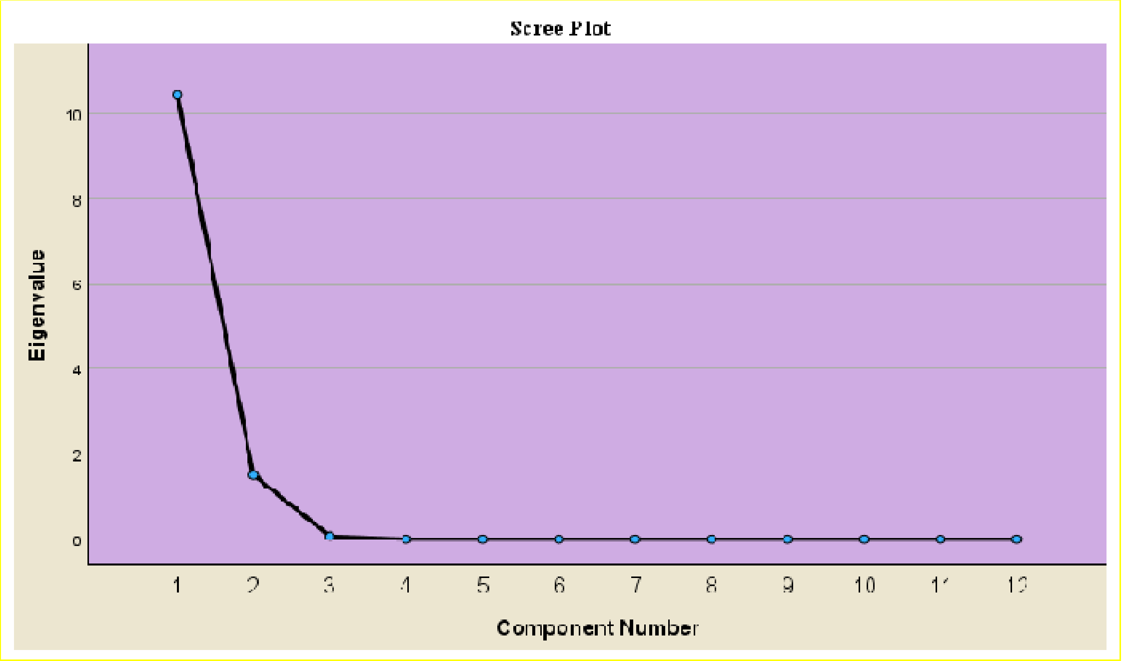
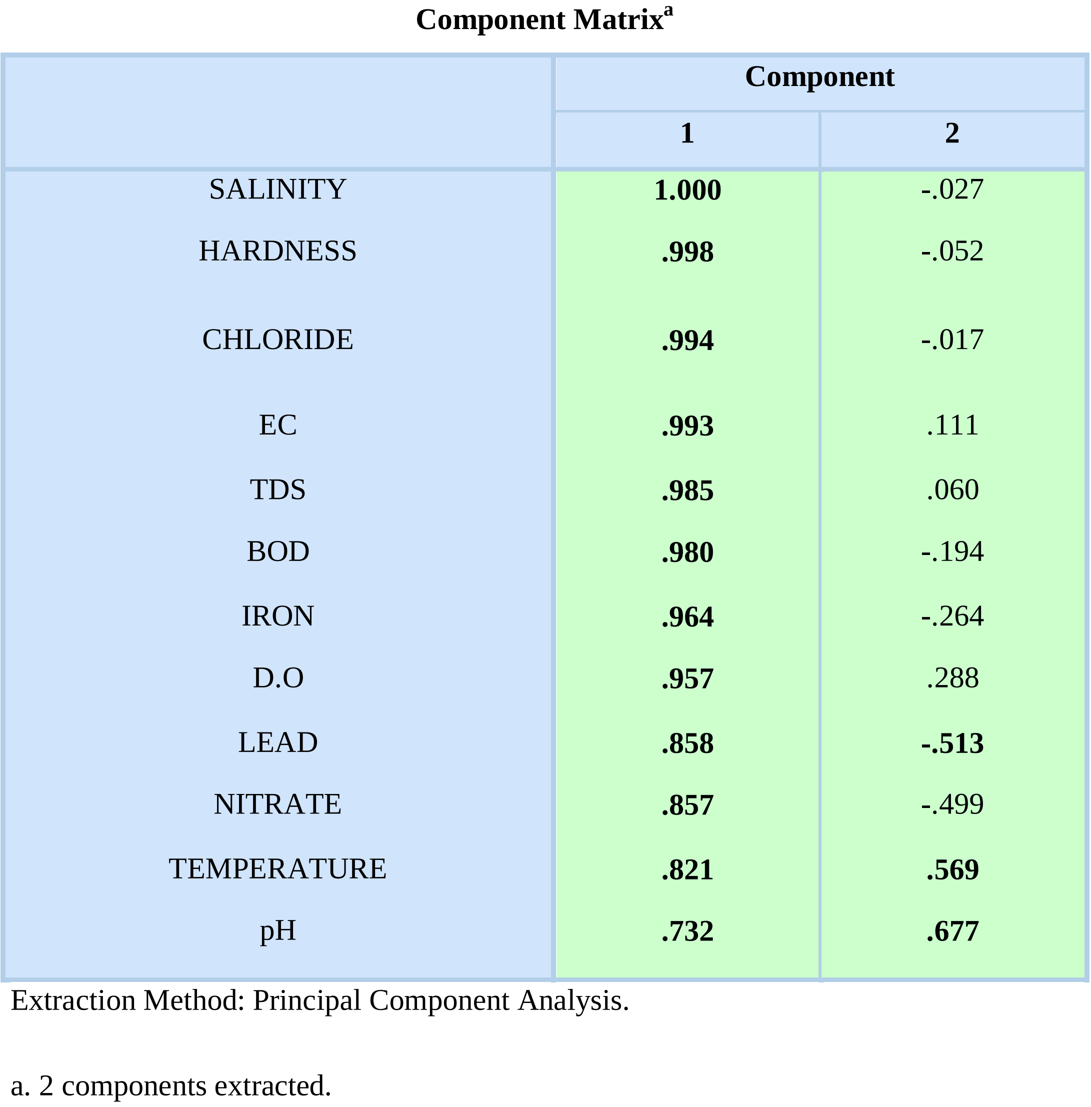


Figure 7.12: Graphical representation of Scree plot.

The plot above represents the component number along with the eigen values in our study area. The eigen values greater than 1 are considered as the principal components. Here, in our study area the principal number of components present is two set of components.

7.4.3.5 COMPONENT MATRIX IN PCA:

The components can be interpreted as the correlation of each item with the component in the form of a component matrix. Each item has a loading corresponding to each of the components. For example, item 1 is correlated with the first component, with the second component and with the third and so on.



Component Matrix[a]

	Component	
	1	2
SALINITY	**1.000**	-.027
HARDNESS	**.998**	-.052
CHLORIDE	**.994**	-.017
EC	**.993**	.111
TDS	**.985**	.060
BOD	**.980**	-.194
IRON	**.964**	-.264
D.O	**.957**	.288
LEAD	**.858**	**-.513**
NITRATE	**.857**	-.499
TEMPERATURE	**.821**	**.569**
pH	**.732**	**.677**

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Figure 7.13: Component Matrix in SPSS

The figure shows the component matrix obtained from the extraction method that was run for factor analysis. Since it shows correlation among the variables (ground water parameters) and the factor components (two set of components) the values range from -1 to +1. The ground water quality parameters represent the variables.

These correlations are obtained using the correlation procedure. In the variable statement, we include the first two principal components, "principal component 1 and principal component 2, in addition to all twelve of the original variables. We use the correlations between the principal components and the original variables to interpret these principal components.

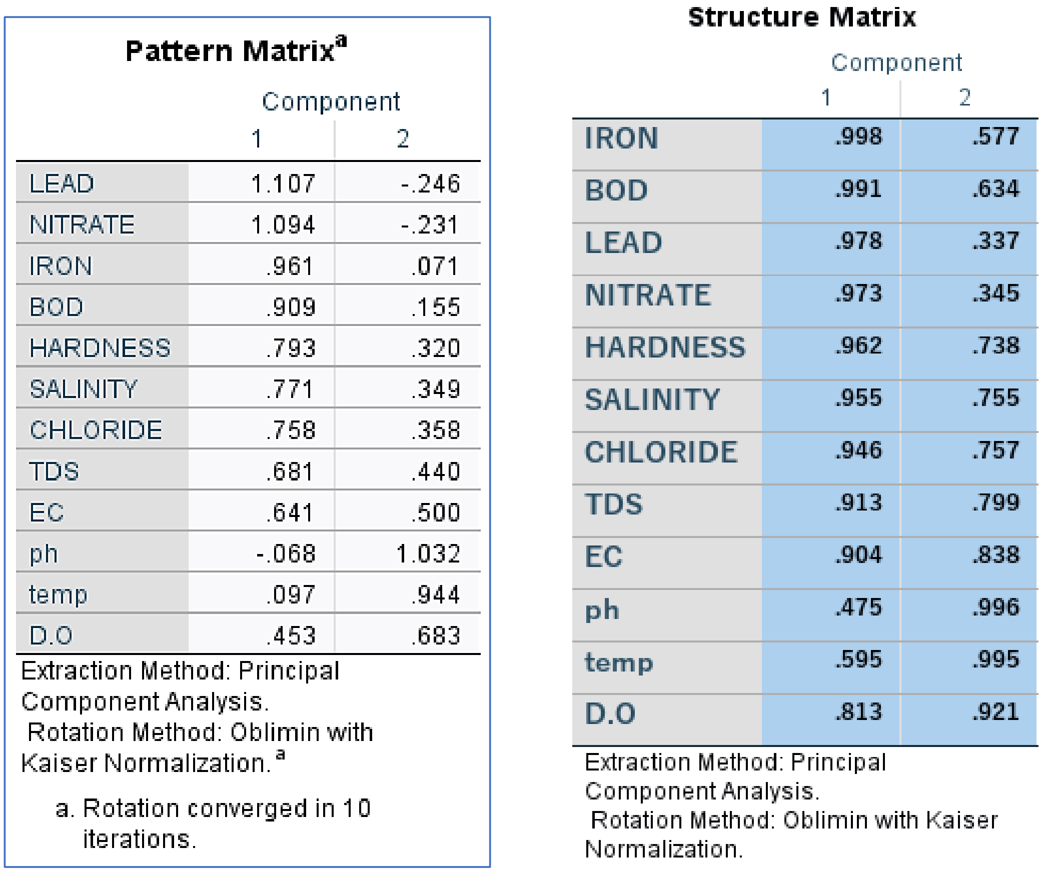
Because of standardization, all principal components will have a mean of 0. The standard deviation is also given for each of the components and these are the square root of the eigenvalue. Interpretation of the principal components is based on finding which variables are most strongly correlated with each component, i.e., which of these numbers are large in magnitude, the farthest from zero in either direction. Which numbers we consider to be large or small is of course a subjective decision. You need to determine at what level the correlation is of importance. Here a correlation above 0.5 is deemed important. These larger correlations are in boldface in the figure 7.12.

Principal component 1 shows all the variables are strongly correlated. These variables vary together according to principal factor 1. However ground water parameter in the form of lead show negative correration according to principal factor 2. This component depicts our analysis unhealthy in the form of lead and minor danger in the form of iron and nitrate content.

7.4.3.6 PATTERN MATRIX AND STRUCTURE MATRIX:

When the rotation is orthogonal (i.e. the factors are uncorrelated; orthogonal and uncorrelated are synonymous), then the rotated factor matrix represents both the loadings and the correlations between the variables and factors. For oblique rotations, where the factors are allowed to correlate (oblivion or promax in SPSS), then the loadings and correlations are distinct. The pattern matrix holds the loadings. Each row of the pattern matrix is essentially a regression equation where the standardized observed variable is expressed as a function of the factors. The loadings are the regression coefficients. The structure matrix holds the correlations between the variables and the factors.

Interpretation of a set of oblique factors involves both the pattern and structure matrices, as well as the factor correlation matrix. The latter matrix contains the correlations among all pairs of factors in the solution. It is automatically printed for an oblique solution when the rotated factor matrix is printed.



Pattern Matrix[a]

	Component 1	Component 2
LEAD	1.107	-.246
NITRATE	1.094	-.231
IRON	.961	.071
BOD	.909	.155
HARDNESS	.793	.320
SALINITY	.771	.349
CHLORIDE	.758	.358
TDS	.681	.440
EC	.641	.500
ph	-.068	1.032
temp	.097	.944
D.O	.453	.683

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.[a]

a. Rotation converged in 10 iterations.

Structure Matrix

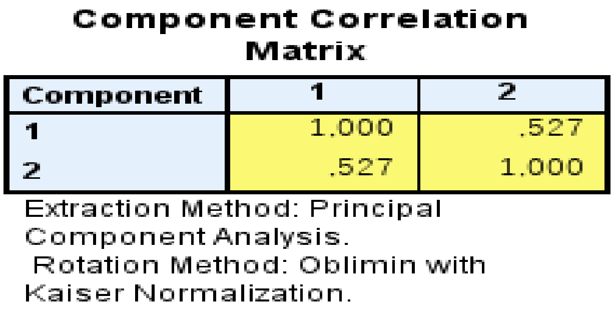
	Component 1	Component 2
IRON	.998	.577
BOD	.991	.634
LEAD	.978	.337
NITRATE	.973	.345
HARDNESS	.962	.738
SALINITY	.955	.755
CHLORIDE	.946	.757
TDS	.913	.799
EC	.904	.838
ph	.475	.996
temp	.595	.995
D.O	.813	.921

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Figure 7.14 : Pattern Matrix and Structure Matrix in SPSS

The figure above shows the output results in our principal analysis in the form of pattern and structure matrix. The replicability and strength of a component are determined by the number of variables per factor or component. A good rule is that a minimum of 4 variables is recommended per factor. All items that load on to factor should have a score of greater than .40 on the pattern matrix. As we can see on the output, the pattern matrix and the structure matrix clearly shows the loadings of each item onto the two factors. It is important to note that there are two distinct factors, with few poor loadings (i.e., < .40) represented by pH and temperature for factor 1 and iron, lead, nitrate, hardness and salinity for factor component 2. Cross loadings (having scores greater than .40 on more than one factor) represented by total dissolved solids and dissolved oxygen can be seen in the pattern matrix. In the structure matrix above, lead and nitrate show poor loadings. If there were any poor loadings/cross loadings, these items would be removed for the next round of principal component analysis.

7.4.3.7 COMPONENT CORRELATION MATRIX:



Component Correlation Matrix

Component	1	2
1	1.000	.527
2	.527	1.000

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Figure 7.15: Component Correlation Matrix.

The above figure shows the summary of the component correlation matrix which shows the correlation among the two principal components.

7.5 K-MEANS CLUSTER ANALYSIS:

K-Means Clustering is an unsupervised learning algorithm which groups the unlabelled dataset into different clusters. Here K defines the number of pre-defined clusters that need to be created in the process, as if K=2, there will be two clusters, and for K=3, there will be three clusters, and so on.

It allows us to cluster the data into different groups and a convenient way to discover the categories of groups in the unlabeled dataset on its own without the need for any training.

It is a centroid-based algorithm, where each cluster is associated with a centroid. The main aim of this algorithm is to minimize the sum of distances between the data point and their corresponding clusters.

The algorithm takes the unlabelled dataset as input, divides the dataset into k-number of clusters, and repeats the process until it does not find the best clusters. The value of k should be predetermined in this algorithm. (Zubair M et.al, 2022)

The k-means clustering algorithm mainly performs two tasks:

- Determines the best value for K centre points or centroids by an iterative process.
- Assigns each data point to its closest k-centre. Those data points which are near to the particular k-centre, create a cluster.

Hence each cluster has datapoints with some commonalities, and it is away from other clusters.

7.5.1 INPUT FOR K-MEANS CLUSTERING

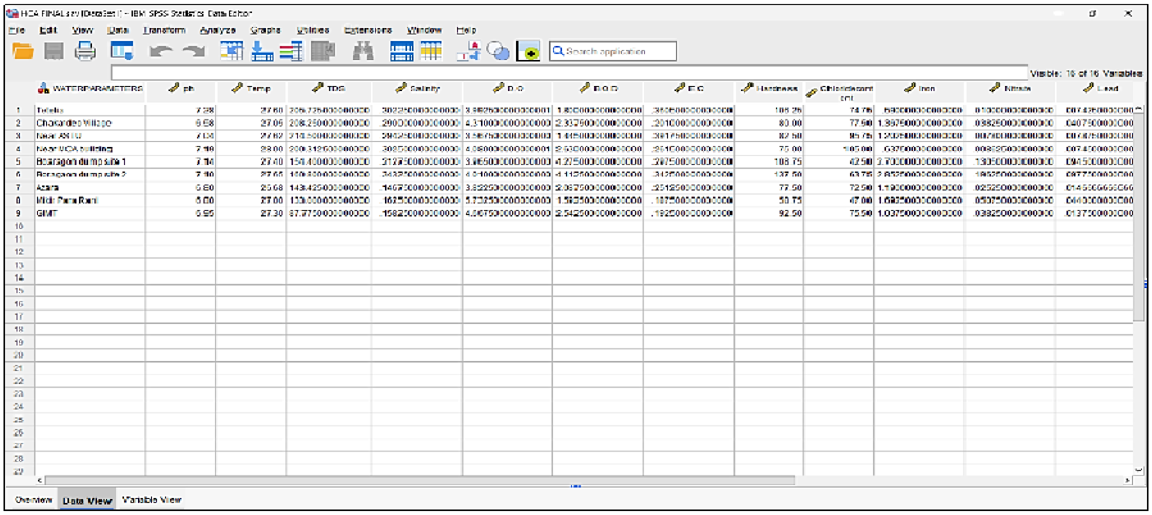


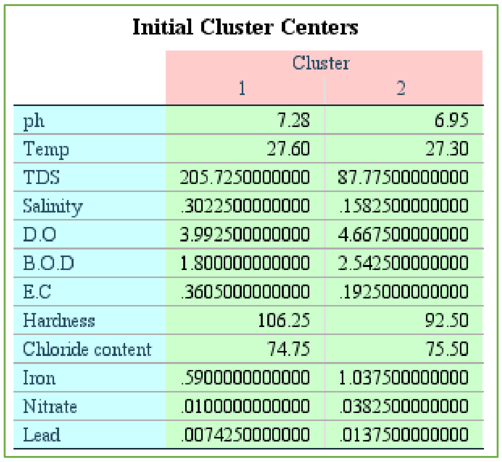
Figure 7.16: Data view dialog window in SPSS.

It represents the input data set in SPSS software to run K-means clustering analysis. The same input is presented as that in Hierarchical Cluster Analysis.

7.5.2 OUTPUT RESULTS:

7.5.2.1 INITIAL CLUSTER CENTERS:

In iterative clustering algorithms the procedure adopted for choosing initial cluster centers is extremely important as it has a direct impact on the formation of final clusters. Since clusters are separated groups in a feature space, it is desirable to select initial centers which are well separated.



Initial Cluster Centers

	Cluster	
	1	2
ph	7.28	6.95
Temp	27.60	27.30
TDS	205.7250000000	87.77500000000
Salinity	.3022500000000	.1582500000000
D.O	3.992500000000	4.667500000000
B.O.D	1.800000000000	2.542500000000
E.C	.3605000000000	.1925000000000
Hardness	106.25	92.50
Chloride content	74.75	75.50
Iron	.5900000000000	1.037500000000
Nitrate	.0100000000000	.0382500000000
Lead	.0074250000000	.0137500000000

Figure 7.17: Initial Clusters

7.5.2.2 FINAL CLUSTER CENTERS:

The final cluster centers are computed as the mean for each variable within each final cluster. The final cluster centers reflect the characteristics of the typical case for each cluster.

The final cluster centroids may not be the optimal ones as the algorithm can converge into local optimal solutions. An empty cluster can be obtained if no points are allocated to the cluster during the assignment step. Therefore, it is quite important for *k*-means to have good initial cluster centers.

Final Cluster Centers

	Cluster	
	1	2
pH	7.06	6.85
Temp	27.55	26.99
TDS	190.66	121.40
Salinity	.29	.16
D.O	3.99	4.74
B.O.D	2.76	2.07
E.C	.30	.21
Hardness	98.33	76.25

Chloride content	76.54	65.00
Iron	1.56	1.30
Nitrate	.07	.04
Lead	.04	.02

Figure 7.18: Final Clusters.

The figure above represents the final cluster centroids obtained from the initial cluster centroids within our study area.

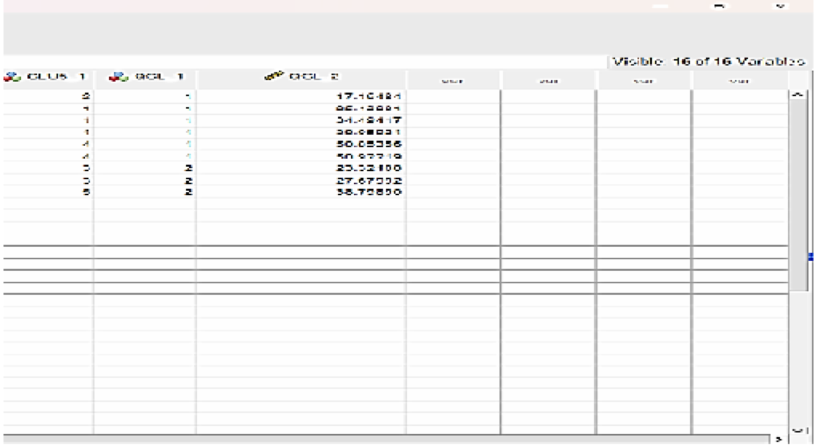
7.5.2.3 NUMBER OF CASES IN EACH CLUSTER:

Number of Cases in each Cluster		
Cluster	**1**	6.000
	2	3.000
Valid		9.000
Missing		.000

Figure 7.19: Summary of K-Means analysis

The above figure shows the number of cases (site names) along with the cluster numbers they are placed. This shows the summary of interpretation of the hierarchical cluster analysis in the form of K- means cluster analysis.

The number of clusters formed from our study analysis is shown to be of two set of clusters. In our study area through K-means algorithm we interpret six number of sites to belong to cluster number one and the other three sites are considered to fall in cluster two.



CLU5_1	QCL_1	QCL_2
2	1	17.10484
1	1	[illegible]
1	1	[illegible]
1	1	[illegible]
4	1	50.05356
4	1	50.97719
3	2	23.32100
3	2	27.67332
5	2	38.72850

Figure 7.20: K-Means output dialog window in SPSS

The figure above shows the proper interpretation of the sites with respect to the clusters achieved from hierarchical cluster analysis. Site number 6 and site number 7 near Boragaon dumping area belongs to the same sub cluster number 4. Chakardeo village, near ASTU and near MCA building of AEC belongs to the same sub cluster number one.

The sites near Azara, GIMT and Mikir Para belongs to the same set of main cluster represented by cluster 2. The other remaining sites belong to cluster 1.

CHAPTER 8

DISCUSSIONS

According to Islam, M. *et al.* (2014**)** in their journal paper "Studies on physio-chemical properties of ground water in some selected sites of Deepor Beel, Assam, India" tested various water samples from 10 different locations based on factors like inlet, outlet, dumping etc. Samples were collected from the study sites during the pre-monsoon seasons and post monsoon seasons of 2009 and 2010. The water quality parameters include temperature, colour, odour, D.O, BOD, Chloride, Fluoride, Calcium and Magnesium. The parameters considered for analysis was done following the methods of American Public Health Association (APHA, 2005). One way analysis of variance (ANOVA) was done to check if any significant differences existed states Cluster analysis was performed taking water variables as parameters to evaluate similarity among the sites. Here ANOVA analysis showed F-Ratio (1.83) > 1 and p-value << 0.06, which indicated water parameters differ with location.

According to Leal W *et.al* (2016) in their journal paper represented dendrograms in graph theoretical terms which allowed it to introduce four measures of cluster frequency in a canonical way, and use them to calculate cluster frequencies over the set of all possible dendrograms, taking all ties in proximity into account. A toy example of well separated clusters was used, as well as a set of 1666 molecular descriptors calculated for a group of molecules having hepatotoxic activity to show how our functions may be used for studying the effect of ties in HCA analysis. Such functions were not restricted to the tie case; the possibility of using them to derive cluster stability measurements on arbitrary sets of dendrograms having the same leaves is discussed, e.g. dendrograms from variations of HCA parameters. It was found that ties occurred frequently, some yielding tens of thousands of dendrograms, even for small data sets.

In their journal paper by Prakash M *et.al* (2011) titled ' Application of Cluster Analysis to Phisico-Chemical Parameters of Munj Sagar Talab , MP' states higher values of cophenetic correlation which indicates good similarity between data matrix of parameters and dendrogram, the conducted cluster analysis stands justified. They concluded that the cluster analysis of station S1 and S3 indicates that they are alike on the basis of phyico-chemical nature. However station S3 showed slight variation from S1 and S2 in cluster forming showed that its physico chemical properties are different from station S1 and S3. This may be due to the presence of anthropogenic activities which were absent in station 1 and 3.

As per the journal paper titled ‘ Fctor and Cluster Analysis of Water Quality Data of the Groundwater Wells of Kushtia, Bangladesh’ by Hossain Md *et. al* (2013) describes multivariate statistical analyses including factor analysis, cluster analysis and multidimensioning scaling for twenty six groundwater samples collected from both shallow and deep tube wells rangng from 20-60 m in depth. The results show that a few factors adequately represents the traits that define water chemistry. According to this, the physico-chemical parameters are groupedin three different principal components or factors. Also with the hierarchical cluster analysis for the study area, it states that the water samples have been classified into 3 clusters. They are very high, high and moderately as enriched groundwater as well as groundwater with elevated SO4.

In our study area near Deepor Beel, nine stations were selected for the analysis to be carried out. Nine groundwater samples from various sources of shallow and deep tube wells ranging from 100 ft (30.48 m) to 150 ft (45 m) in depth were collected using standard methods of collections and procedures(Islam M *et. al, 2014).* These samples were tested for twelve different phisico-chemical and heavy metal ground water parameters. Various multivariate data analyses were carried out for these nine different ground water samples. These analyses were being interpreted in IBM SPSS software package downloaded from the official website of IBM. Principal Component Analysis (PCA), Heirarchical Cluster Analysis (HCA), K- Means Cluster analysis and One way ANOVA.

The various nput data for these analysis to run and the out dta results obtained from the SPSS software are clearly being represent int above chapter. From one way ANOVA we get to know that the null hypothesis is rejected if F-ratio>F-critical and $p \leq 0.05$ I.e., the parameters show a significant difference. Otherwise, the null hypothesis is accepted that concludes that there is no significant differences within or between the groups. In our study area, all the parameters show values of F-ratio < F-critical and $p \geq 0.05$ which results in no significant differences among the parameters for a span of one year within our prescribed time period. Only the on-field temperature showed a significant difference for the selected time period.

The output results obtained for hierarchical cluster analysis shows the number of clusters the stations are grouped in which was done on the basis of the concentration of the ground water variables which keeps on showing slight variation for aperiod of one year from October 2022 to September 2023. This similarity or dissimilarity behaviour of the stations are represented in a mtrix having the values of squared Euclidean distance. In our study area the station 1(near ASTU) and station 2(near MCA building, AEC) shows value of small Euclidean distances. Similary station 6 and station 7 near Boragaon landfill area shows the same type of pattern. This infers that these sites are somehow similar in terms of the concentration of the ground water parameters during our time of study . Also higher values of the squared Euclidean distances can be seen for station 8 (near GIMT) and station 4 (chakardeo village, gorchuk). Same behaviour can be seen fir station 9 (near Azara) and station 5 (Mikir Para, Rani). From these various sub clustes are obtained in the next output result for HCA. Five subclusters were obtained and two main clusters are obtained which can be seen in a dendroram plot. The interpretation of hierarchical cluster analysis were dne by the method of K-Means Cluster analysis available in the SPSS software.

In the results obtained from K-Means we infer which stations belong to which clusters in a more proper way. The K-Means analysis describes that there are six stations that falls in the category of cluster 1. These stations includes station 3 (Tetelia), station 4 (Chakardeo village), station 1 (near ASTU), station 2 (near MCA, AEC), station 6 and station 7 near Boragaon landfill area. The other cluster includes station 5, 8, 9 belongong to the areas near Mikir Para(Rani), GIMT and Azara respectively. These were calculated on the basis of the distance from the cluster centroids to the respective source of groundwater samples.

Further from the analysis done by Principal Component Analysis(PCA) in the SPSS software results in the formation of two sets of principal components or factors. These two sets are being obtained on the basis of the input data provided. Various matrices of component , pattern and structure matrix are obtained.. The components were decided by the SPSS software using the eigen values . Since in our results, only two components having eigen values greater than 1 cab be found from the explaination of the total variance set. This is again demonstrated in the form of scree plot. It is a clear plot between the eigen values and the component number.

Method of extraction was carried out in our sanalysis for the groundwater samples. It shows extraction value of positive 1 from initial loadings (+ve) for the ground water parameters like salinity, iron and lead content. It shows that these parameters are properly explained by the two set of components. The component matrix shows all the parameters to be of equal importance for prinvipal component number one as it gas coefficients values greater than 0.5. Similarly, temperature, lead content and ph values sows coefficient greater than positive or negative 0.5 which depicts the importance of these parameters in the principal component 2. Thus, a finer conclusion was obtained from the analysis which shows a similarity between these two principal set of components or factors.

CHAPTER 9

SOLUTE TRANSPORT MODEL: HYDRUS-1D

9.1 INTRODUCTION TO HYDRUS:

HYDRUS is a software package which is used widely for simulation of movement of water, heat and solute transport through unsaturated, partially saturated, or fully saturated porous media. This package consists of basically modelling in 1D, 2D and 3D. In this study, HYDRUS-1D computer codes will be used for simulation solute transport through saturated porous medium. Usually, flow movement and solute transport can take place in vertical, horizontal, or in an inclined direction. Generally, the software consists of different varieties of computation modules such as the standard direct module, the standard inverse module, a dual-permeability direct module, a dual-permeability inverse module, the Unset Chem module for major ion chemistry and transport, and the HP1 module for multicomponent transport as well as the HYDRUS-1D interactive graphics-based user interface.

The HYDRUS-1D program basically works on numerically solving the Richards equation for variably-saturated water flow and advection-dispersion type equations for heat and solute transport. The solute transport equations used in HYDRUS-1D package considers the advective-dispersive transport in the liquid phase, as well as diffusion in the gaseous phase. Moreover, this program is coded to simulate models with different water flow and solutes transport boundary conditions (Simunek, et al., 2009).

9.2 GENERAL INFORMATION

9.2.1 WATER FLOW:

Water under the land surface occurs mainly in two zones, the saturated zone and the unsaturated zone. Unsaturated zone is characterized by the filling up of the voids between the particles with water as well as with air. On contrary, the voids in the saturated zone are completely filled with water. The top surface of the saturated zone is referred to as the water table. An intermediate layer exists between the unsaturated and the saturated zone of water profiles. This zone can be termed as the transition zone, with some voids being saturated or almost saturated with water that is held by the capillary fringe.

Richard's equation for variably-saturated flow is a combination of mass balance equation and Darcy-Buckhimgam equation.

The mass balance equation states that the rate of change of saturation in a closed volume is equal to the rate of change of the total sum of fluxes into and out of that volume. Mathematically, this equation can be written as,

$$\frac{\partial\theta}{\partial t} = \frac{-\partial q}{\partial z} \qquad (9.1)$$

Where θ is the volumetric water content, [L^3L^{-3}], t is time [T], q is the volumetric flux density [LT^{-1}], z is the spatial coordinate [L].

Darcy's law (1856) stated that the flow rate Q through pipe filled with a sand was directly proportional to its cross-sectional area A and to the difference of hydraulic head h across the layer, and inversely proportional to the length of the pipe:

$$Q = - KA\frac{h_2 - h_1}{L} \qquad (9.2)$$

Where, coefficient of proportionality K is a hydraulic conductivity, [LT^{-1}].

In 1907, Buckingham executed the Darcy's law to a partly saturated flow. The results obtained from this implementation showed that the hydraulic conductivity is a function of water content i.e K=K(θ). This implies that decrease in θ leads to a significant decrease in K. Thus, Darcy's law for unsaturated flow can be written as,

$$\frac{\partial\theta}{\partial t} = - K(\theta)\frac{\partial h}{\partial z} \qquad (9.3)$$

Where h is hydraulic head and defined as:

$$h = H(\theta) \quad z$$

Richard’s equation for unsaturated flow in vertical direction is formed by combining eqn.(9.2) and eqn.(9.3)

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K(\theta)\left\{\frac{\partial h}{\partial z} + 1\right\}\right] \qquad (9.4)$$

HYDRUS-1D uses the Richard’s equation with slight modification. The one dimensional form of Richard’s equation given by *D.Jacques and Jirka Simunek* (HYDRAS-1D) can be written as :

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(\theta)\left\{\frac{\partial h}{\partial z} + cos\beta\right\}\right] \qquad (9.5)$$

Where,

β is the angle between the flow direction and the vertical axis (i.e β $=0^0$ for vertical flow, 90^0 for horizontal flow and $0^{0<}$ β $<90^0$ for inclined flow), and K is the unsaturated hydraulic conductivity [LT^{-1}] given by (Simunek, et al., 2005).

$$K(h,z) = K_s(r)K_r(h,z)$$

Where, Kr is the relative hydraulic conductivity and Ks the saturated hydraulic conductivity.

9.2.2 SOLUTE TRANSPORT:

Solute transport models through a porous medium in HYDRUS is basically a flow movement a concerned solute of specific concentration considering the porous medium to be a deforming one. The solute transport model in HYDRUS-1D uses advection-dispersion equation for its simulation. For a specified concentration of solute, the flow movement of solute through the soil profile is graphed against various parameters in HYDRUS-1D.

For non-adsorbing solutes during one-dimensional water flow, the equation is given by:

$$\frac{\partial}{\partial t}(\theta C) \mid \frac{\partial}{\partial q}(qC) \quad \frac{\partial}{\partial z}\left(D'\frac{\partial C}{\partial z}\right) = 0 \qquad (9.6)$$

Where, $D^{'} = D(\theta)$ is longitudinal dispersion coefficient.

The equation for the combined flow of solute and moisture movement in the soil profile is given by:

$$\theta(z,t)\frac{\partial C}{\partial t} + q(z,t)\frac{\partial C}{\partial z} - \frac{\partial}{\partial z}\left(D^{'}(z,t)\frac{\partial C}{\partial z}\right) = 0 \qquad (9.7)$$

In most cases the solutions for eqn. (9.7) is obtained by considering that q and D vary slightly near the front over depth but are functions of time. In this case, the eqn. (9.7) can be written as

$$\frac{\partial C}{\partial t} + u(z,t)\frac{\partial C}{\partial z} - D(z,t)\frac{\partial^2 C}{\partial z^2} = 0 \qquad (9.8)$$

Thus, the analytical solution of the advection-dispersion equation is:

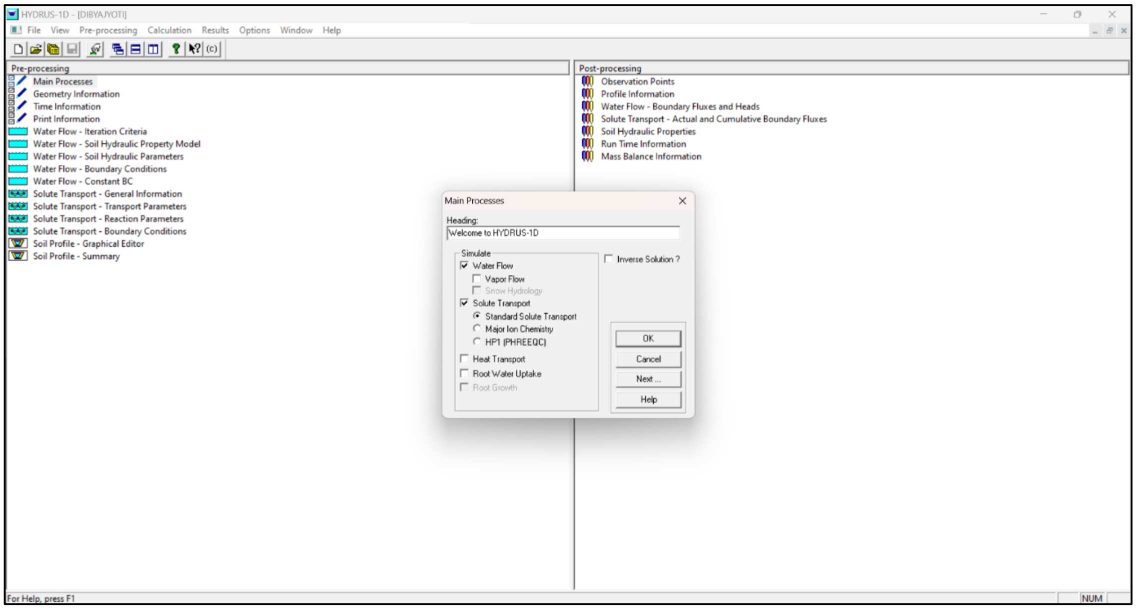
$$C = \frac{1}{2} erfc \frac{z\theta - 1}{\sqrt{4\sigma_l T\theta}} \qquad (9.9)$$

9.3 PRE-PROCESSING OF HYDRUS-1D MODEL:

The HYDRUS model developed for this project is based on the experimental data that indicated the actual soil qualities, conditions of flow and various other parameters of the selected site. These input parameters which are required for the simulation of the HYDRUS-1D model were collected from a previous project outputs of *Kalita et al.,2019.* Also few soil physical properties of Boragaon landfill soil were collected from a previous paperwork of *Kartha et.al, 2020.*

9.3.1 MAIN PROCESSES OF HYDRUS 1-D

The concentration of most of the parameters included in this study was found to be on the higher side near the dump yard area at Boragaon. So, the soil profile selected for the solute transport modelled using HYDRUS-1D is the Municipal dump yard location (site7). The location is assumed to be such that where the leachate from the dump yard flows to the Deepor Beel, and thus one of the highly concentrated solutes(parameter) movement can be studied through the soil profile.



Main Processes

Heading: Welcome to HYDRUS-1D

Simulate

☑ Water Flow

☐ Vapor Flow

☐ Snow Hydrology

☑ Solute Transport

● Standard Solute Transport

○ Major Ion Chemistry

○ HP1 (PHREEQC)

☐ Heat Transport

☐ Root Water Uptake

☐ Root Growth

☐ Inverse Solution ?

Figure 9.1: Main processes dialog window in HYDRUS-1D modeling.

9.3.2 GEOMETRY INFORMATION

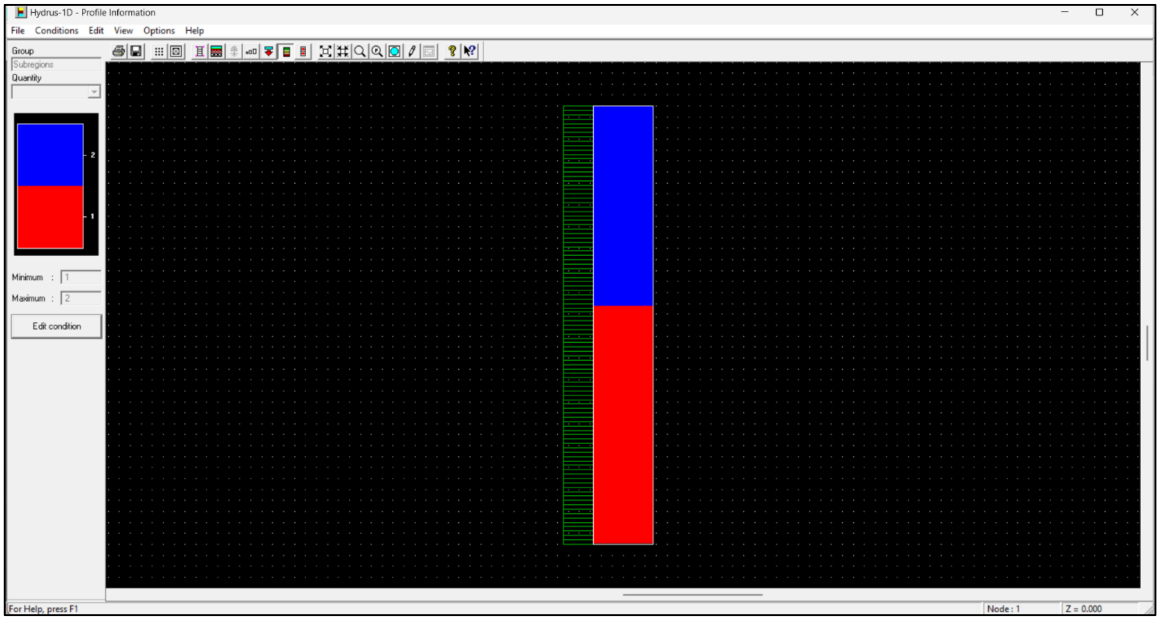
The physical soil properties of Boragaon landfill soil includes specific gravity of soil solids 2.39, bulk density (1447 kg/m3), natural moisture content (26.17%), Porosity (52.01%), saturated hydraulic conductivity (0.000116 m/s), coefficient of uniformity (7.79) and coefficient of curvature (1.43) (Kartha *et al*., 2020).

The soil profile considered for this model has a depth of 200 cm, with two layers of soil subregions. The material composition of the soil around Deepor Beel comprises of sand (47.2 – 53%), clay (23.9 – 31.2%) and silt(17.8-24.9%) (Kalita *et al*., 2019). The subregions of the soil profile consist of:

Subregion 1 – depth from 0 to 90 cm.

Subregion 2 – depth from 90 to 200 cm.

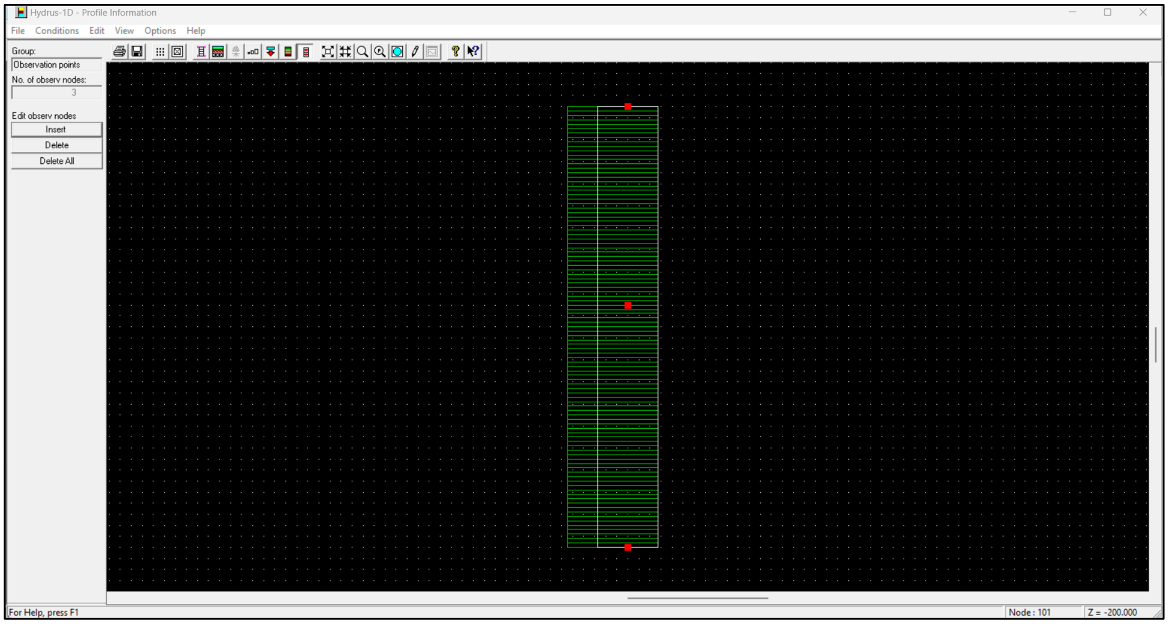
Observation points are marked at z=0 cm, z= 90 cm and z= 200 cm for the solute transport movement with respect to various parameters of soil, depth and time which are presented in graphical form in the HYDRUS-1D program



Group: Subregions
Minimum : 1
Maximum : 2
Node : 1
Z = 0.000

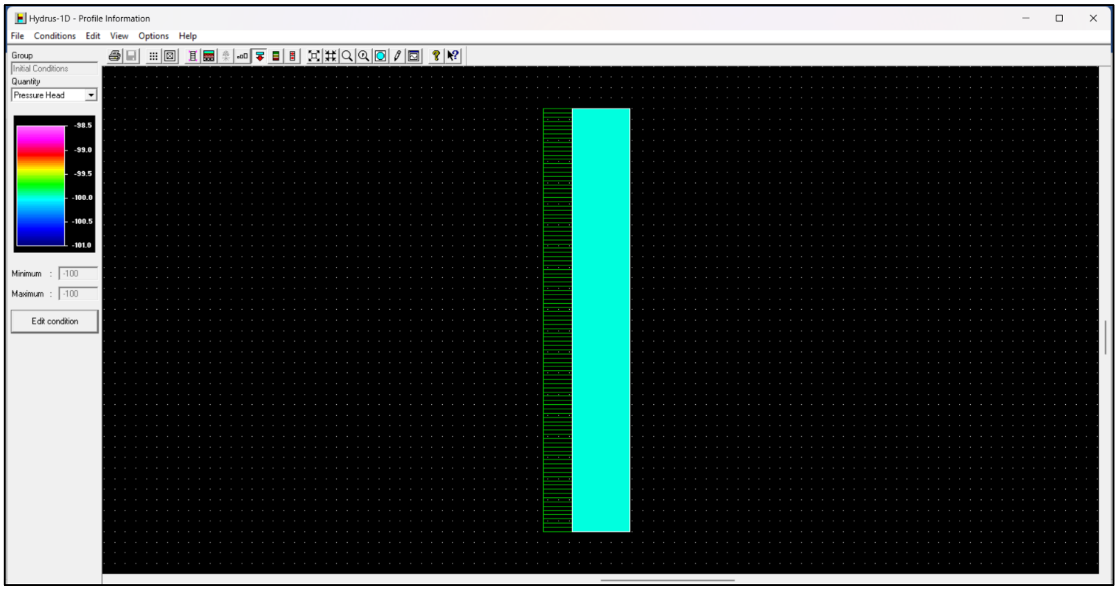
Figure 9.2: Subregion window obtained from soil summary-graphical indicator available in preprocessing modelling of HYDRUS-1D.

The blue region indicates one region from 0cm depth upto 90cm depth. The next region shows depth variation from 90cm to 200cm indicated by red colour depicting the next subregion in our study area.



Group: Observation points
No. of observ nodes: 3
Node : 101
Z = -200.000

Figure 9.3: Observation nodes at z1=0 cm, z2=90 cm and z3=200 cm.



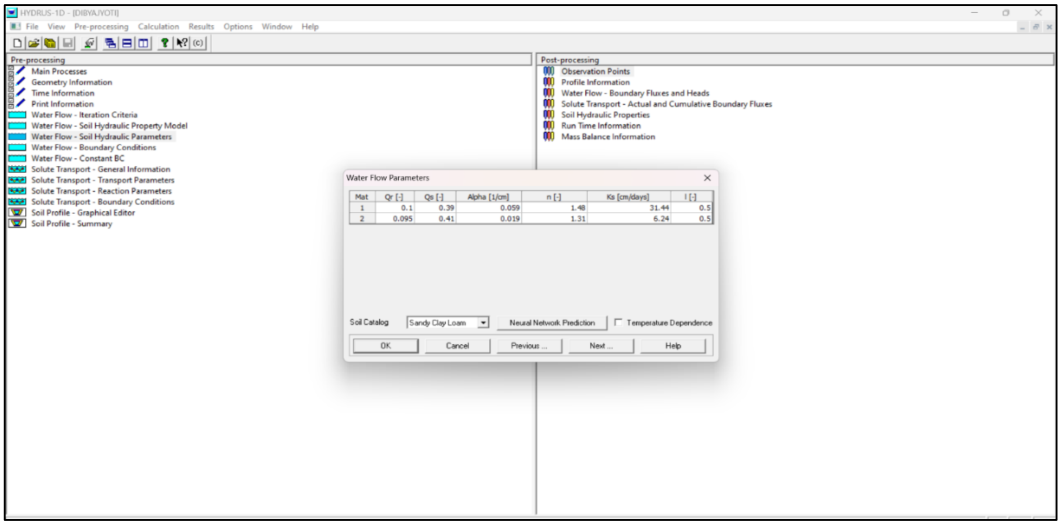
Group: Initial Conditions
Quantity: Pressure Head
Minimum : -100
Maximum : -100

Figure 9.4: Constant pressure head distribution window (HYDRUS 1D).

An Initial constant pressure head is taken as 100cm. negative since acting downwards below GL

9.3.3 SOIL DATA:

The different properties of the soil along with the soil materials present in the concerned soil profile are one of the basic input based on the which the HYDRUS-1D modelled is developed. For the development of the solute transport model, the different soil parameters included in this study are residual water content (θ_r), saturated water content (θ_s), saturated hydraulic conductivity (K_s), pore connectivity parameter (l), empirical coefficients Alpha (α) and n.

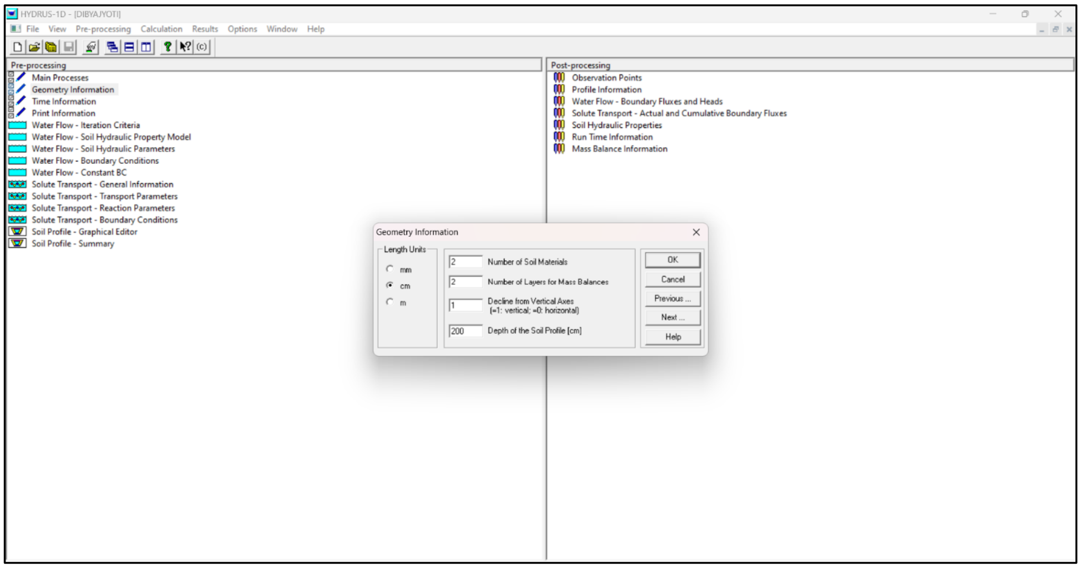


Mat	Qr [-]	Qs [-]	Alpha [1/cm]	n [-]	Ks [cm/days]	l [-]
1	0.1	0.39	0.059	1.48	31.44	0.5
2	0.095	0.41	0.019	1.31	6.24	0.5

Soil Catalog: Sandy Clay Loam

☐ Temperature Dependence

Figure 9.5: Soil property dialog window in HYDRUS-1D.



Length Units: ○ mm ● cm ○ m

2 Number of Soil Materials

2 Number of Layers for Mass Balances

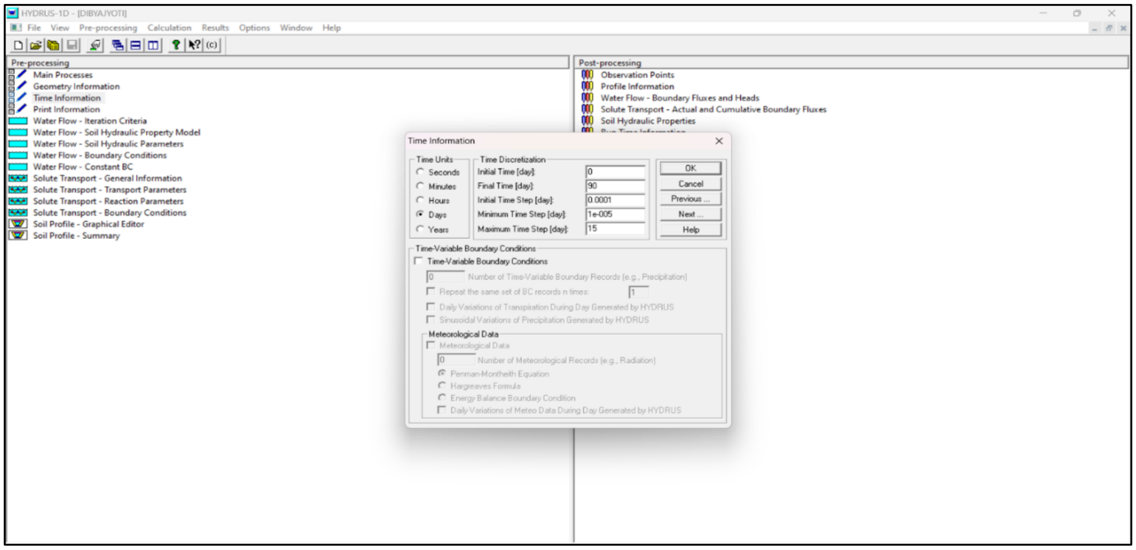
1 Decline from Vertical Axes (=1: vertical; =0: horizontal)

200 Depth of the Soil Profile [cm]

Figure 9.6: Geometry information window in HYDRUS-1D modelling.

9.3.4 TIME INFORMATION AND ITERATION CRITERIA:

The time period for the simulation of this model is 90 days. This time span considered is during October, November, and December 2022.



Time Information

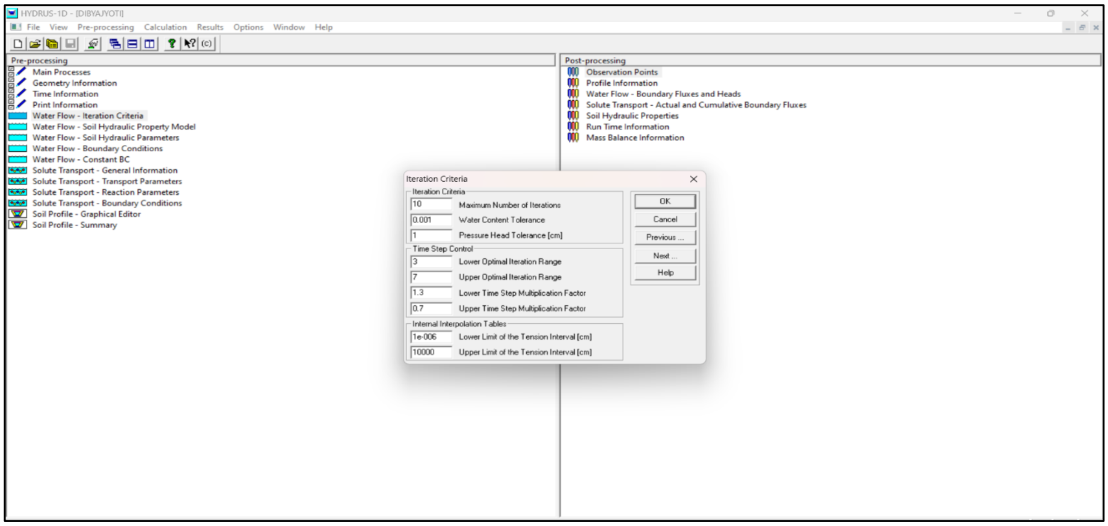
Time Units
○ Seconds
○ Minutes
○ Hours
● Days
○ Years

Time Discretization
Initial Time [day]: 0
Final Time [day]: 90
Initial Time Step [day]: 0.0001
Minimum Time Step [day]: 1e-005
Maximum Time Step [day]: 15

Time-Variable Boundary Conditions
☐ Time-Variable Boundary Conditions
0 Number of Time-Variable Boundary Records (e.g., Precipitation)
☐ Repeat the same set of BC records n times: 1
☐ Daily Variations of Transpiration During Day Generated by HYDRUS
☐ Sinusoidal Variations of Precipitation Generated by HYDRUS

Meteorological Data
☐ Meteorological Data
0 Number of Meteorological Records (e.g., Radiation)
● Penman-Montheith Equation
○ Hargreaves Formula
○ Energy Balance Boundary Condition
☐ Daily Variations of Meteo Data During Day Generated by HYDRUS

Figure 9.7: Time information dialog window (HYDRUS-1D)



Iteration Criteria

Iteration Criteria
10 Maximum Number of Iterations
0.001 Water Content Tolerance
1 Pressure Head Tolerance [cm]

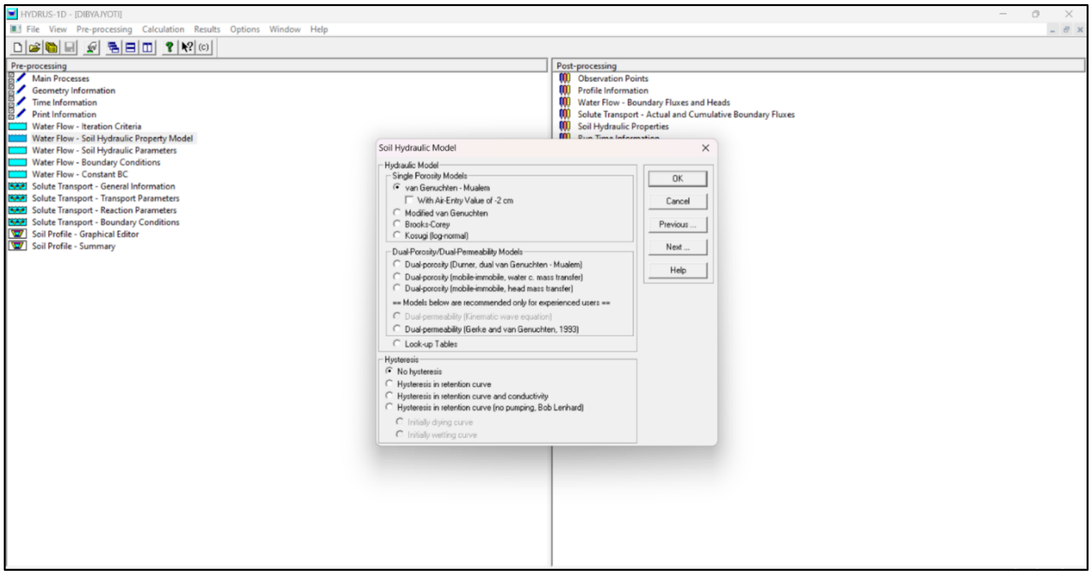
Time Step Control
3 Lower Optimal Iteration Range
7 Upper Optimal Iteration Range
1.3 Lower Time Step Multiplication Factor
0.7 Upper Time Step Multiplication Factor

Internal Interpolation Tables
1e-006 Lower Limit of the Tension Interval [cm]
10000 Upper Limit of the Tension Interval [cm]

Figure 9.8- Iteration criteria dialog box (HYDRUS 1-D)

9.3.5 SOIL HYDRAULIC PROPERTY MODEL:

This command of the HYDRUS-1D defines the various hydraulic models that can be used. For development of flow model van Genuchten-Maulem single porosity model without hysteresis is considered for this study. Single porosity model describes uniform flow in porous media while the other models are applied to simulate preferential flow or transport. In this case Richards' equation and Fickian based convection-dispersion equation for solute transport are solved for the entire flow domain.



Hydraulic Model

Single Porosity Models

● van Genuchten - Mualem

☐ With Air-Entry Value of -2 cm

○ Modified van Genuchten

○ Brooks-Corey

○ Kosugi (log-normal)

Dual-Porosity/Dual-Permeability Models

○ Dual-porosity (Durner, dual van Genuchten - Mualem)

○ Dual-porosity (mobile-immobile, water c. mass transfer)

○ Dual-porosity (mobile-immobile, head mass transfer)

== Models below are recommended only for experienced users ==

○ Dual-permeability (Kinematic wave equation)

○ Dual-permeability (Gerke and van Genuchten, 1993)

○ Look-up Tables

Hysteresis

● No hysteresis

○ Hysteresis in retention curve

○ Hysteresis in retention curve and conductivity

○ Hysteresis in retention curve (no pumping, Bob Lenhard)

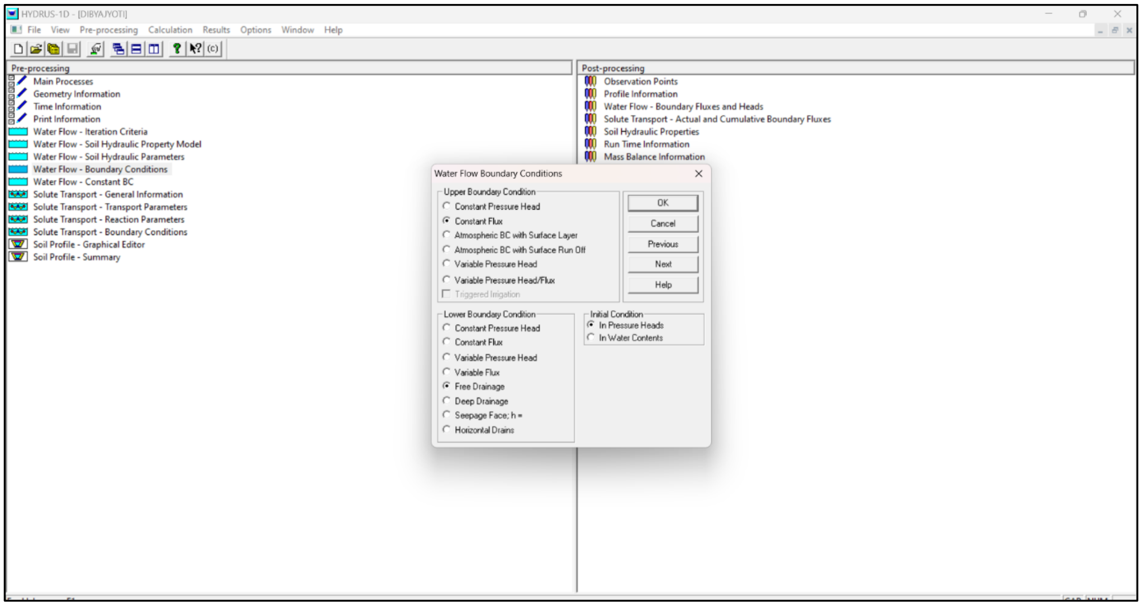
○ Initially drying curve

○ Initially wetting curve

Figure 9.9: Soil hydraulic property model window (HYDRUS-1D) .

9.3.6 FLOW BOUNDARY CONDITIONS:

The boundary conditions that prevails in the upper surface and lower surface of the soil profile considered for this study is defined in this command. The movement of the solute through the soil layers with a constant flow flux is being considered as the upper boundary condition. The lower boundary condition of the water flow is given a free drainage under gravity. An initial constant pressure head is assumed at -100 cm for the entire flow.



Water Flow Boundary Conditions

Upper Boundary Condition
- ○ Constant Pressure Head
- ● Constant Flux
- ○ Atmospheric BC with Surface Layer
- ○ Atmospheric BC with Surface Run Off
- ○ Variable Pressure Head
- ○ Variable Pressure Head/Flux
- ☐ Triggered Irrigation

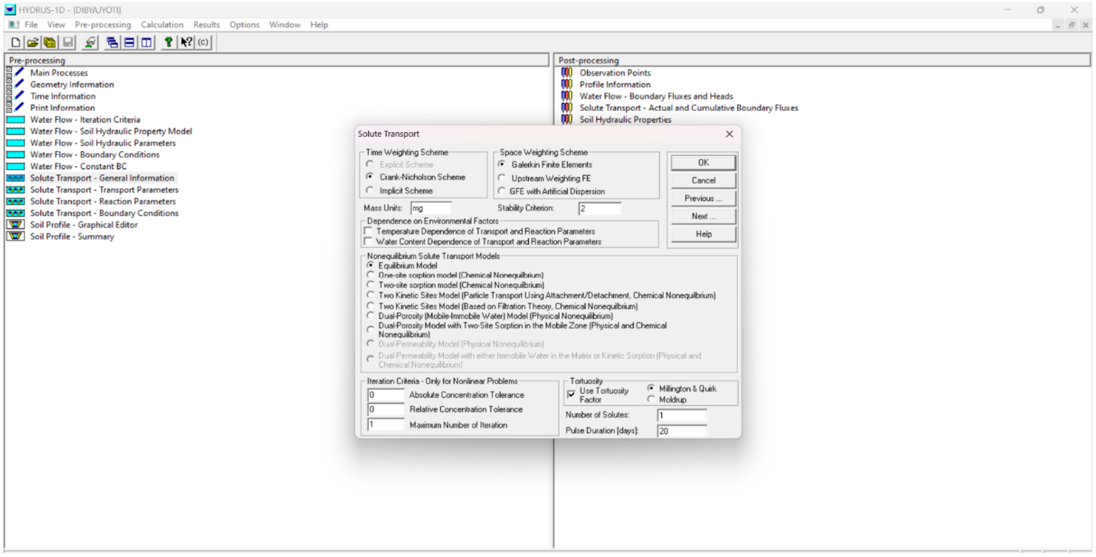
Lower Boundary Condition
- ○ Constant Pressure Head
- ○ Constant Flux
- ○ Variable Pressure Head
- ○ Variable Flux
- ● Free Drainage
- ○ Deep Drainage
- ○ Seepage Face; h =
- ○ Horizontal Drains

Initial Condition
- ● In Pressure Heads
- ○ In Water Contents

Figure 9.10: Water flow boundary conditions (HYDRUS1D)

9.3.7 SOLUTE TRANSPORT – GENERAL INFORMATION:

This function of the HYDRUS-1D enables to define the time weighting scheme, space weighting scheme, and some other parameter as shown in the dialog box.



Solute Transport

Time Weighting Scheme
- ○ Explicit Scheme
- ● Crank-Nicholson Scheme
- ○ Implicit Scheme

Space Weighting Scheme
- ● Galerkin Finite Elements
- ○ Upstream Weighting FE
- ○ GFE with Artificial Dispersion

Mass Units: mg
Stability Criterion: 2

Dependence on Environmental Factors
- ☐ Temperature Dependence of Transport and Reaction Parameters
- ☐ Water Content Dependence of Transport and Reaction Parameters

Nonequilibrium Solute Transport Models
- ● Equilibrium Model
- ○ One-site sorption model (Chemical Nonequilibrium)
- ○ Two-site sorption model (Chemical Nonequilibrium)
- ○ Two Kinetic Sites Model (Particle Transport Using Attachment/Detachment, Chemical Nonequilibrium)
- ○ Two Kinetic Sites Model (Based on Filtration Theory, Chemical Nonequilibrium)
- ○ Dual-Porosity (Mobile-Immobile Water) Model (Physical Nonequilibrium)
- ○ Dual-Porosity Model with Two-Site Sorption in the Mobile Zone (Physical and Chemical Nonequilibrium)
- ○ Dual-Permeability Model (Physical Nonequilibrium)
- ○ Dual-Permeability Model with either Immobile Water in the Matrix or Kinetic Sorption (Physical and Chemical Nonequilibrium)

Iteration Criteria - Only for Nonlinear Problems
0 Absolute Concentration Tolerance
0 Relative Concentration Tolerance
1 Maximum Number of Iteration

Tortuosity
- ☑ Use Tortuosity Factor
- ● Millington & Quirk
- ○ Moldrup

Number of Solutes: 1
Pulse Duration [days]: 20

Figure 9.11: Solute transport window – General Information (HYDRUS-1D)

The important consideration in this command is the pulse duration. In this study, the solute concentration is allowed to pulse in the upper boundary of the soil layer for first 20 days and its movement along the vertical soil profile is studied for specified time period. For simulation of the model, equilibrium solute transport model is selected with Crank-Nicholson as time weight scheme and Galerkin finite elements as space weight scheme.

9.3.8 SOLUTE TRANSPORT PARAMETERS:

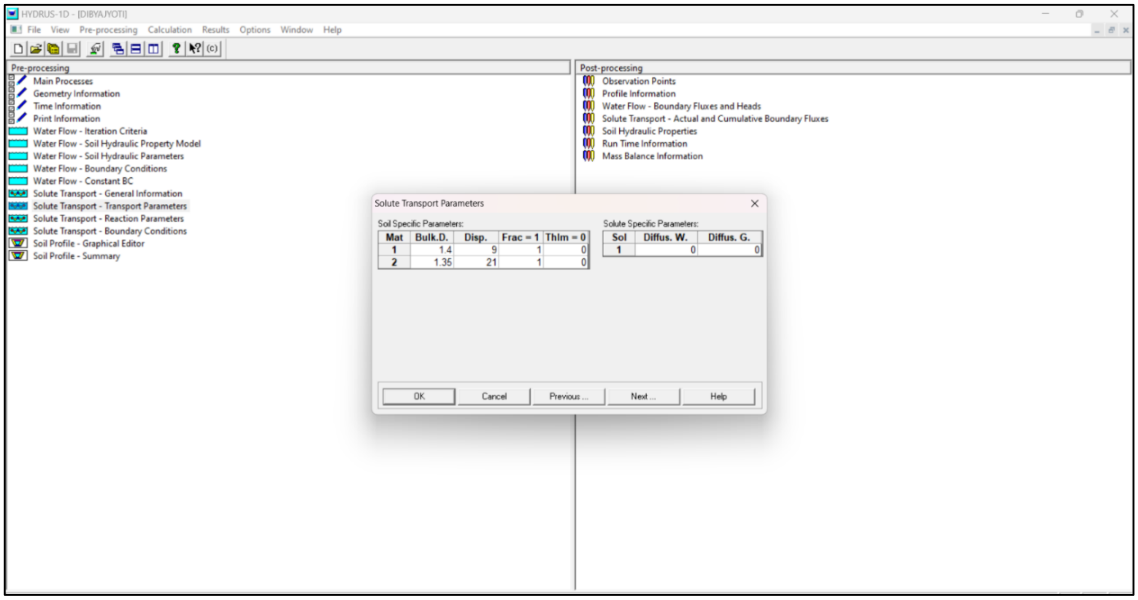
Another important input for simulation of the solute transport model are the different solute transport parameters. Solute transport parameters needed are Bulk density, longitudinal dispersity.

Moreover, the other two parameters dimensionless fraction of adsorption sites, and immobile water content which are set equal to one and zero respectively when physical non-equilibrium is not considered.

Disp. for the upper material = 9 cm, i.e., one-tenth of the travel distance.

Disp. for the lower material = 21 cm

The solute specific parameters are set to zero in this study.



Solute Transport Parameters

Soil Specific Parameters:

Mat	Bulk.D.	Disp.	Frac = 1	ThIm = 0
1	1.4	9	1	0
2	1.35	21	1	0

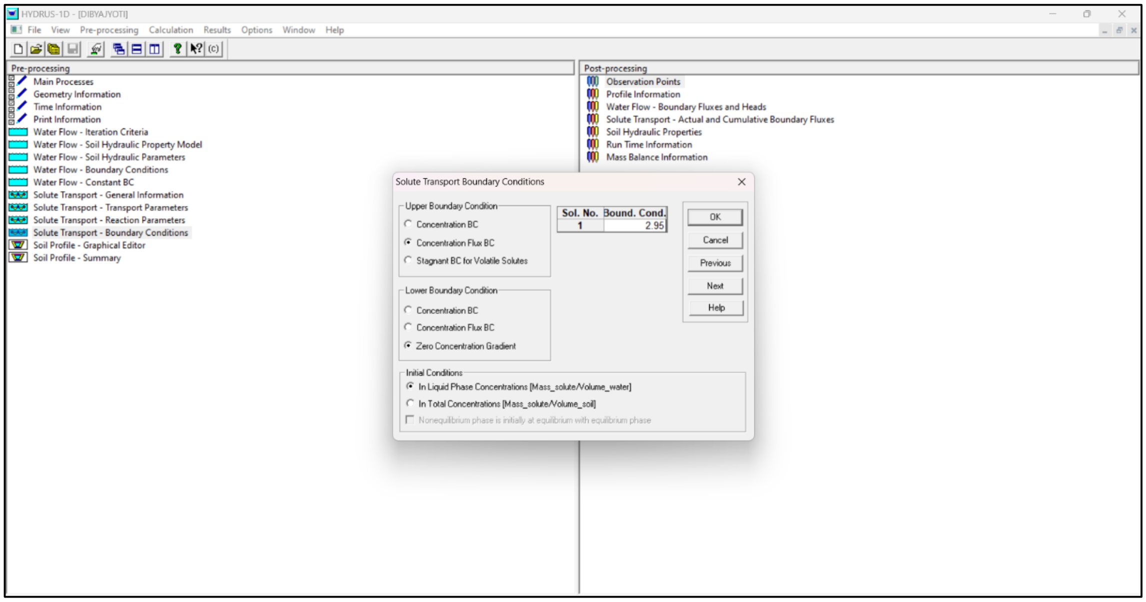
Solute Specific Parameters:

Sol	Diffus. W.	Diffus. G.
1	0	0

Figure 9.12: Solute transport parameters dialog window in HYDRUS-1D

9.3.9 SOLUTE TRANSPORT BOUNDARY CONDITIONS:

The solute concentration for the simulation of the model, iron concentration= 2.95 mg/l is considered. Concentration of iron was found to be highest at the Boragaon site(Site No-7) during the month of December from previous results. The solute transport boundary condition defines the interaction of the solute in its transport with the soil. In this 1D modeling, a concentration flux is used as an upper BC and Zero concentration gradient is assumed as a lower boundary condition with liquid phase concentrations as an initial condition.



Solute Transport Boundary Conditions

Upper Boundary Condition
○ Concentration BC
● Concentration Flux BC
○ Stagnant BC for Volatile Solutes

Sol. No.	Bound. Cond.
1	2.95

Lower Boundary Condition
○ Concentration BC
○ Concentration Flux BC
● Zero Concentration Gradient

Initial Conditions
● In Liquid Phase Concentrations [Mass_solute/Volume_water]
○ In Total Concentrations [Mass_solute/Volume_soil]
☐ Nonequilibrium phase is initially at equilibrium with equilibrium phase

Figure 9.13: Solute concentration and boundary conditions (HYDRUS-1D)

9.4 OUTPUT:

Pre-processing stage of HYDRUS-1D models have been completed with the above mentioned inputs. After this model development, simulations were performed to get the outputs. Generally, the HYDRUS code provides three different groups of output files, which are; T-level information, P-level information, and A-level information. Here, in this research, we made use of two different output files from these two groups, namely;

- NOD_INF.OUT file, which is from the P-level information group and used concentration profiles in the soil horizon with respect to its depth at the end of the simulation period.

- OBS_NODE. OUT gives transient values of the pressure head, water content and solution concentrations, as obtained during the simulation at specified observation nodes.

9.5 LIMITATIONS OF THE MODEL:

Study of solute movement through an unsaturated soil profile is known for its complexities. The composition of various soil material adds on the difficulty. So to develop and simulate the model on solute transport through an unsaturated soil profile certain limitations and assumptions were taken into consideration to reach the specified outcomes in this project. Some of the limitations adopted in this model development are mentioned as follows:

- A constant pressure head (-100 cm) was considered which indicated that the ground water table was 100 cm below the top surface for the entire soil profile.
- A one-dimensional vertical movement was assumed and simulated in the model, though three dimensional flow representing more correctly the reality. However, the one-dimensional vertical movement is the dominant direction of flow in the unsaturated zone, in a large-scale field condition it could be seen as a simplification of the reality. But one should be aware that one-dimensional flow overestimates concentrations comparing to three-dimensional spreading.
- The soil properties were not obtained practically, instead the data used in this model is taken from research papers given by *Kalita et al.,2019*.
- A single porosity model was used to describe the uniform flow in the unsaturated porous media which neglects both the variability in the soil properties, and non-equilibrium flow.
- HYDRUS-1D model uses various soil parameters such as saturated water content, residual water content, pore connectivity parameter, empirical coefficients α and n. These values are obtained based the percentage of different material present in the soil. Since, the percentage of the composition of individual materials were not available so these parameters were considered on basis of average composition from the HYDRUS software program

CHAPTER 10

POST-PROCESSING OF HYDRUS-1D MODEL

10.1 INTRODUCTION:

As mentioned in earlier chapters, the principal focus of this project is to analyze the ground water quality of the Deepor Beel and development of a solute transport model for better understanding of the flow movement of water, interaction and solute movement along the vertical soil profile at the dumping site in Boragaon. The solute transport model is developed using HYDRUS-1D software package, which is one of the most widely used programs on study of water flow, heat transport and solute transport in variably saturated flow. The HYDRUS-1D model works through a pre-processing and post-processing units for simulation of the focused objective of this study.

In the previous chapter, the details of the pre-processing stage are being already discussed. The post-processing of the HYDRUS-1D model is nothing but the outcome of the inputs that are presented to the software during pre-processing stage. So, this chapter basically represents the relationship between the various the parameters of soil, water flow and how they interact with the solute transport movement along the soil profile with a specified concentration on a graphical format. The graphical representation will give the details about pressure head, water content, hydraulic conductivity water fluxes and solute concentration at different depth of the soil profile.

10.2 GRAPHICAL OUTPUT OF HYDRUS-1D

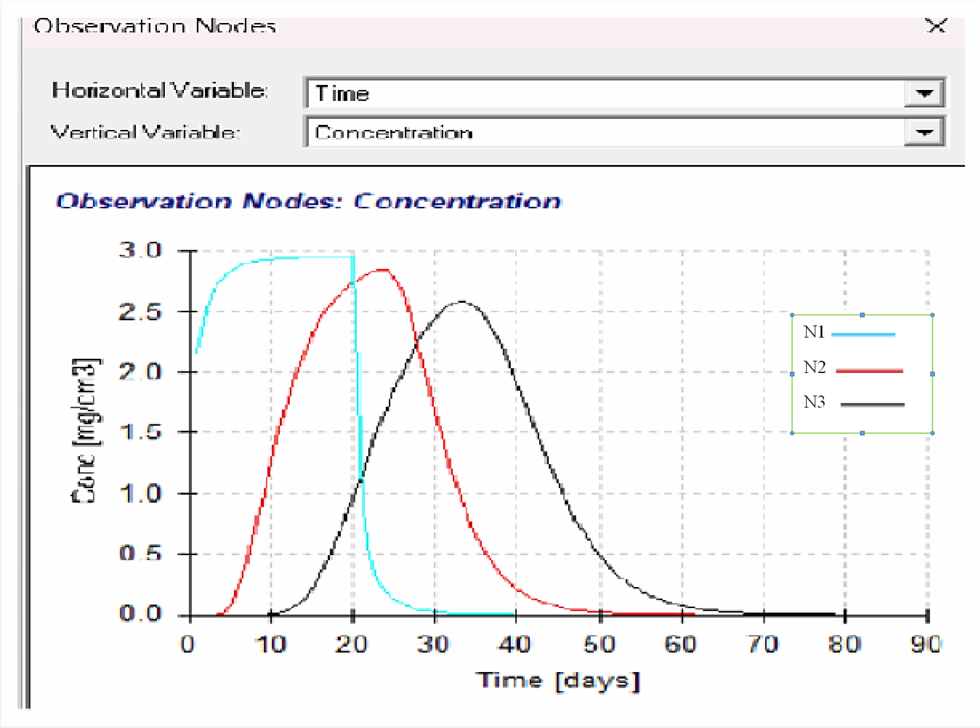
10.2.1 Observation Points:

The soil profile considered in this solute transport model is 200 cm in depth. Three observation nodes have been selected at different depth in vertical direction of the soil profile. These three observation nodes are designated as N1, N2 and N3. Observation nodes are located at different depths, N1 at 0 cm which the top surface of the soil profile.

N2 at 90 cm which is taken at the junction between the two layers of soil.

N3 at 200 cm which is the bottom boundary of the soil profile.

These selected locations along the soil profile provide the details about the variation of concentration of solute, pressure head, water content and water fluxes at different depth with respect to time.



Horizontal Variable: Time

Vertical Variable: Concentration

Figure 10.1: Solute concentrations versus time at selected observation points.

The graph represents the the varaition of solute concentration at different selected points with respect to time. The solute transport model developed in this study considered a solute concentration of 2.95 mg/cm^3 with a pulse duration of 20 days.

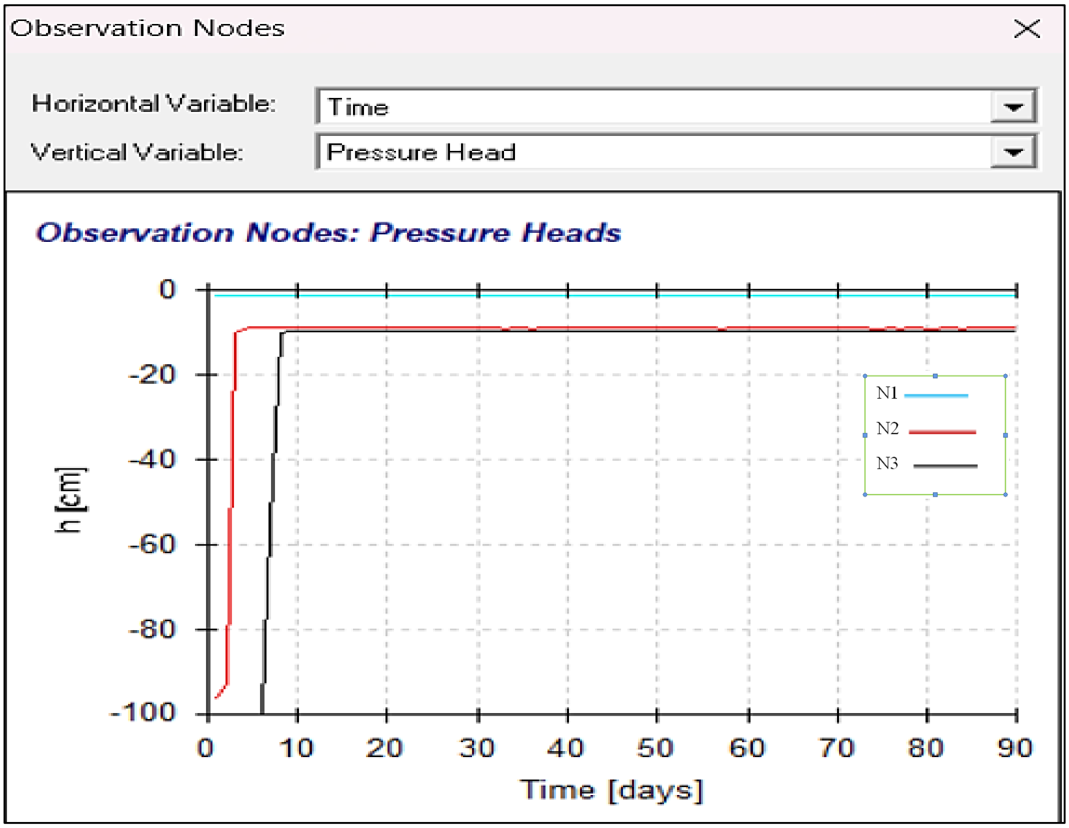
In this fig , it shows that solute concentration at N1(blue line) keeps on increasing for the intial 20 days while the solute pulse is active at the upper Constant Flux boundary.

There has been a decresing pattern of solute concentration at N1 after 20 days, which tends towards zero after about 40 days. This implies that the top surface of the soil profile becames solute free gradually after pulse activation duration. Had the pulse continued indefinitely, the entire profile would have contained to increase in concentration. The time taken the solute for transport along the the soil profile is dependent on the different soil properties and hydraulic conductivities of the different layers of soil that is considered in this study.

The concentration of solute at N2= 90 cm, starts from zero after about 5 days and increases gradually to reach peak value of 2.84 mg/cm^3 approximately as flowing water continues to carry solutes downward from the soil above this observation point and then decreases towards zero at around 65 days.

The transport of solute along the soil profile towards the bottom boundary N3 takes about 9 days. After 9 days, the solute starts to break through the N3 observation point which is the lower layer of the soil profile. The solute concentration at the bottom boundary reaches its peak at around 35 days and then starts a decreasing trend in concentration towards the end of the simulation period. It is to be noted that the peak value for different obsevation point is reducing, as the solute moves towards greater depth.

10.2.2 Pressure head Vs Time:



Observation Nodes

Horizontal Variable: Time

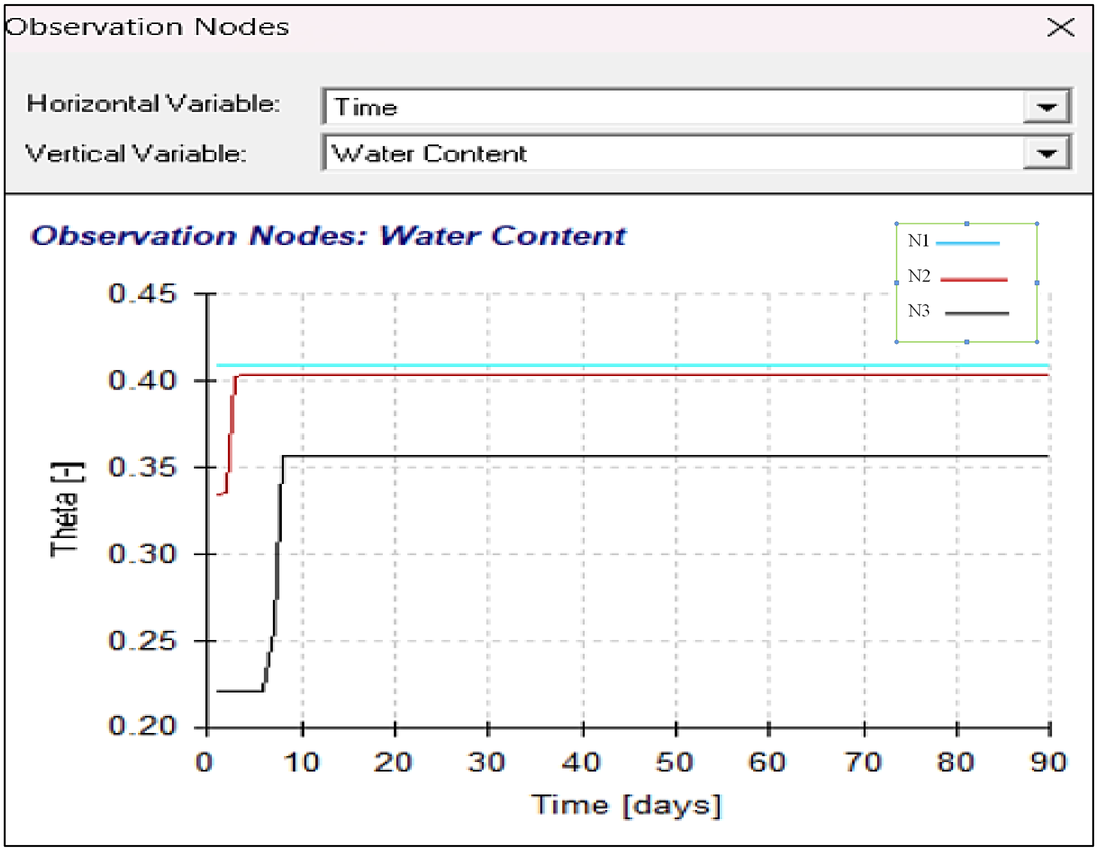
Vertical Variable: Pressure Head

Figure 10.2: Pressure heads versus time at selected observation points (N1- 0 cm, N2- 90 cm, N3- 200 cm)

In the figure the graph shows how the pressure heads varies with time at the selected observation points, i.e N1- 0 cm, N2- 90 cm and N3- 200 cm. In this study, initially a pressure head of -100 cm was assumed, which varied as the wetting front approaches the selected nodes. Moreover, the timing is variation of pressure heads at selected points are based on the hydraulic properties of the soil profile provided in the pre-processing stage of the model. When the wetting front approaches a certain depth, the pressure head increases from the initial value of -100 cm and eventually reaches close to 0 cm, which is equal to the imposed positive pressure head at the surface as presented in HYDRAS-1D model.

From the graph it can be seen that the wetting front passes from the surface towards the selected nodes N2 and N3 at times of approximately 5 days and 8 days approximately.

10.2.3 Water content Vs Time:



Horizontal Variable: Time

Vertical Variable: Water Content

Figure 10.3 - Variation of soil water content with time.

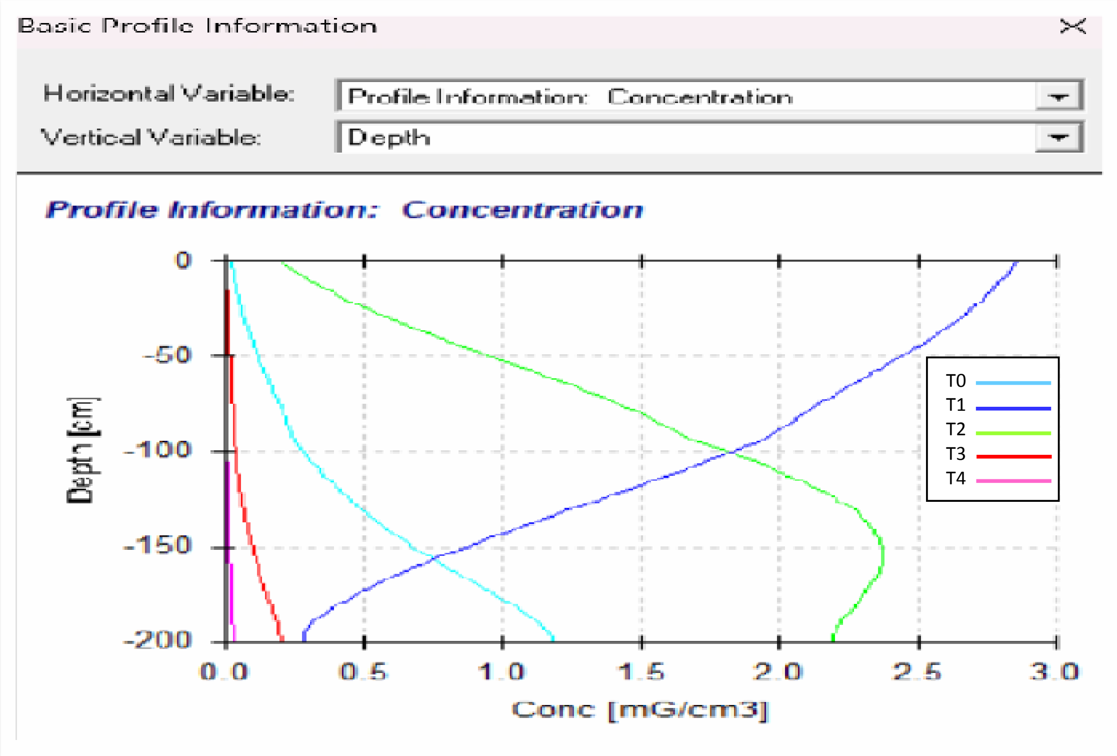
This graph represents how water content in soil profile varies with time at different observation points. In this study, the saturated water content for the two layers of soil has been obtained according to the properties and composition of the soil as given in the HYDRUS software package.

The above graph indicates the increase of water content at top surface at N1 during initial period and then reaches a constant value after saturation due to the constant upper water flux condition. At points N2 and N3, the water content increases from a lower value than the initial surface water content but increases to a peak value of 0.41 and 0.3572 after 4.5 days and 8 days respectively. After saturation is reached, the water content at different observation points N1, N2 and N3 remains constant for the entire simulation period.

10.3 Profile Information:

The profile information command displays solute concentration, water content and other parameters versus depth at selected Print Times. In this study, simulation of model is done for a period of 90 days, so on equal duration six numbers of print times are selected. These print times are noted at T1= 15 days, T2= 30 days, T3= 45 days, T4= 60 days, T5= 75 days and T6= 90 days.

10.3.1 Concentration Vs Depth:



Basic Profile Information

Horizontal Variable: Profile Information: Concentration

Vertical Variable: Depth

Figure 10.4 - Variation of concentration of solute with time

In this figure, variation of the concentration of solute versus depth at selected times is displayed graphically. In this study, the solute transport model was developed with a input of initial solute concentration equal to 2.95 mg/cm^3. The pulse duration of solute concentration is assumed for 20 days.

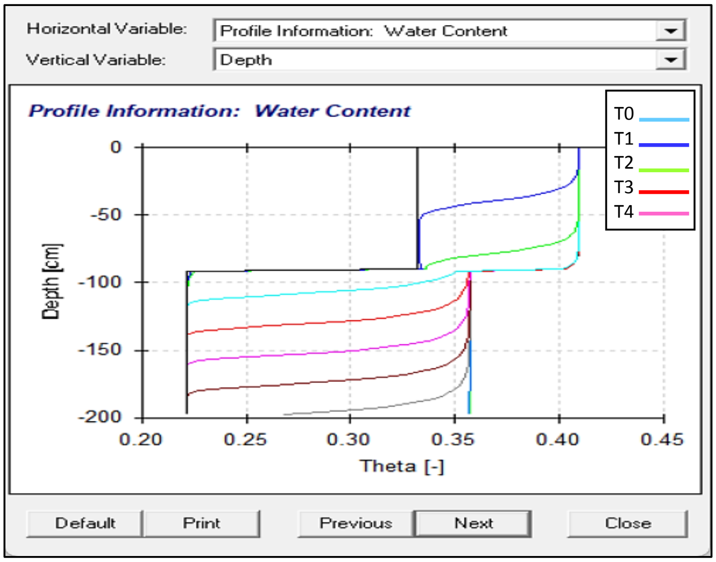
The above graph shows that at T1= 15 days, there is a declination in the concentration peak along the depth of the profile due to solute dispersion. The solute concentration at 15 days is highest at the surface and it gradually decreases with as the depth increases. At the bottom boundary at 200 cm, the solute concentration is proximate to zero.

At T2= 30 days, due to solute dispersion, the concentration of solute at surface is almost zero. As depth increases the concentration of solute increases and is maximum at depth near to 150 cm, then it escapes the bottom boundary with a concentration of approximately 2.35 mg/cm^3.

Similarly, with passing of days, the concentration near the surface becomes zero and it goes on increasing towards the bottom boundary, as it can be seen with T3, T4 and so on but with a lower concentration than it was initially present. It is to be noted that with a pulse duration of 20 days, the rate at which the solute concentration is lowering with depth is not appreciable. Thus, it indicates that if the concentration of harmful metal in the dump yard area is injected for a long duration, it is defining that the concentration of such solute might continue to disperse into the ground water storage.

10.3.2 Water content vs Depth:

In this fig the graph shows the variation of water content along the depth of soil. The water content at T0= 0 day, is the initial water content that is given to the model. Water content in the soil profile represented by T1= 15 days, shows increase in amount. This increase in water content is based on the contact upper water flux boundary condition that is applied in the HYDRUS-1D model. Moreover, there is an abrupt change in the water content at the interface (at a depth of 90 cm from the surface of the soil profile) between the two soil types. The water content is not continuous along the soil depth is due to the different water retention properties (and thus retention curves) and hydraulic conductivity of the two materials.

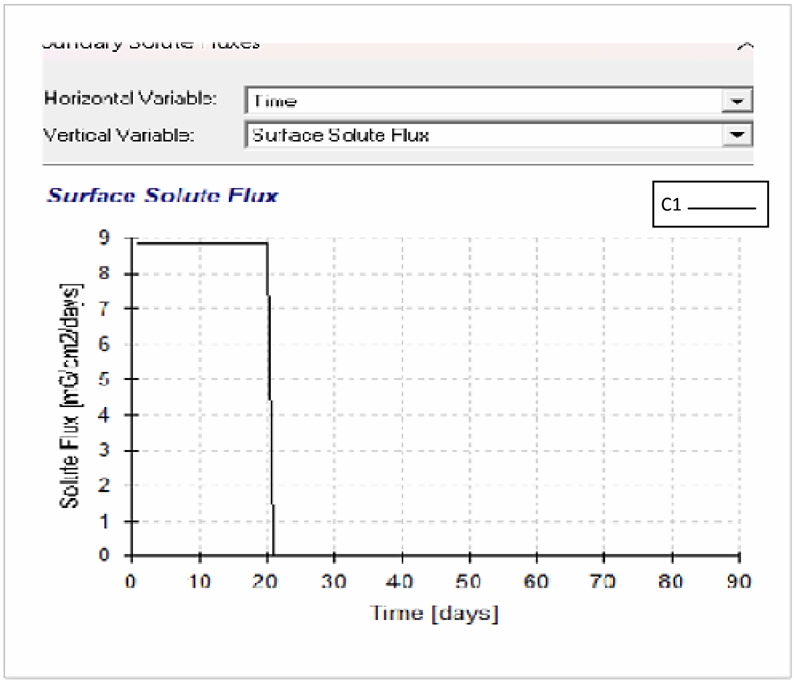


Horizontal Variable: Profile Information: Water Content

Vertical Variable: Depth

Figure 10.5: Variation of water content with depth

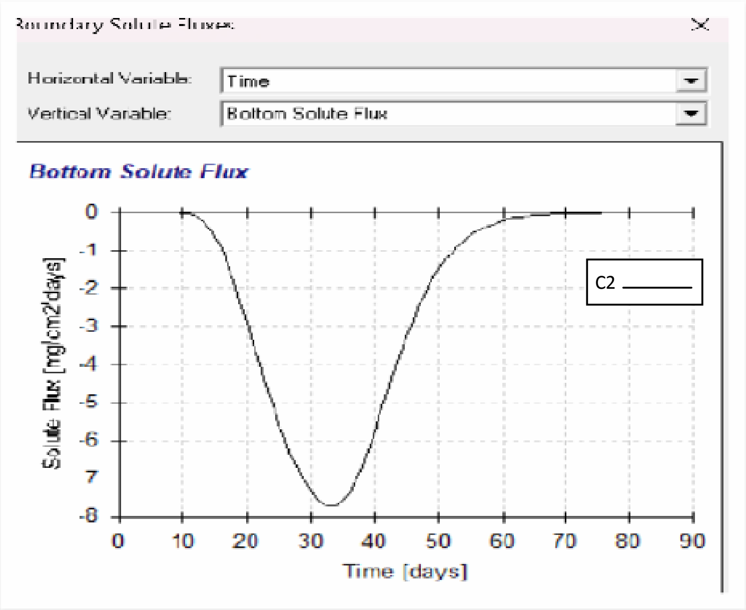
10.3.3 Solute flux Vs time:



Horizontal Variable: Time

Vertical Variable: Surface Solute Flux

Figure 10.6: Influx of solute versus time


Boundary Solute Fluxes

Horizontal Variable: Time

Vertical Variable: Bottom Solute Flux

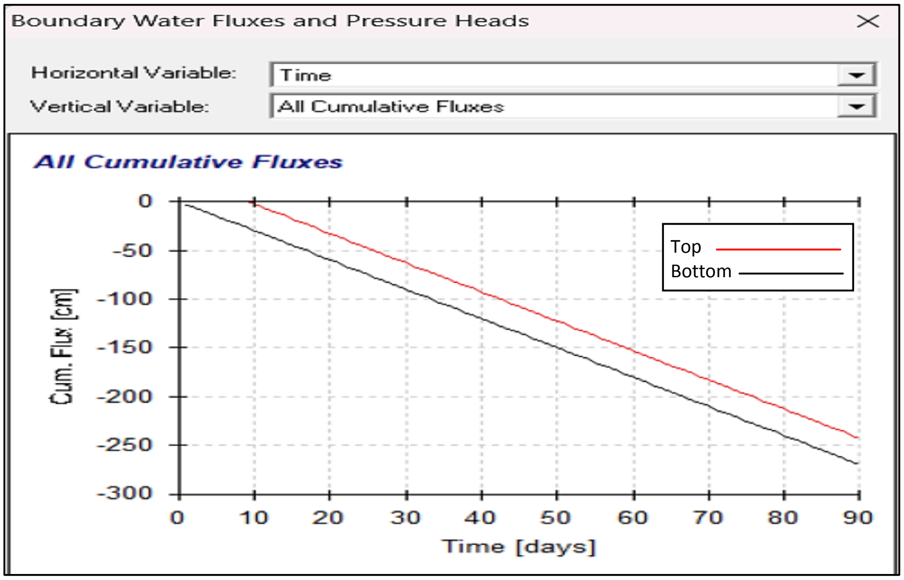
Figure 10.7: Efflux of solute with respect to time

The above graphs represent influx of solute at the soil profile and efflux of solute through the lower layer with respect to time. In the pre-processing stage of the development of HYDRUS-1D model, a solute concentration of 2.95 mg/cm^3 given as initial concentration with a pulse duration of 20 days. The variation of the solute influx on the surface and bottom layer will be dictated in the above graph. HYDRUS-1D model considers the solute fluxes to be positive when entering the transport domain and negative when leaving the transport domain. This convention of the HYDRUS model is totally opposite to that of water flow, which are always positive upwards and negative downwards.

The above graph displays that the influx of solute into the surface is constant for the 20 days and then it tends to zero. The influx of the solute attains a constant value of 8.85 mg/cm^2/day. The constant value of influx resulted from the input of initial concentration of 2.95 mg/cm^3 and the upper constant flux of -3 cm/day for a period of 20 days (i.e., 2.95 mg/cm^3 x 3 cm/day = 8.85 mg/cm^2/day).

The efflux of solute through the bottom layer started nearly after 9 days. The efflux gradually increases and reaches a peak value after 35 days approximately. After this point, the bottom solute efflux decreases corresponding to the fact that there was no influx of solute at the top surface after 20 days. The sum of the influx and efflux curves at any time defines the amount of solute stored within the soil profile.

10.3.4 Water fluxes Vs Time:



Horizontal Variable: Time

Vertical Variable: All Cumulative Fluxes

Figure 10.8: The surface flux (negative and into the soil profile) and the bottom flux (negative and out of the soil profile) versus time.

In this figure, water fluxes variation on both top and bottom surface are shown with respect to time. In this solute transport model, a constant flux boundary condition is assumed. HYDRUS-1D program considers the convention of z-axis to be positive in upward direction, so downward fluxes (against the direction of the z-axis) as negative and upward fluxes (in the direction of the z-axis) as positive.

The graph shows that due to the constant flux condition, the movement water flow at upper boundary is continuous during the entire the simulation period. But, the drainage of water through the bottom boundary starts with a slight delay. The lower "Free Drainage Boundary" allows unit gradient gravity drainage in HYDRUS-1D program. So, the initial magnitude of flux on the bottom boundary layer is very small at the starting days of the simulation i.e upto 8 to 9 days approximately. It is to noted that after 9 days, there is break in the bottom flux graph and it increases significantly. This change is due to the approaching wetting front on the lower boundary of the soil profile. The two lines in the graph almost extend parallel to which, which signifies that inflow of water in the upper front is equal to the outflow through the bottom front. Thus, the water balance of the soil profile reaches a steady state.

10.4 DISCUSSION:

According to Naveen B.P. et. al. (2018), in their paper “A study on contamination of ground and surface water bodies by leachate leakage from a landfill in Bangalore, India” discussed on the effects of potential leachate leakage from municipal dump yard to the nearby water bodies. In their study, they focused on testing the physico-chemical parameters of the leachate from the dump yard and the quality of contaminated soil in the nearby water bodies. Samples were collected from one season in April,2012 from the MSW leachate, a open well and a pond nearby the dump yard. The various parameters that were tested for these three sites were pH, Conductivity (µS/cm), TDS (mg/l), Calcium (mg/l), Alkalinity (mg/l), Sodium (mg/l), Potassium (mg/l), Nitrate (mg/l), Heavy metals. The results showed that pH of the samples were proximate to normal standards, but alkalinity and concentrations of all the major anions like chlorides, nitrates, sulphates were considerably high in the leachate sample. Moreover, concentrations of heavy metals were found to be low in leachates samples except for Fe and Zn as compared to the other sites. Bicarbonates and carbonates are the dominant anion found in the leachate samples compared to sulphates and chlorides as obtained from the diagram. Moreover, a contaminant transport model (fluidyn-POLLUSOL model) was used to know the contaminant flow and interaction through soil. For assessing the contaminant transport parameters of metal ions through soil, the column tests were conducted based on which simulation were done in fluidyn-POLLUSOL model. Thus, they concluded that MSW in the landfill site had deteriorated the quality of soil and water in the nearby areas. The ground water model showed that zinc concentration was limited to upper soil layers and iron concentrations showing higher percolation, which in turn indicated towards pollution of nearby water bodies due to seepage of ground water.

According to Rubio C.M. et. al. (2012), in their paper "Applicability of Hydrus-1D in a Mediterranean Mountain Area Submitted to Land Use Changes" evaluated the reliability and accuracy of the Hydrus-1D model to simulate the measured dynamics of water flow in a silt loam soil profile in an abandoned crop area within the Can Vila research basin (0.56 km^2), which is in the head basin of the Llobregat River, northeast of Spain. In their study, their focus was to determine the hydraulic properties of the soil profile, to parameterize the van Genuchten model and field saturated hydraulic conductivity and then calibrate Hydrus-1D model using water contents and pressure heads. The experimental data set included water potential data measured at 0.2, 0.4, and 0.6 meters of depth using SKT600 tensiometers. For the observed water contents, two-time domain reflectometry (TDR) profiles (A and B) were used between surface and 0.6 meters of depth. The field-saturated hydraulic conductivity was obtained for 3 depths (0.15, 0.25, and 0.50meters). For calibration and validation of the HYDRUS-1D model under transient conditions, field data for the period from 28th of September to 30th of November of 2003 (64 days) were used along with pressure heads were used as initial boundary conditions. The results obtained in their study showed that the profile was classified as silt loam (according to USDA), with silt content always higher than 57g·kg^{-1}, sand content between 110g·kg^{-1} and 210g·kg^{-1}, and clay content between 200 g·kg^{-1} and 280g.kg^{-1}. Moreover, using the van Genuchten equation, various soil hydraulics properties were obtained along with the N-parameter which is less than 1.20. Despite to obtain an excellent fitted values for N-parameter, these values were solved using Hydrus-1D. Simulation using Hydrus-1D gave an acceptable fit volumetric water content using an air entry value of −2cm in the van Genuchten equation from surface to 0.6 meters of depth. Notable results were obtained during simulation of pressure heads using HYDRUS model. Initially in dry conditions, with an accumulated precipitation of about 264.4mm after a dry period, the study showed that simulations slower at deeper levels (0.4 and 0.6m depth). But, simulation for the same period starting with wet conditions indicated that the response of the model is faster, especially at the deeper levels. Thus, in research they concluded that algorithm of Hydrus-1D solved correctly the Richards equation for the concerned silt loam soil profile under natural conditions, although the model simulated the pressure head data with smaller differences.

In our study area the HYDRUS-1D model, is provided with the required input for the simulation of the model in the pre-processing stage and the outputs of the execution of the model is obtained in the post-processing stage in graphical form. The soil profile considered was 200 cm in depth and the basic soil properties for the model were taken from the research work of *Kalita (2019)*. The solute considered was iron with practical concentration that was obtained during this study. A simulation period of 90 days was considered (October 2022- December 2022) for the model since the solute concentration of iron for this time period was the highest near the landfill area and after the execution of the model, the results were displayed in graphical form. Concentration of other heavy metals like lead and nitrate were found to be low. The graphical datasheet of the HYDRUS-1D model gave a clear picture of the movement of solute and its interaction with different soil properties. The graphical outputs include concentration solute with depth and time, variation of water content and pressure head with time, Influx and efflux of solute at different time period. The results of this model showed that continuous influx of harmful solutes on the surface of the Deepor Beel could lead to break through of this solutes through the soil column into the groundwater storages.

The graphical output of the HYDRUS-1D solute transport model gives a distinct and clear picture of the solute movement, water flow, water content, pressure head and concentration profile variation along the soil profile with respect to time and depth. The concentration of the solute with depth is seen to be getting lower, yet the rate of reduction in concentration with time is low. This indicates that if a continuous influx of solute takes place in the dumping area of Boragaon (**SITE 7, Table 5.1**) then any harmful solute concentration can break away into the groundwater storage which is not a good sign.

CHAPTER 11

CONCLUSION

The results in this project study has been obtained in accordance to the objectives that were aimed to be achieved at the starting of this project. Keeping up with the objectives of this study, the sites were selected in such a manner that testing can done in areas which are closer to the dump site as well as away from the dumpsite. So, the results that were obtained from the study clearly points towards high concentration of certain parameters in sites closer to dumpyard, a low to moderate increase or decrease from standard limits in other sites. From the results obtained it can be seen that waste water generated by industry or house hold, and water flowing through the agricultural land may also affect the water quality. However, the water near to the dump site is showing some frequent changes in ground water quality parameters with change in seasons. On concentrating on the site 7 i.e., the ground water area near the Municipality dumping zone, it is evident that ground water tends to be acidic, higher iron concentration, increasing hardness and turbidity and lower in D.O level than the other sampling sites which were subjected to less pollutant matter.

Multivariate data analysis for the water parameters of our study area was done in IBM SPSS statistics software package. It results in the conclusion that the study area is divided into two set of main clusters and five set of subclusters. This were so selected based on the concentration of the water parameters for a period of one year within the study area. Station 6 and 7 near Boragaon dumping zone belongs to the same sub cluster and stations belonging to areas near ASTU, AEC and Chakardeo belongs to same sub cluster. Also, from the analysis carried out by dimensional reduction of factors, we conclude the number of principal components in our study area to be 2. Various parametrs depict various relationships with the components based on their factor loading scores.

Since the results of site 7 which is near the dumping zone are not appreciable, the solute movement model was developed using HYDRUS-1D with the highest iron concentration recorded in this study. HYDRUS-1D model is considered as an accurate tool for the transport models and the model was prepared with input indexes such as constant recharge flux, practical iron concentration, prevailing top and bottom boundary condition and movement of the solute through a soil column of the Deepor Beel. The model dictates that if the concentration of different parameters goes on increasing in the water of Deepor Beel, it is quite clear that the solute might transport through the soil towards the ground water storage. The model did act as a convenient tool in knowing the how the solute interacted with soil properties in its vertical movement with respect to time and depth. Thus, it can be concluded that through the detailed testing of specified parameters at different sites, the water quality of Deepor Beel near the municipal dumping zone at Boragaon is deteriorating gradually. With further increase of dump waste flowing into the Deepor Beel, the water quality might be subjected to such a level degradation that purification will not be possible. Moreover, the effect of the poor water quality on the biodiversity is noteworthy situation. Last but not the least, the contamination of the groundwater storage due to the movement of harmful solutes from the dumpyard must not be ignored.

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