 ISSN 2091-2609

OPEN ACCESS

Available online at www.ijasbt.org

International Journal of Applied Sciences and Biotechnology

A Rapid Publishing Journal

APPLIED SCIENCES		BIOTECHNOLOGY
Biochemistry	Immunobiology	Microbial biotechnology
Molecular biology	Bioinformatics	Medical biotechnology
Microbiology	Novel drug delivery system	Industrial biotechnology
Cell biology	Pharmacology	Environmental biotechnology
Cytology	Neurobiology	Nanotechnology
Genetics	Bio-physics	
Pathology	Botany	
Medicinal chemistry	Zoology	
Polymer sciences	Allied science	
Analytical chemistry	Earth science	
Natural chemistry		

If any queries or feedback, then don't hesitate to mail us at:
editor.ijasbt@gmail.com

Sahoo BN and Baruah DC (2013). Int J Appl Sci Biotechnol, Vol. 1(2): 49-58
DOI: 10.3126/ijasbt.v1i2.8201

Research Article
International Journal of Applied Sciences and Biotechnology
ISSN: 2091-2609

INVESTIGATION OF THE EFFECT OF FORMATION WATER DISPOSAL ON GROUND WATER IN OIL FIELDS OF ASSAM, INDIA

B. N. Sahoo*[1], D. C. Baruah[2]

[1] Chief Engineer (S&E), OIL, Duliajan, Assam, India
[2] Professor, Department of Energy, Tezpur University, Assam, India

*Corresponding author email: bnsahoo@oilindia.in

Abstract

One of the major waste products of oil industry is formation water which comes with crude oil from underground and this is considered as pollutant because of the presence of several undesirable elements exceeding the permissible limits. The conventional oil field practice is to dispose the formation water by injecting underground. Such underground injection is practiced in many oil fields across the globe. The ground water pollution threat by injected formation water has been a subject matter of investigation in some oil producing regions. The oil fields in Assam (India), some of which have been operating for about 50 years, also resort to similar disposal practice through some designated wells. The present study concerning underground disposal of formation water in 15 disposal wells of 3 oil fields in Assam analysed water samples collected during three consecutive years and could not detect migration of pollutant formation water to nearby ground water.

Keywords: Formation water, disposal well, monitoring well, ground water, contamination.

Introduction

The hydrocarbon industry all over the world is given paramount importance from global energy scenario point of view. In India, this industry is a premier industrial sector both from country's economic as well as energy requirement considerations. The in-country production of hydrocarbon is much less than the requirement. India needs about 100 million tons of crude oil per annum, where as its indigenous production is only about 40 million tons. Since there is a wide gap between supply and demand of hydrocarbon, therefore, search for this fossil fuel is continuing since few decades and it will continue in a more vigorous manner in coming days.

The upstream sector of hydrocarbon industry plays a major role in country's crude oil and natural gas production. The exploration, drilling and production of hydrocarbon are basically under the purview of upstream sector of hydrocarbon industry. Each stage of this hydrocarbon production activity involves certain degree of environmental hazard. There are many cases of severe pollution due to these activities in oilfields (Stone, 2003).

Ground water pollution hazard due to oilfield pollutants with specific reference to formation water

The waste drilling fluid, oily sludge and more specifically the formation water which are the byproducts generated along with various operations in hydrocarbon industry are major sources of pollution. These pollutants find their way and traverse to various environmental receptors causing potential danger of polluting the same. The water bodies, both surface and underground are more susceptible to such pollution in oil fields.

The drilling fluid is used while drilling a well. The drilling fluid is generally recycled and reused, but sometimes it is discharged to the pits with impervious lining due to operational problems. This may lead to pollution of surface water in case it flows out of its container pit. Similarly oily sludge is stored in concrete pits for its further use. Any surface runoff from these sludge pits may lead to pollution of surface water bodies.

The water which is generated along with crude oil is called formation water. This formation water is separated from crude oil and injected underground for its disposal since it is an useless byproduct. The other two pollutants in the oilfield i.e. waste drilling fluid and oily sludge as mentioned above may cause surface water pollution but the formation water has the greater potential to contaminate ground water since it is injected underground.

The formation water is by far the largest volume of by product associated with oil and gas production industry. Generally, the older the oil field more is the production of formation water. In subsurface formations, naturally occurring rocks are generally permeated with fluids like water, oil or gas or a combination of these fluids. It is believed that the rock in most oil bearing formations was completely saturated with water prior to the invasion of petroleum (Amyx et al., 1960). The less dense hydrocarbons migrated to trap locations displacing some of the water from the formation and became hydrocarbon reservoirs. Thus reservoir rocks normally contain hydrocarbon and water. This water is referred as connate water or more popularly as formation water in Indian oil fields. This formation water is also referred as produced water when the reservoir is produced and this associated water is brought to the surface along with the oil and gas. Thus formation water is any water which is present in the reservoir with the hydrocarbon resources and produced to the surface with the crude oil and natural gas. This produced formation water is highly saline and contains other dissolved materials (Cline,1998).The formation water is an integral and unavoidable part of hydrocarbon recovery process (Khatib and Verbeek, 2003). Management of formation water is a key issue for the hydrocarbon producers because of its large volume of generation and high handling cost. Out of various options for management of formation water, the mostly adopted options by the hydrocarbon producing companies are underground injection for increasing oil recovery in the deep reservoir zone and the injection to non pay zones in the porous rocks for mere disposal purpose (Stone, 2003).

In the oil fields of India including the upper Assam oil fields, the general practice of managing the formation water is to inject underground for disposal purpose (Patel et al,2003). The aging oilfields in Tinsukia and Dibrugarh districts of Assam produce more formation water along with crude oil. Production of formation water in these old oilfields is also in increasing trend. This water produced along with oil is highly saline, very rich in dissolved minerals and has a high temperature than the normal atmospheric water temperature.

Ground water pollution hazard due to formation water in oil fields of Dibrugarh and Tinsukia districts

In upper Assam basin, the aquifers commonly show a lenticular character indicating that the sand and gravel layers were deposited in channel beds whereas the silt and clay beds were formed in the flood plains. These sand and gravel beds may lead to enhanced migration of injected water.

The ground water regime in the Dibrugarh and Tinsukia district has been classified into 2 distinct categories (CGWB, 1993). The categories include a shallow aquifer group within 50 m and a deeper aquifer group from 50 m to 250 m from the ground surface. The average annual rainfall in Dibrugarh and Tinsukia district is about 1400-2000 mm (IMD, 2006). The bore hole logs for ground water in Dibrugarh District indicates a 2 m thick zone of granular materials within 50 m of ground level and a lower 50 m granular zone within 150 m of ground level.

The oil fields in Dibrugarh and Tinsukia district of Assam are oil rich regions of India. There are three major oil fields in this area *viz.* Naharkatiya, Digboi and Moran. The crude oil production started in Naharkatiya and Moran since about last fifty years while Digboi field is still older. The amount of production of formation water along with crude oil is in increasing trend in these fields since they are older. From economic consideration, the crude oil and gas production is required to be continued even if the production rate of formation water goes high.

There are seven major Oil Collecting Stations (OCSs) in the study area. The crude oil is collected from different well surrounding those OCSs. The separation of oil, gas and formation water is done in the oil collection station by thermo chemical process. The separated formation water is injected by pump to underground selected rocks through designated wells called disposal wells made for the purpose (Stone, 2003). The formation water is highly saline, contains dissolved minerals which are beyond the tolerable limit. The salinity of the formation water in the oil field of Dibrugarh and Tinsukia districts of Assam range from 1000 mg/l to 3000 mg/l (Patel et. al., 1998). The oil field in the study area has disposed in an average 3000 m^3 of formation water daily from its various oil collecting stations which is an environmental concern since the injected water has a potential to migrate and contaminate the ground water of the area.

Literature review on the subject indicated that studies of this nature i.e. investigation of the potential of contamination of ground water from underground injection of formation water is going on in other oil producing countries whereas in India particularly in upper Assam oil fields, such studies could not be traced. Therefore, it was of interest to carry out an investigation in this oil field of India with the following objectives.

With this background, the present study was undertaken with the following objectives:

Objectives

1. To formulate a strategy for investigating probable contamination of ground water by underground disposal of formation water in the oil fields of Dibrugarh and Tinsukia districts of Assam.
2. To investigate the problem by carrying out water quality analysis of the area and comparative study of the same.
3. To verify the results of the water quality analysis by statistical procedure.
4. To find out the zone of influence of injected formation water in disposal well for verification of the result.

Methods and Materials:

The methods for carrying out such investigation elsewhere in the world were reviewed from literature. It was revealed that carrying out underground water quality analysis and its comparative study with the chemical characteristics of formation water gives a good indication of any contamination of the former (Mclin, 1997). The Oil and grease, Total Dissolved Solids, Chloride, Total Suspended Solid are the constituents which draws more attention in contamination studies of formation water (Breit et al., 1998). The present work plan was formulated accordingly.

The study elements were identified. The Naharkatiya oil field has five OCS; each OCS is disposing their formation water through two or three disposal wells. Digboi oil field has one OCS which is attached to two disposal wells. Moran oil field has one OCS and two corresponding disposal wells. The depth of injection of formation water in disposal wells varies from 400 m to 1800 m. Ground water monitoring tube wells were identified around each OCS. These mentioning wells were at a distance of 15 m to 50 m from the disposal wells. These were selected at closer distance to disposal wells with a view that closer the well to the disposal points more is the chance of contamination. Altogether 33 ground water monitoring wells were identified in study area. Baseline wells for ground water sample were also identified at a distance of 300 m - 500 m from disposal wells i.e. away from the disposal point in areas which are not affected due to its distance factor. The water sample collected from these baseline wells were taken as control data. Nineteen such baseline monitoring wells were selected in the study area. They general lay out of the formation water disposal wells and its corresponding ground water monitoring and base line wells for the three oil fields of the study area is given in figures 1,2 and 3.

Selection of Sampling Points in study area

The formation water samples were collected from the pump delivery at oil collecting stations under study. After separation of crude oil the formation water is stored in tanks from where the pump suction is taken and the formation water is injected to disposal wells. The pumps in each oil collecting station have sampling points in their delivery line. The formation water samples have been taken from these sampling points in the oil collecting stations.

The water samples from monitoring tube wells have been taken for each monitoring well of the study area. The locations of monitoring tube wells with corresponding formation water disposal well were earmarked in the field. The samples were collected quarterly i.e. during January to March, April to June, July to September and October to December every year for three consecutive years from 2003 to 2006. These monitoring wells are of depth 20 m to 25m used for drinking water purpose.

The base line monitoring wells have been identified and earmarked in Naharkatiya, Digboi and Moran oil fields considering the spatial distance from the monitoring wells. Nine wells in Naharkatiya, five wells each in Digboi and Moran oil fields have been earmarked for sample collection. These base line monitoring tube wells are basically hand pumps or deep tube wells of depth ranging from 25 m to 110 m used for potable water. The base line wells have been selected in areas away from monitoring well and have been considered to be free from any impact of disposed formation water. The samples from base line water wells have been considered as control samples for comparison purpose. The spatial position of formation water disposal wells, ground water monitoring wells and baseline wells has been shown in figure 4.

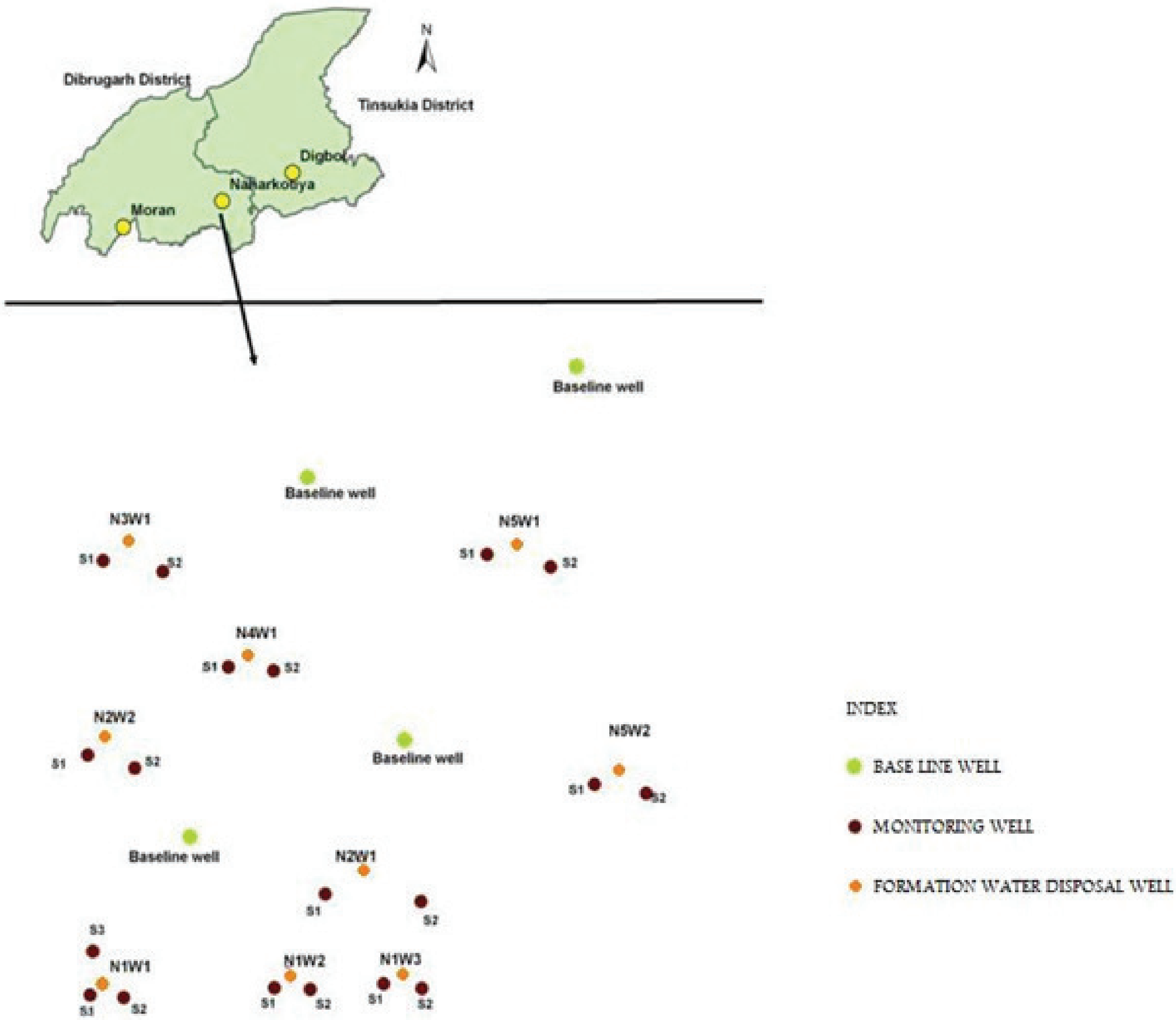

Fig. 1 Location of formation water disposal, ground water monitoring and base line wells in Naharkatiya field.

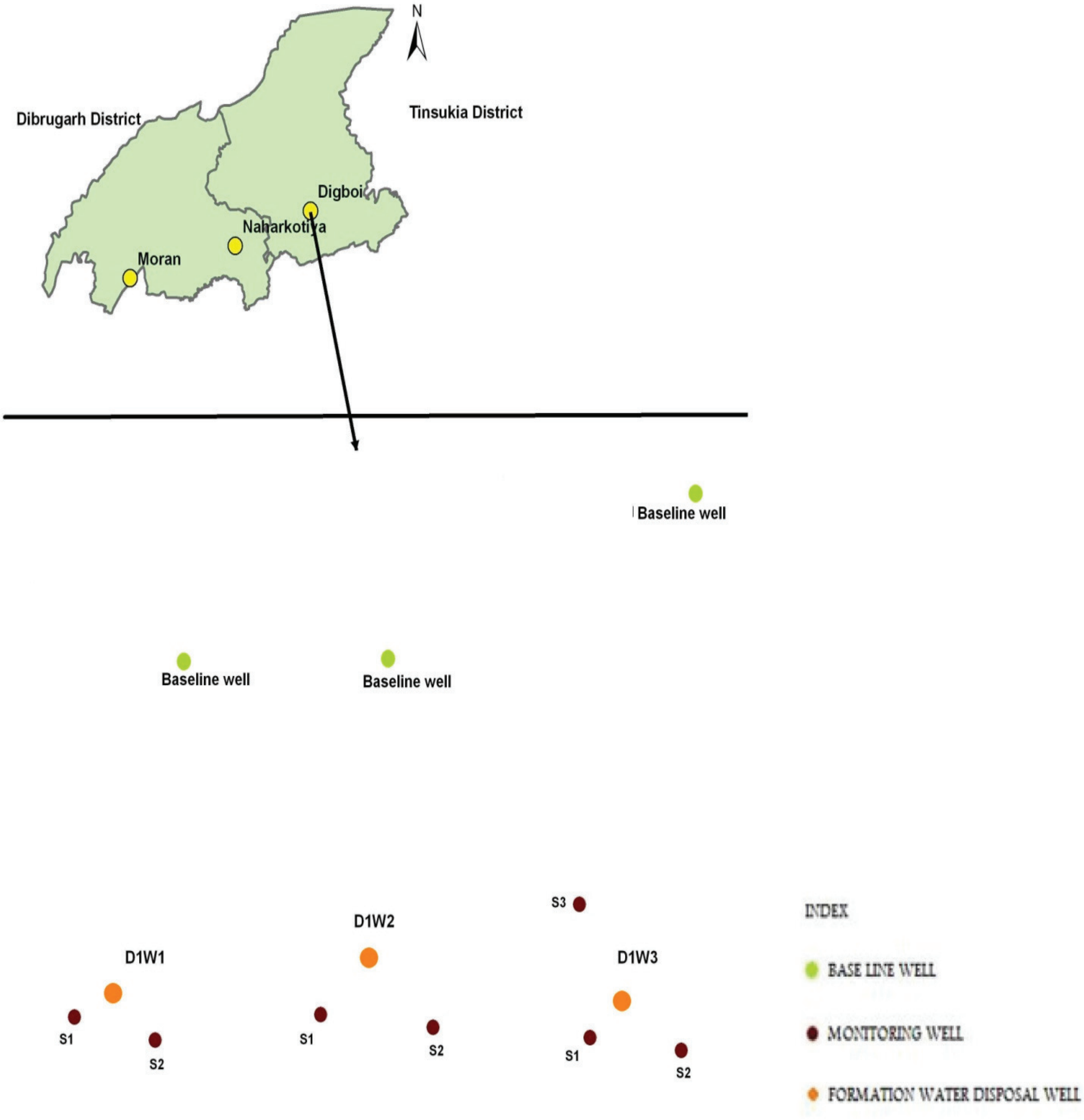

Fig. 2 Location of formation water disposal, ground water monitoring and base line wells in Digboi field.

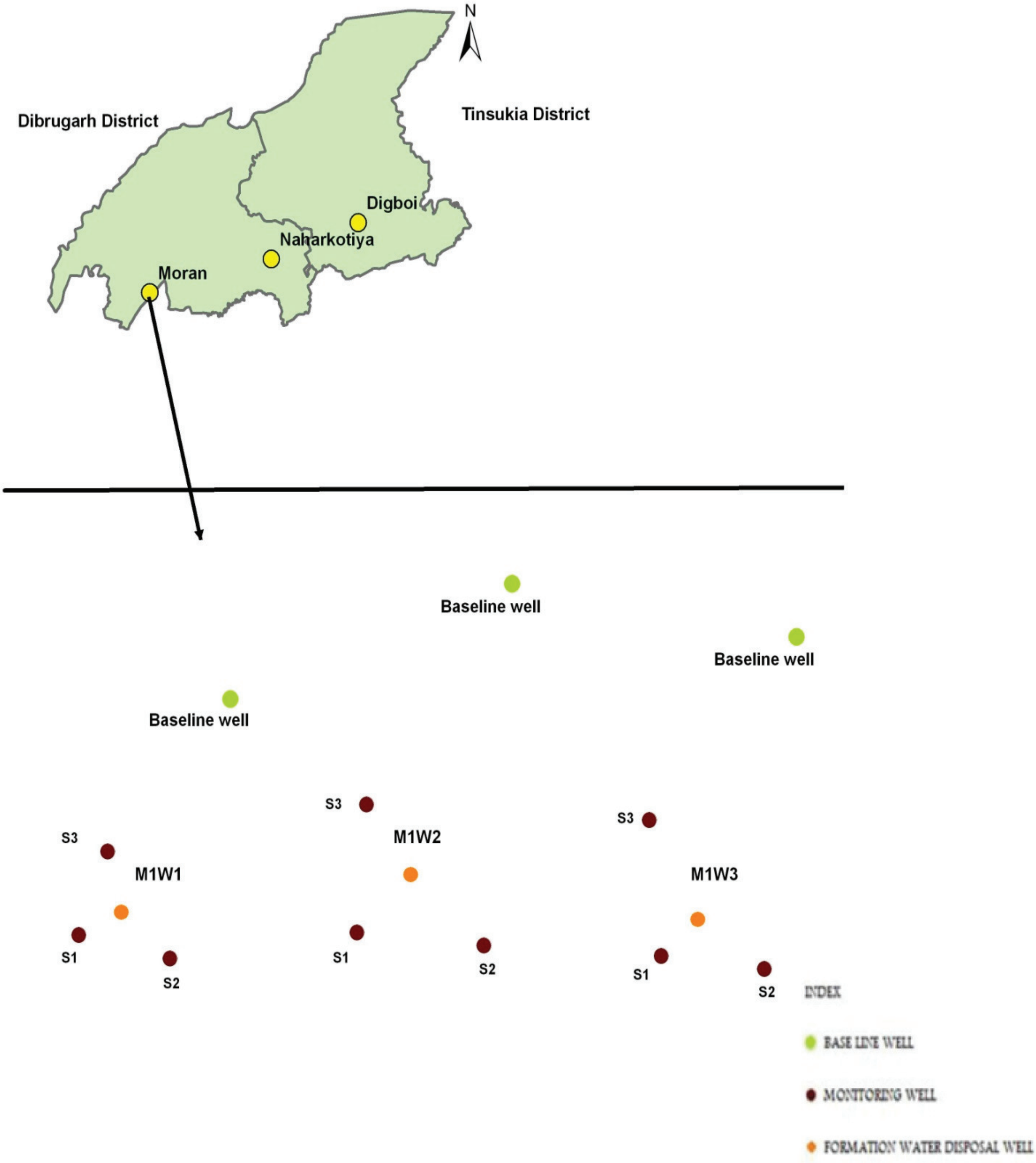

Fig. 3 Location of formation water disposal, ground water monitoring and base line wells in Moran field.

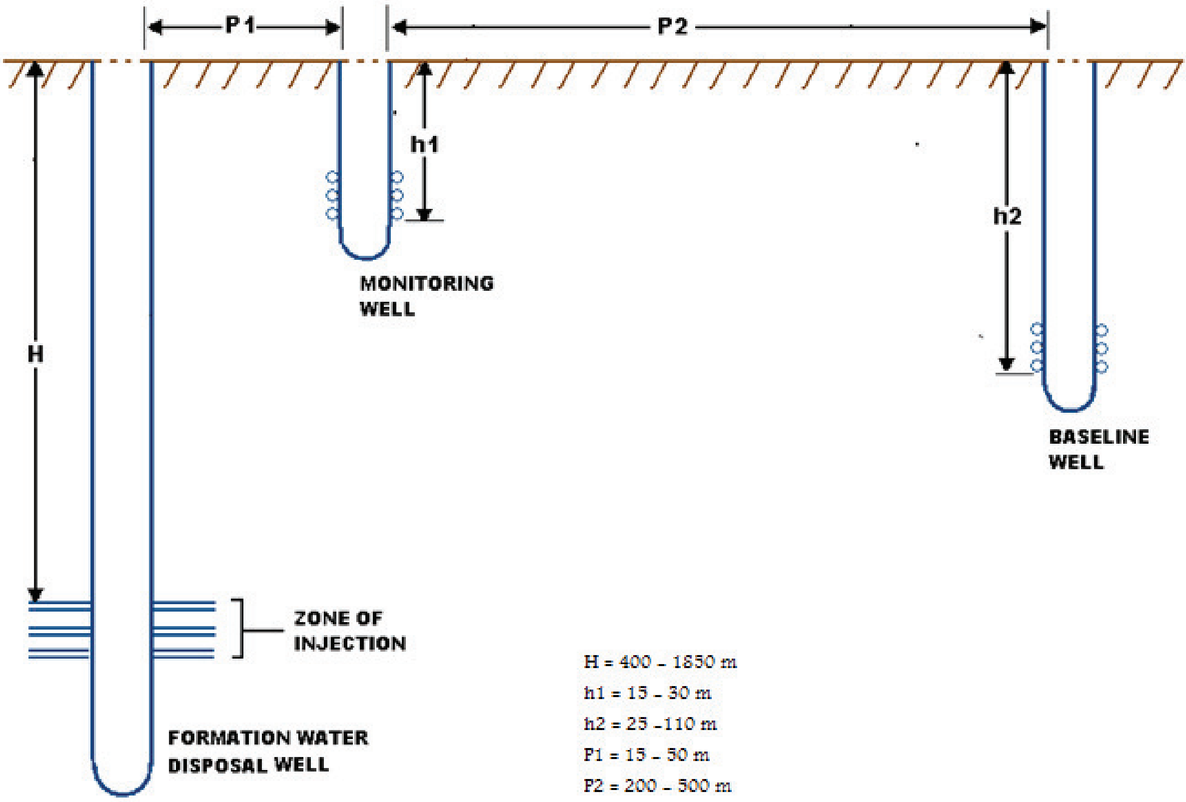

Fig. 4 Spatial Position of Formation Water Disposal, Monitoring and Baseline Wells.

Testing of Water Quality

Formation water samples were collected from the oil collecting stations in the study area and analysed for its physico-chemical properties and heavy metals. The ground water samples from identified monitoring tube wells (total 33 numbers) were collected and analysed for three replications. The ground water samples collected from the base line monitoring stations identified for the purpose were analysed. The range of various parameters was decided from analysis and the average was also calculated over 12 replications in three years. The range and average of various parameters were calculated for formation water, monitoring well and base line ground water samples.

Formation water samples were collected from the delivery of the disposal pumps in each oil collecting stations of the study area. As mentioned earlier the monitoring tube wells are located at a distance ranging from 15 m to 50 m from the disposal wells. The baseline monitoring tube wells were selected at a distance of 200 m to 500 m away from the point of disposal. Total 807 water samples collected from study area as shown in the Table 1.

Table 1 Water samples collected from various sources

Locations	Source	Number of samples (Replicated thrice)
Oil Collecting Stations	Formation water disposal pump	84
Monitoring wells	Tube wells	396
Base line wells	Tube wells	228

Analysis of samples

Analysis of samples was carried out as per the standard practice stipulated by APHA, 1998 guidelines. The parameters which are concerned with formation water characteristics *viz.* pH, temperature, alkalinity ($CaCO_3$), TDS, TSS, Chloride, Magnesium, Sulphate, Oil and Grease, Copper, Iron, Lead, Zinc were analyzed in the water samples of monitoring wells and compared with that of formation water.

Result and discussion

The analysis result of water samples of formation water, ground water from monitoring wells and base line wells has been shown in Table 2

From Table 2, it can be seen that the physico-chemical analysis of all important parameters of formation water, ground water monitoring wells and base line wells from contamination point of view indicate that the analytical value of a particular parameter are almost same in case of monitoring well and baseline well water samples whereas that of formation water is different. The same pattern is seen in all the parameters. From this comparative study it is evident that the constituents of formation water disposed underground have no impact on the physico-chemical properties of the ground water aquifer in the study area from contamination point of view.

Table 2-Summary of physico-chemical analysis of important quality parameters and their comparison amongst the samples collected from monitoring wells, baseline wells and formation water.

Parameters	Source of Samples								
	Naharkatiya			Digboi			Moran		
	Base line Well	Formation Water	Monitoring Well	Base line Well	Formation Water	Monitoring Well	Base line Well	Formation Water	Monitoring Well
pH	6.8	8.2	6.7	7.1	7.9	6.6	7	8.8	6.7
Temp (^{0}C)	24	41	24.1	24.2	42.5	23.9	24	47	23.8
Alkalinity (mg/l) (as $CaCO_3$)	101	2726	65	80	2701	79	72	3852	72
TDS(mg/l)	107	2344	107	118	2968	108	108	3100	108
TSS(mg/l)	22	264	22	20	258	22	15	306	12
Magnesium (mg/l)	0.4	26	ND	0.22	4.5	0.04	0.18	10	ND
Chloride(mg/l)	10	1470	12	12	1046	10	7	1548	8.3
Sulphate(mg/l)	12	123	8.6	8	193	8.5	9	220	8.4
Oil & Grease (mg/l)	3.3	174	0.9	2.7	130	0.001	2.6	210	1.1
Copper(mg/l)	ND	0.005	ND	ND	0.003	ND	ND	0.011	ND
Iron(mg/l)	2.45	0.01	2.21	2.16	1.2	2.16	0.30	0.08	0.90
Lead (mg/l)	ND	0.004	ND	ND	0.002	ND	0.1	.002	ND
Zinc(mg/l)	ND	0.003	ND	0.26	0.04	ND	0.23	0.15	ND

Statistical Analysis

Formulation of Hypothesis to test possible contamination of ground water by formation water

Statistical analysis of variants can give accurate significant differences for pollution parameters analysis and accepted as a decision making study (Rossiter D.G., 2006).

As discussed in previous sections, water samples from three independent sources *viz*., (i) formation water disposal well, (ii) ground water monitoring well and (iii) baseline monitoring well, were collected using standard procedure for all the three oil fields *i.e.* Naharkatiya, Digboi and Moran. The water samples were further analysed for some specific measurable quality parameters which has also been discussed in previous sections. Altogether water samples of 15 formation water disposal wells (W) were collected covering 7 oil collecting stations of three oil fields. Each of these 15 wells has corresponding neighbouring ground water monitoring stations (S) varying between 2 and 3. Three formation water disposal wells have three neighbouring ground water monitoring stations each, whereas remaining 12 wells have 2 each. Baseline monitoring wells, 9, 5 and 5 in numbers are commonly available for all the formation water disposal wells of Naharkatiya, Digboi and Moran oil fields, respectively.

In general, if migration of formation water to nearby ground water body, from where samples of monitoring well are drawn, is ruled out than water sample of monitoring well should be unaffected by formation water. The tests results of water quality parameters of a given formation water disposal well are compared with the results of corresponding neighbouring monitoring stations. Such comparison is repeated for all the formation water disposal wells of all the three oil fields. The results of water quality analysis of these two locations are also used to test the significance of such comparison using following Hypothesis.

H_0: The quality parameter x of formation water resembles with x of neighbouring ground water monitoring stations.

H_1: The quality parameter x of formation water does not resemble with x of neighbouring ground water monitoring station.

where, x is a quality parameter and the above hypothesis was tested for all the quality parameters considered for the study and repeated for all the formation water disposal wells.

Further, the quality parameters pertaining to a given ground water monitoring station are also compared with the quality parameters of baseline monitoring wells available in corresponding oil field. Accordingly, these two sets of results (water quality of baseline monitoring wells and ground water monitoring wells) are also used to test the following hypothesis.

H_0: There is no significant difference between the water quality parameter x of a ground water monitoring well and baseline monitoring well.

H_1: There is significant difference between the water quality parameter x of a ground water monitoring well and baseline monitoring well.

The statistical software MINITAB version 13 was used for the statistical analysis and we have also mentioned that all the tests are right tail test. The following statistical tests were carried out;

(i) One sample t test to find out any significant difference between the water quality parameters of monitoring wells and the baseline wells.

(ii) One sample t test to find out any significant difference between the water quality parameters of monitoring wells and the formation water.

From the statistical analysis, it was seen that the value of p in case of all the parameters for formation water *vs.* monitoring well water in Naharkatiya, Digboi and Moran fields is more than 0.05. If the probability (p) value is less than 0.05, then it is strong evidence against the hypothesis. In the case of formation water and the monitoring well water, the Hypothesis taken was the parameter x of formation water resembles parameter x of monitoring well water. The values of p for all the parameters in case of formation water and the monitoring well water is much more than 0.05. The concentration of important water quality parameters from contamination point of view like TDS, Chloride and Oil & Grease is very high in formation water in comparison to monitoring well water. The value of p for these important parameters like TDS, Chloride and Oil & Grease is 01 i.e. much more than 0.05 in Naharkatiya field, hence the hypothesis is rejected, which means the formation water quality does not resemble the water quality of monitoring wells in Naharkatiya field. In Digboi and Moran field, the value of p for TDS, Chloride and Oil & Grease is also 01, which again strongly rejects the hypothesis which means the parameters of formation water do not resemble the parameters of monitoring wells in these fields also. Therefore, the water of monitoring wells has not been affected due to injection of formation water.

Similarly, the hypothesis formed in case of ground water monitoring well *vs* base line well water parameters is that there is significant difference between the parameter x of monitoring well water and parameter x of baseline well water. The p value in case of all the parameters of water from monitoring wells *vs.* base line wells is greater than 0.05 which means the hypothesis has failed. The value of p for important parameters such as TDS, Chloride and Oil & Grease in case of monitoring and base line well water in Naharkatiya field is 01. In case of Digboi field the p value is 0.747 for TDS, 0.961 for Chloride and 01 for Oil & Grease which are much above 0.05. In case of Moran, the value of p for TDS is 0.932, for Chloride 1.046 and for Oil &Grease 01. It is evident from all these probability values (p) that the hypothesis is strongly rejected since the values are more than 0.05 in these cases i.e. there is no significant difference between the parameter x of monitoring well water and parameter x of base line well water . Hence, there is no significant difference between the water qualities of monitoring and base line wells. Therefore, they are remaining same and unaffected due to injection of formation water.

Conclusion

The analysis of water quality of formation water, monitoring well and baseline well water of the study area and their comparison, statistical analysis of water parameters by forming hypotheses to find out their level of variance which was insignificant, all these conclude that the ground water quality in the oil fields of Dibrugarh and Tinsukia districts of Assam has not been contaminated due to underground disposal of formation water in this area with the prevailing practice of disposal in the fields. However, the present investigation has been carried out considering the comparative study of water quality parameters and its validation by statistical analysis. The study recommends further research in this area including the hydrology and flow theories.

References

Stone B (2003) Management of Produced water, Oxford publications, Washington: 37-41

Amyx J, Bass D and Whiting RL (1960) Petroleum Reservoir Engineering. McGraw Hill publishers, New York: 234-247

Cline JT (1998) Treatment and Discharge of Produced water for Deep offshore disposal **2**: 17-19

Khatib Z and Verbeek P (2003) Water to Value-Produced Water Management for Sustainable Field Development of Mature and Green Fields, Journal of Petroleum Technology, Jan: 26-28

Central Ground Water Board, Govt. of India. (1993) Hydrogeology and Ground Water Potential of Dibrugarh District, Assam. Technical Report series D. No. **26**: 12-17

Indian Meteorological Department - IMD (2006). Monthly Tables on Meteorological data for Dibrugarh area.

Patel H, Borgohain D and Jena S (2003) Hydro geochemistry of Upper Assam Oil field. *JPT* **2**: 11 – 14

McLin S G (1997) Evaluation of Aquifer Contamination from Salt Water Disposal Wells **2**: 53-60

Breit G, Klett TR, Rice CA, Ferderer DA and Kharaka Y (1998) National Compilation of Information about Water Co- produced with Oil and Gas. *JPT* **41**: 20-23

Utvik TI (2003) Composition and Characteristics of Produced Water in the North Sea. *JPT* **59**: 26-27

Rossiter DG (2006) An Introduction to Statistical Analysis. McGraw Hills: 17-31 (http://www.itc.nl/personal/rossiter)