Investigation on Domestic Groundwater Contamination by Oil Ponds, Using Groundwater Flow Modeling. A case study in the city of Jikharrah. eastern Libya.

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التحقيق في تلوث المياه الجوفية المحتمل بواسطة برك النفط، باستخدام نمذجة تدفق المياه الجوفية. دراسة حالة في مدينة اجخره شرق ليبيا

الملخص:

منطقة الدراسة هي منطقة اجخره في الصحراء الليبية جنوب إجدابيا، الهدف الرئيسي من هذا البحث هو دراسة تأثير أحواض المياه المصاحبة للنفط في منطقة الدراسة على آبار المياه الجوفية المجاورة، لهذا الغرض تم جمع سبع عينات من برك النفط التي تحتوي على المياه المصاحبة للنفط في المنطقة، تم إجراء التحليل الكيميائي لتحديد نسبة تواجد وتركيز الملوثات الكيميائية الضارة في هذه المياه وهي (زيت وشحم (oil &grease)، زنك (Zn)، حديد (Fe)، رصاص (Pb)، صوديوم (Na)، كادميوم (Cd)، كبريتيدات (S) والنيكل (Ni) والكبريتات (SO4) والملوحة (TDS) والألمنيوم (Al) وأوضح التحليل الكيميائي أن بعض هذه العينات بها مستويات تركيز أعلى من المواصفات المحلية والعالمية، باستخدام حزمة MODFLOW من هيئة المسح الجيولوجي الأمريكية (USGS)، وهي عبارة عن برنامج نمذجة لتدفق المياه الجوفية، تم تحديد نمط تشتت هذه الملوثات حيث تشير نتائج التحليل الكيميائي إلى جانب نمذجة تدفق المياه الجوفية إلى أنه في حالة استمرار تدفق المياه المصاحبة للنفط إلى برك النفط المجاورة والمحيطة بمنطقة الدراسة دون معالجة علمية مناسبة، فإن كارثة بيئية واجتماعية واقتصادية ستؤثر على هذه المدينة، وقد توقعت النمذجة وصول هذه الملوثات إلى المياه الجوفية لآبار منطقة الدراسة المجاورة لهذه البرك مباشرة خلال السنة الأولى من النمذجة، سيسود التلوث بهذه الملوثات في منطقة الدراسة بأكملها خلال عشرين سنة بعد بدء ضخ هذه المياه الملوثة. مشيرة إلى أن بعض هذه الأحواض النفطية قد تم إنشائها قبل 40 سنة، وأحدثها أقيم قبل 10 سنوات. يجب على جميع الجهات الحكومية وشركات النفط الرسمية العاملة في المنطقة أن تفي بالتزاماتها الإنسانية والأخلاقية لوقف هذا التلوث وتأمين المدينة من كارثة بيئية.

الكلمات المفتاحية: *التلوث، المياه المصاحبة للنفط، المياه الجوفية، أحواض النفط.*

Abstract:

The study area is Jikharrah area in the Libyan Desert, south of Ajdabiya. The main objective of this research is to study the effect of the pools of the accompanying water in the study area on the groundwater wells in the vicinity. For this purpose, seven samples were collected from oil ponds containing accompanying water in the area. Chemical analysis was performed to determine the occurrence and concentration of harmful chemical pollutants in this water which are (oil and grease, Zinc (Zn), Iron (Fe), Lead (Pb), Sodium (Na), Cadmium (Cd), Sulphides (S), Nickel (Ni), Sulphates (SO4), Salinity (TDS) and aluminum (Al)). The chemical analysis indicated that some of the samples have higher concentration levels than local and international standards. Using US Geological Survey (USGS) MODFLOW package, the dispersion pattern of these pollutants was determined. The chemical analysis results together with groundwater flow modelling indicate that an environmental, social and economic disaster will affect this town. Modelling has predicted the arrival of these pollutants to the groundwater wells adjacent to these ponds immediately during the first year of modeling. Contamination with these pollutants will prevail in the entire study area during twenty years after the start of pumping these polluted waters. All official state agencies and oil companies operating in the area must fulfill their human and moral obligations to stop this pollution and safe the town from an environmental disaster.

Keywords: Pollution, water associated with oil, Groundwater Flow Modeling, MODFLOW, oil ponds.

Introduction:

Oil is one of the primary energy sources in modern society; with the development of the social economy, oil demands have increased dramatically. However, many oil spills cause soil and groundwater pollution, and these have become irreversible environmental problems (Allan and Elnajjar, 2012), Oil spill is an unintended release of petroleum hydrocarbon liquids into the environment, and it represents a form of pollution. This term usually refers to oil spills in the seas, Where oil is poured into sea water, and also may happen on land (Allan and Elnajjar, 2012), Groundwater may also be polluted as a result of transporting oil by road by cracking or breaking of pipes and oil leakage from them in addition to collision of oil transport trucks. Other ways of groundwater pollution may be through water contained in oil pools carrying multiple wastes; or by the contents of water accompanying the oil, which leads to its penetration into soil causing severe damage to that area, as oil may reach groundwater (Alexandros et al., 2015). Groundwater is the supply of freshwater found beneath the earth’s surface. It is our most valuable natural resource.. Groundwater provides about 97 percent of the world’s total supply of drinkable water. Groundwater is a source of lifestyle for many people, but human activity without supervision contributes a lot to polluting various water sources contamination, Contaminants are generally dissolved and carried by infiltrating rainwater into unsaturated soil above the water table. (Allan and Elnajjar, 2012),The oil is characterized by its high ability to interact and spread in several forms and access to air, soil, freshwater, seas or oceans based on many vital factors. The various forms of reaction of oil in nature are diffusion, drifting, evaporation, natural dispersion, emulsion (water in oil emulsification), dissolution, oxidation, sedimentation and biodegradation. There are a large number of harmful compounds contained in crude oil, all of which pollute the earth and water environment, which are in the form of toxic organic oil pollutants or toxic inorganic oil pollutants. (Clark, 1995). The water found in petroleum reservoirs is usually brine consisting mostly of sodium chloride (NaCl) in quantities from 10 to 350 ppt; seawater has about 35 ppt. Other compounds (electrolytes) found in reservoir brines include calcium (Ca), magnesium (Mg), sulfate (SO_4), bicarbonate (HCO_3), iodine (I), and bromine (Br). Brine specific gravity increases with salinity in units of about 0.075 per 100 ppt. (Engle et al., 2014).

Objectives of the study: -

1- To assess the effects of various pollutants on shallow and deep groundwater.

2- To know groundwater quality trends and to determine the damage caused by pollutants to groundwater

3- To determine the time period for pollution in order to treat and avoid pollutants from reaching groundwater.

Material and Methods

The study site

Jikharra is an oasis and a town in eastern Libya in the Libyan Desert, and is located within the "oases south of Benghazi". It forms an almost equilateral triangle with each of the oases of Gallo and Oujla, and it is located at Longitude 21.39 E and Latitude 29.18 N, and about 200 km south to the town of Ajdabiya (Fig.1).

This area is rich in oil resources that surround Jikharra from all directions (oil fields - natural gas fields). Due to the suspension of oil exports in Libya during the period (2014/2015), oil companies were forced to empty their daily production of oil in large and huge pools at different distances from the town's location (Fig. 1) for fear of damage in the facilities of those oil wells. Seven oil pools of different sizes and depths surrounding the town were chosen to study the extent of the effect of water accompanying the oil on eleven groundwater wells in the study area (Fig. 1).
(Al-Labbad, 2017)

Methods of Investigations

Chemical Analysis Methods

The aim and purpose of the chemical analysis is to know and calculate the amount of chemical toxins that will seep through the soil and deep gaps in the soil and rocks and reach the surface water or groundwater in the study area.

The concentrations of the elements in the pond were determined, and their suitability and conformity with the international specifications of WHO was examined; if they are in accordance with the standard specifications of the water accompanying the petroleum or not.

Groundwater Flow Modelling

The groundwater flow in the study area is modeled using USGS Modflow V. 6 Software. The modeling process requires the input of certain parameters such as recharge and discharge data, topographic data, pollutants data in addition to other flow data. In this study the following data were used as input for modeling the diffusion of harmful pollutants in the area.

Oil-Water ponds (recharge data)

Seven oil ponds were chosen to serve as input data for recharge as well as source of pollution (Table 1). Some of these ponds are located in the near vicinity of Jikharra, while the others are a little bit remote (Fig. 1). Results of chemical analysis of ponds' water are shown in the next section Table (3) shows a summary of the concentrations of these eleven pollutants together with safe concentration limits as set by WHO for Libya.

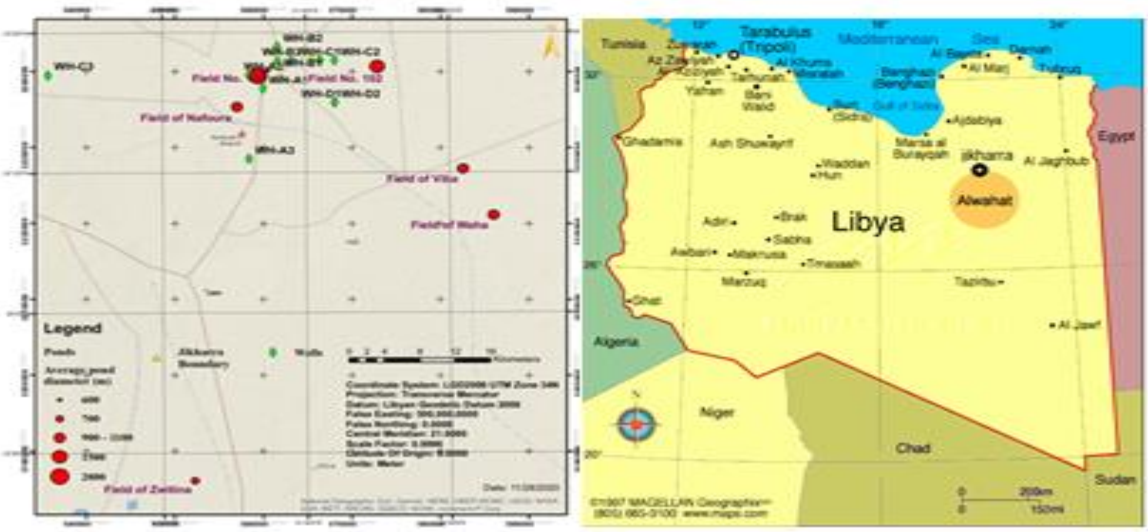


Figure (1): Location map of Jikharra Town, oil ponds and well sites. Variation in ponds' diameter is shown in red circles.

Surveys of environmental protection organizations, experts and some of the company's engineers in the study area indicate that the amount of water accompanying the oil that flows into the oil lakes can reach a minimum of (2000 cubic meters) per day.
So, for an individual pond the flow is estimated to be in the average of 300 cubic meters per day.

Table 1: Oil ponds in the study area (for locations see figure 2; note that Field of Jikharra and Field No. 104 are located very close to Jikharra Town).

Oil Field	Oil ponds	Pond depth (m)	Pond circle diameter (m)
Field No. 102	19 - 771	3 – 1.5	1500
Field of Viba	19 - 772	2.5 - 2	1000
Field of Waha	19 - 773	2 – 1	1000 – 1200
Field of Zwitina	19 - 774	1.5 – 2	600 – 800
Field of Nafoura	19 - 775	1 – 2	800 – 1000
Field of Jikharra	19 - 776	3 m	2000
Field No. 104	19 - 777	3 m	600 m

Domestic Water wells (discharge data)

Eleven wells were chosen for the purpose of this study (Fig. 1). All wells are utilized for agricultural purposes, with five of them used for drinking purposes as well. In our model, these wells serve as a discharge source (Sink). Table (2) shows details of these wells; of which discharge rate is entered in the model.

Digital elevation model (DEM)

The digital elevation model of the area (Fig. 2) is obtained from the USGS web site and is used to construct the model top. Attempts were made to use DEM as a General Head Boundary (GHB), but unfortunately that was not possible and a persistent error message appears and hence the authors used elevation data instead.

Topographic data

Topographic data for the area is obtained from Satellite Geodesy web site https://topex.ucsd.edu/cgi-bin/get_data.cgi. These data are used to construct the topographic map of the area (Fig. 3).

Pollutants – contaminants concentration data

Results of chemical analysis of wastewater of the seven ponds are entered in the model as initial values of contaminants in the ponds (Table 4).

Table (2): Total depths and discharge rates of some of the wells in the study area. (For locations see Fig. 2).

Well No.	Purpose of use	Total depth (m)	Discharge rate (m^3/day)
WH – A1	Agriculture	51	216
WH – A2	Agriculture + drinking	8	864
WH-A3	Agriculture + drinking	40	1872
WH – B1	Agriculture	6	72
WH – B2	Agriculture	45	2016
WH – B3	Agriculture + drinking	6	1008
WH – C1	Agriculture	50	1728
WH – C2	Agriculture	50	1872
WH – C3	Agriculture + drinking	50	206
WH – D1	Agriculture + drinking	18	1296
WH – D2	Agriculture + Industrial	54	1152

Hydraulic conductivity

Hydraulic conductivity (Kx) of top layer (which is sand) is entered in the model as 1*10-5 m/s or 0.864 m/day

General Head Boundary (GHB)

As mentioned earlier the topography is utilized to serve as GHB for the studied area. Contours of 85, 65, 45 and 35 m were used as GHB.

In MODFLOW, the Conductance is described as having units of L^2/T and is equal to KLW/M where:

K = the hydraulic conductivity of the sediment in the boundary condition such as a river or drain,
L = the length of the boundary condition in the cell,
W = the width of the boundary condition, and
M = the thickness of the sediment in the boundary condition perpendicular to flow between the boundary and the cell. Usually this will be vertical thickness of the sediment.
However, if Conductance Interpretation is set to Calculated, Conductance should be treated as if it were KW/M instead of KLW/M, its units would be L/t, and an appropriate formula would be

$(K_z*DrainWidth)/DrainSedimentThickness$

if Conductance Interpretation is set to Calculated for a Polygon Object, Conductance should be treated as if it were K/M instead of KLW/M, its units would be 1/t, and an appropriate formula would be

$K_z/DrainSedimentThickness$

In our model Kz is assumed to be Kx/10, drainWidth is averaged using Global Mapper Software, the thickness of the top layer is assumed (based on well data) to be 60 m and hence the conductance for GHB is calculated based on the above equations as shown in Table (3).

Table (3): Conductance values for GHB.

GHB	Type	Conductance	Unit	Attribute
85 m	Polyline	17.16	m/day	Calculated
65 m	Polyline	24.54	m/day	Calculated
45 m	Polyline	9.57	m/day	Calculated
45 m	Polygon	0.00144	1/day	Calculated
35 m	Polygon	0.00144	1/day	Calculated

Results

Results of chemical analysis and groundwater flow modeling will be shown in this section.

Chemical Analysis

Chemical analysis of wastewater of oil ponds reveals the concentrations of eleven pollutants: Oil & Grease, Zn, Fe, Pb, Na, Cd, S, salinity, Ni, Al and SO4.
Table (4) shows the Concentration of pollutants in the oil ponds adjacent to the study area.
From the table (4) it is clear that iron (Fe), lead (Pb), sodium (Na), salinity, Sulphate and three samples of Cd fall within the safe concentration range according to WHO standards for Libya. The other five contaminants (oil and grease, zinc (Zn), Sulphur (S) nickel (Ni) and aluminum (Al) show high concentrations and in some cases extremely high concentrations as in the case of Zn and Ni.

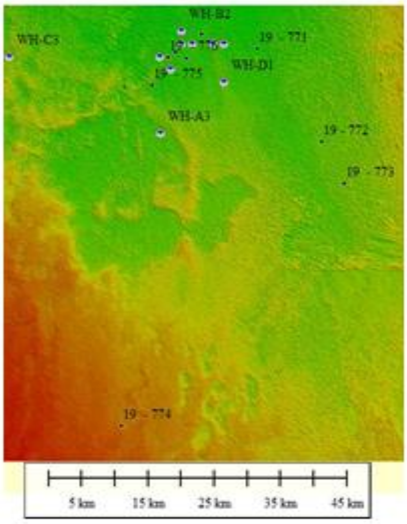


Figure (2): Digital Elevation Model of the study area.

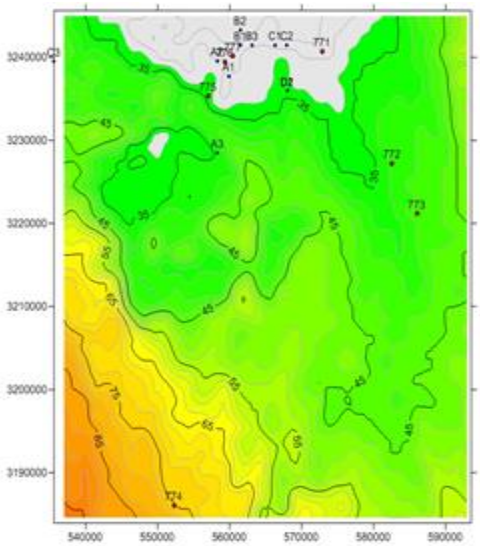


Figure (3): Topographic map of the study area.

(Fig. 4) shows the distribution of the concentrations of four of these pollutants in the area. Judging by the size of the symbol, it is very clear that the ponds around Jikharra contain very high concentrations of most of these pollutants.

Groundwater Flow Modeling

The groundwater flow is modeled using USGS MODFLOW V. 6 Software. The parameters mentioned in section 2.2.2. are used as input for the model. The groundwater flow is modeled for 20 years. Results of the modeling are shown in Figures 5, 6, 7 and 8 for oil and grease, Zinc, Sulphur and Nickel respectively.

Discussion

A large volume of water (called produced water) is usually extracted as a byproduct during oil and gas production, which is mixed with dispersed oil, grease, dissolved solids and suspended solids (Chakrabarty, et al., 2010). Discharging of produced water may pollute surface and underground water as well as soil.

Within the results of the laboratory analysis table (4) and the statistical analysis table (5) it was found that there are four chemical elements that are very high in their concentration and that exceeded international and local standards and specifications within these oil ponds, and these elements are - (oil and grease, zinc, sulfur, Nickel) and to support our research with advanced scientific methods and to give results and indicators that support the previous two analyzes, the method of the US Geological Survey program was used, and the results were as follows:

Table (4): Concentration of pollutants in the area (in ppm). Red color indicates that the concentration of the pollutant is above the standard concentration for domestic water use.

Field Name	Oil & Grease	Zn	Fe	Pb	Na	Cd	S	Salinity	Ni	Al	SO_4
Field No. 102	2.48	69.8	5.08	0.02	15	0.003	5.07	67	52.1	0.5	0.311
Field of Viba	12.15	70.1	7.88	0.2	31.5	0.005	0.91	89	56.3	1	1.44
Field of Waha	2.967	60.8	4.8	0.004	18	0.02	6.17	75	48.8	1.2	0.16
Field of Zwitina	3.79	65.5	3.9	0.1	16	0.1	5.23	77	48.26	0.55	0.19
Field of Nafoura	1.874	62.9	8.51	0.6	31	0.12	6.11	69	61.2	0.23	1.8
Field of Jikharra	1.55	70.1	6.23	0.02	20	0.23	0.85	80	55.3	0.5	0.63
Field No. 104	5.072	70.8	5.13	0.01	25	0.009	5.8	65	49.8	1.3	0.255
Max. allowable concentration for Libya.	0.1	0.7	100	8.8	200	0.005	0.2	97000	0.004	0.2	400
Max. allowable concentration for world.	-	-	0.1 – 1.0 (0 – 50)	0.1 – 1.0	1 – 100	0.004 – 0.024	14 – 17	2 – 1500	0.6 – 9.0	0.005 – 0.010	40 - 50

Table (5) Statistical analysis of some pollutants in the oil ponds adjacent to the study.

Pollutant	Mean X	S.R	S.D	V	F.pr	L.S.d 95%	C.V%	Min	Max
Oil and Grease	4.269	1.389	3.674	13.50	0.989	6.968	86.1	1.550	12.15
Fe	5.933	0.642	1.698	2.885	1.000	7.180	-9.24	3.93	8.510
Pb	0.13	0.08	0.21	0.04	0.295	<0.001	10.56	0.004	0.60
Na+	22.36	2.602	6.884	47.39	1.000	27.41	-8.21	15.00	31.50
S	5.933	0.993	2.628	6.908	0.99	7.863	-4.97	0.91	9.130
Salinity	74.57	3.176	8.404	70.62	1.000	80.74	-23.16	65	89
SO_4	0.683	0.25	0.66	0.44	0.128	1.173	1.26	0.160	1.80
Zn	67.14	1.534	4.059	16.48	1.000	70.12	6	60.80	70.80
Ni	53.11	1.789	4.735	22.42	1.000	56.59	-29.12	48.26	61.20

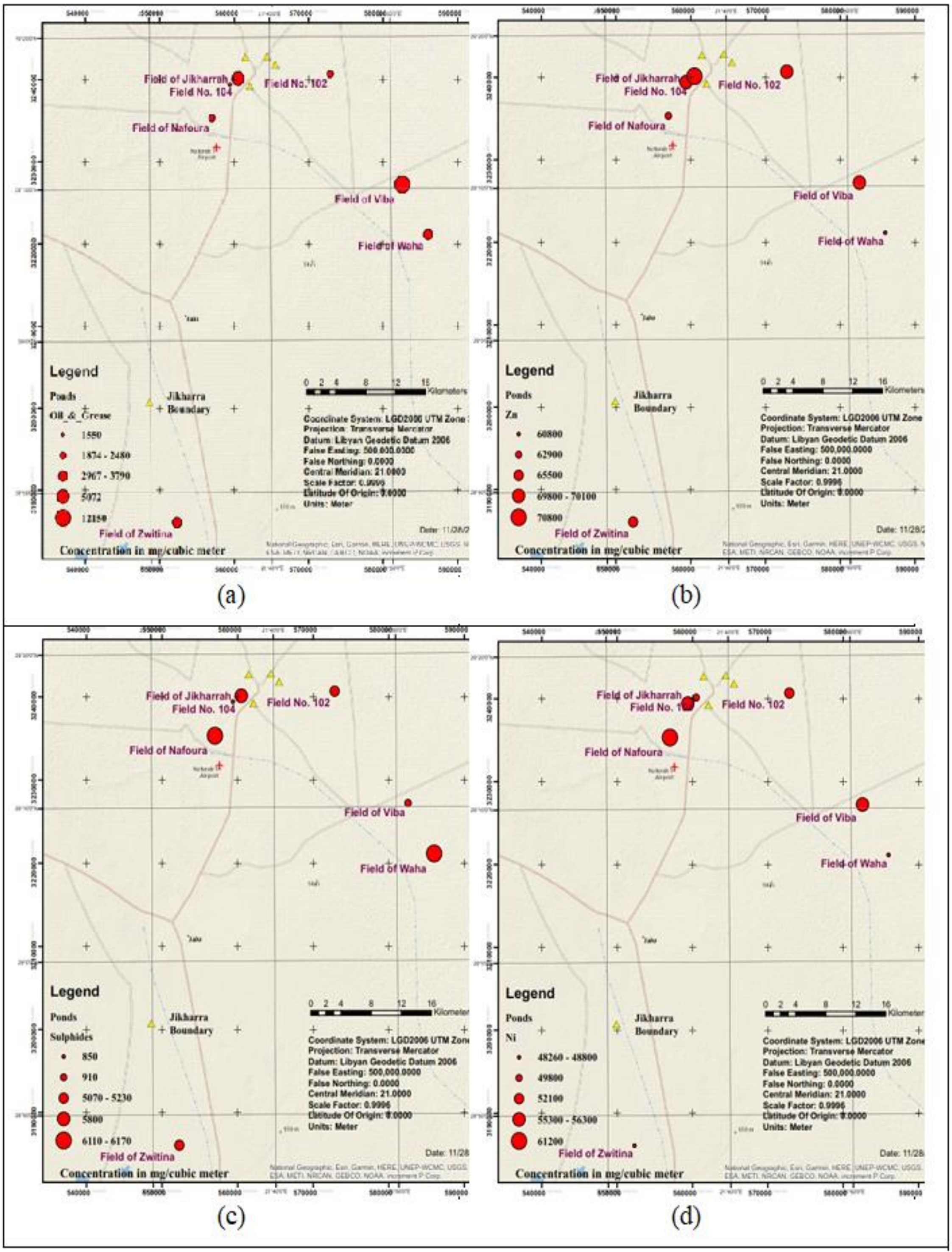


Fig. 4: Distribution of the concentrations of some pollutants in the area; (a) oil and grease, (b) Zn, (c) S, (d) Ni.

Contaminant (Oil and Grease)

The range of concentration of oil and grease is between 1.550 - 12.15 mg/l (Table 5), which indicates that all the samples are above the safe concentration level for drinking water in Libya (0.1 mg/l). Groundwater flow modelling shows that pollution by oil and grease will commence immediately (first year) affecting the vicinity of the ponds and continues steadily to affect all the area (Fig. 5. b). From the figure it can be readily seen that Jikharra area is dominated by bluish and greenish colors in the first year which indicates that concentration levels of > 1.4 mg/l are affecting the water wells of the area. In the following years the area of safe concentration level (indicated by a deep blue color) diminishes leaving space for more pollution (Fig. 5. c and d).

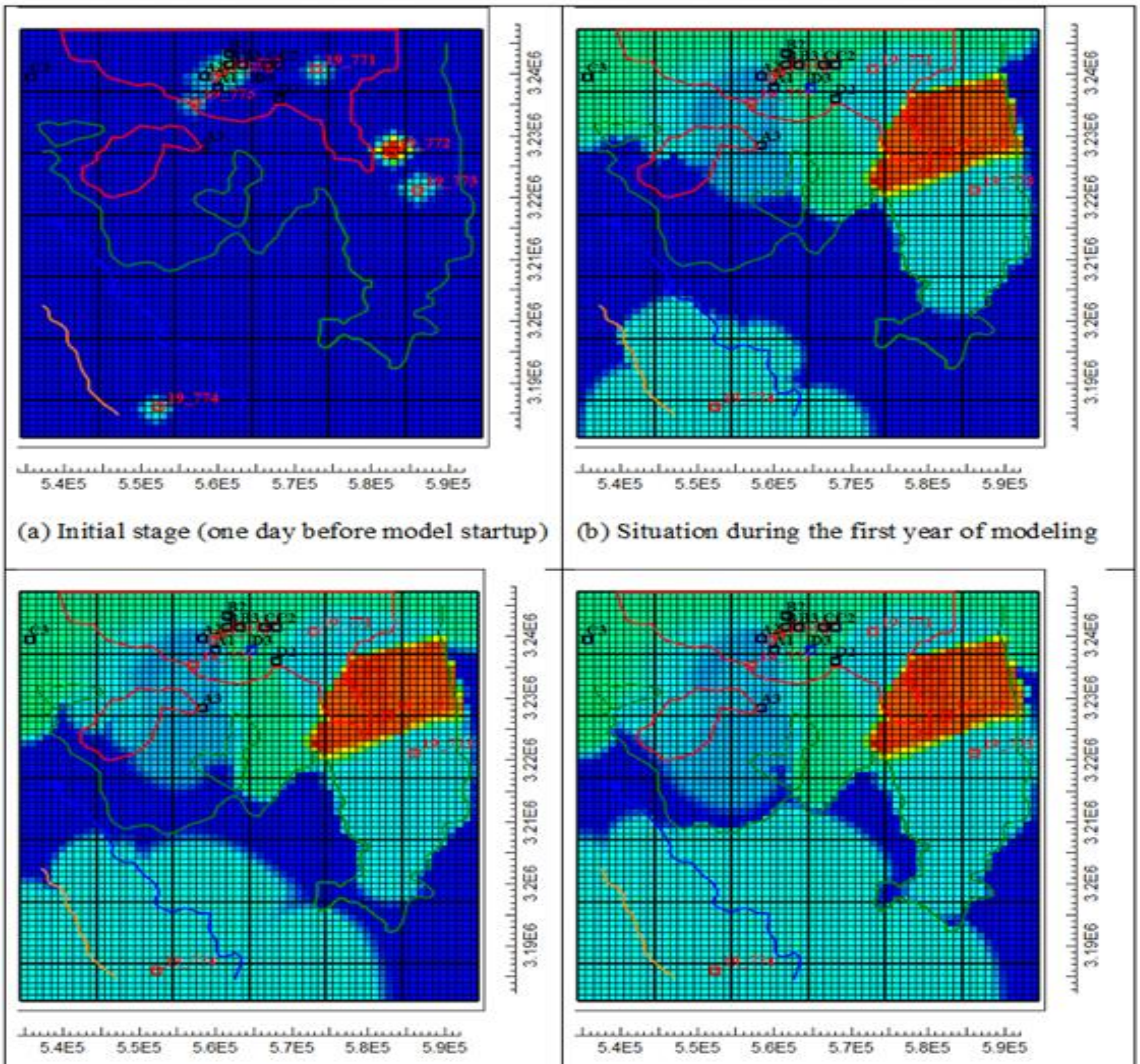
All countries of the world and international and local organizations and others indicate their technical recommendations that the natural waters are free of high concentrations of oil and grease and that the maximum limit for them should not exceed from (0.1 - 2.0 mg / liter) because higher concentrations result in change of its chemical and physical characteristics and make it unsuitable for drinking. In the results obtained in this study, the concentration of oil and grease was very high, especially in some samples, where it was found to be 12.150 mg/l.

Modeling result confirms that the percentage and spread of oils and grease in the oil ponds adjacent to the study area is high. These pollutants may reach the underground water wells in the town and cause several changes in the properties of drinking water.

Contaminant (Zn)

The range of concentration of Zinc is between 60.80 - 70.8 mg/l (Table 5). These concentrations are almost hundred times the safe concentration level for drinking water in Libya (0.7 mg/l). Figure 6 (a) indicates that even in the initial stage, the concentration of Zn is very high in Jikharra area (red and orange colors). As in the previous contaminant groundwater flow modelling shows that pollution by Zn will commence immediately in the first year, affecting the vicinity of the ponds and continues steadily to affect all the area (Fig. 6. b). From the figure it can be readily seen that Jikharra area is dominated by red and orange colors in the first year which indicates that concentration levels of > 70 mg/l are affecting the water wells of the area. In the following years the area of safe concentration level (indicated by a deep blue color) diminishes leaving space for more pollution (Fig. 6. c and d).

Zinc is a trace element that is essential for human health. When people absorb too little zinc they can experience a loss of appetite, decreased sense of taste and smell, slow wound healing and skin sores. Zinc-shortages can even cause birth defects**.**



(a) Initial stage (one day before model startup)

(b) Situation during the first year of modeling

(c) Situation during the Fifth year of modeling

(d) Situation during the fifteenth year of modeling

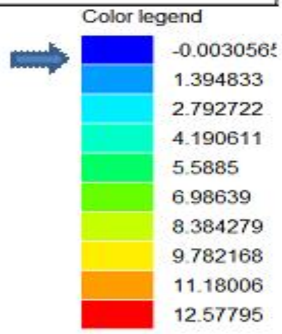


Fig. 5: Dispersion pattern for contaminant ***Oil and Grease****:(a) The initial stage (one day before model startup), (b) during the first year, (c) during the fifth year and (d) during the fifteenth year.*

Note that the safe concentration is 0.1 ppm which lies between the first and second degrees of the color scale.

Although humans can handle proportionally large concentrations of zinc, too much zinc can still cause eminent health problems, such as stomach cramps, skin irritations, vomiting, nausea and anemia. Very high levels of zinc can damage the pancreas and disturb the protein metabolism, and cause arteriosclerosis. Extensive exposure to zinc chloride can cause respiratory disorders .(Degremont, 1991).

There is no evidence that zinc causes cancer in humans. Zinc may also increase the acidity of the water. Zinc can not only pose a threat to livestock, but also plant species. Often plants have a zinc absorption that their systems cannot handle, due to a buildup of zinc in the soil. Zinc can interrupt activity in the soil, as it negatively affects the activity of microorganisms and earthworms. The decomposition of organic matter may be seriously slowed down due to the excess of zinc in these contaminated waters (Degremont, 1991)

Zinc can be a danger to unborn and newborn children; when their mothers have absorbed large concentrations of zinc the children may be exposed to it through blood milk of their mothers. (Milkins, 2013).

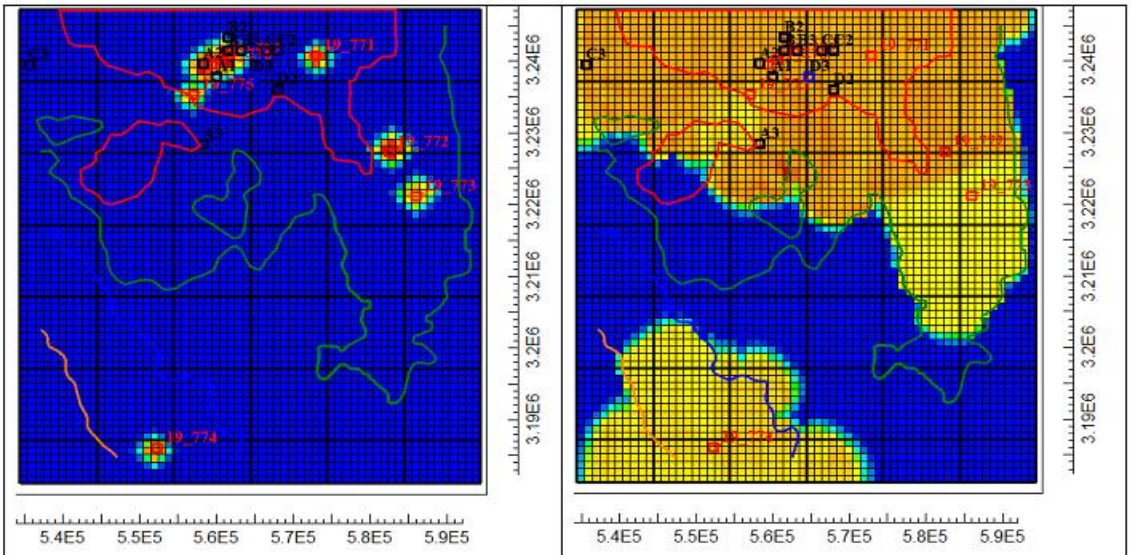
Contaminant (Sulfur **S).**

Results of chemical analysis indicate that the concentration of S in the area ranges between 0.85 and 9.130 mg/l (Table 5). All these values are well above the maximum allowable safe concentration level for Sulphur as per Libyan standard (0.2 mg/l). The same phenomenon is observed in the modeling of the dispersion of S in the area; immediate pollution of the areas surrounding the ponds from the first year (Fig. 7. b). Once more, the same scenario is repeated here with the safe zone diminishes with time to less than 20% of the total study area after 15 years.

Elemental sulfur is a non-metallic mineral yellow in color, brittle, does not dissolve in water, tasteless and odorless, highly flammable with a blue flame. Sulfur is present in crude oil in the form of hydrogen sulfide H_2S) and sometimes in the solid form. Crude oil containing a very small percentage of sulfur content (less than 0.5%) is considered sweet oil, and oil containing a high percentage of sulfur (higher than 0.5%) is considered or called sour oil. The element sulfur in general is undesirable in crude oil because of the problems it causes many problems such as: difficulty in distilling the sulfur-containing crude oil, the ability of sulfur to cause corrosion and the accumulation of sulfur inside equipment in the refineries, which increases the cost and time of its maintenance.

Sulfur dioxide can affect health and the environment. Short-term exposure to sulfur dioxide can damage the human respiratory system and make breathing difficult. People with asthma, especially children, are sensitive to the effects of SO_2. At high concentrations, gaseous sulfur oxides can harm trees and plants by damaging foliage and reducing growth. Sulfur dioxide and other sulfur oxides can contribute to acid precipitation that can harm sensitive ecosystems.

In a recent study by (Brinkmann et al., 2019), it was found that chemical elements such as nitrogen, sulfur or oxygen of heterocyclic aromatic hydrocarbons, pose a threat to human health and the ecosystem.



(a) Initial stage (one day before model startup

(b) Situation during the first year of modeling

(c) Situation during the Fifth year of modeling

(d) Situation during the fifteenth year of modeling

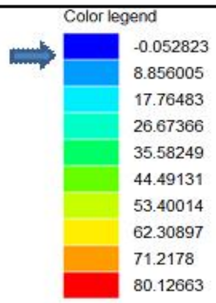
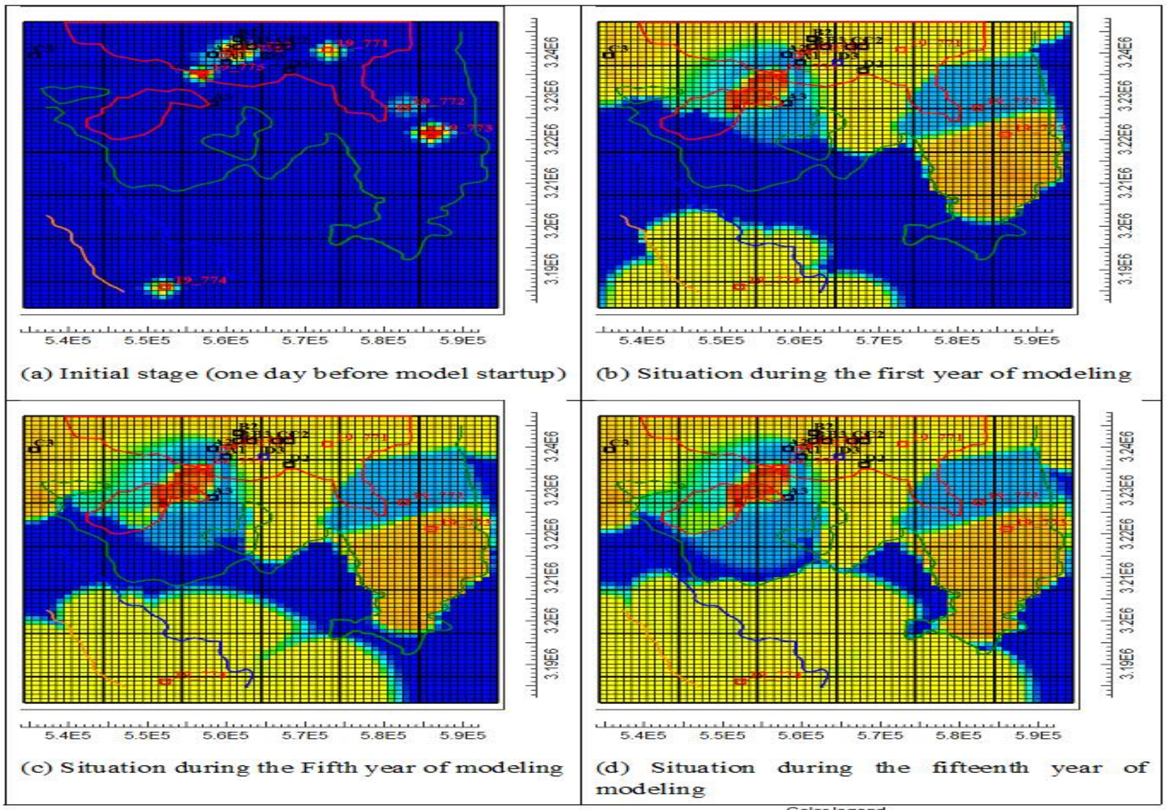


Fig. 6: Dispersion pattern for contaminant Zinc ***(Zn)****:(a) The initial stage (one day before model startup), (b) during the first year, (c) during the fifth year and (d) during the fifteenth year.*

Note that the safe concentration level is 0.7 ppm which lies between the first and second degrees of the color scale.

Contaminant (Nickel Ni)

Nickel represents the most hazardous contaminant in the area with concentration values ranging between 48.26 and 61.2 mg/l which is 12000 times the maximum allowable concentration level for Ni according to Libyan standards (0.004 mg/l). Again, like zinc, even in the initial stage, concentrations of Ni in the ponds' sites appear in red and yellow colors indicating high concentration levels (Fig. 7 (a)). These red and yellow colors dominate more than 50% of the study area during the first year of modeling. This indicates the rapid wide spread of the contaminant in the area. Even the areas with blue color here represent zones of higher concentration than the safe concentration level (Fig. 7 (a)). Nickel concentrations in groundwater depend on soil usage, pH, and depth. Acid rain increases nickel movement in soil and thus may increase nickel concentrations in groundwater. (Brinkmann et al., 2019). Human exposure to nickel by mouth is primarily associated with gastrointestinal and nervous symptoms after acute exposure and exposure through the skin or inhalation may lead to an allergy to nickel. Oral nickel absorption is able to trigger eczema reactions in the skin in individuals who are sensitive to nickel. (World Health Organization. (WHO)., 2019).



(a) Initial stage (one day before model startup)

(b) Situation during the first year of modeling

(c) Situation during the Fifth year of modeling

(d) Situation during the fifteenth year of modeling

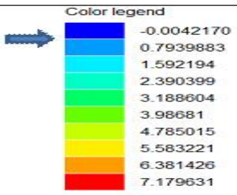


Fig. 7: Dispersion pattern for contaminant Sulphur (S): (a) The initial stage (one day before model startup), (b) during the first year, (c) during the fifth year and (d) during the fifteenth year.

Note that the safe concentration is 0.2 mg/l which lies between the first and second degrees of the color scale.

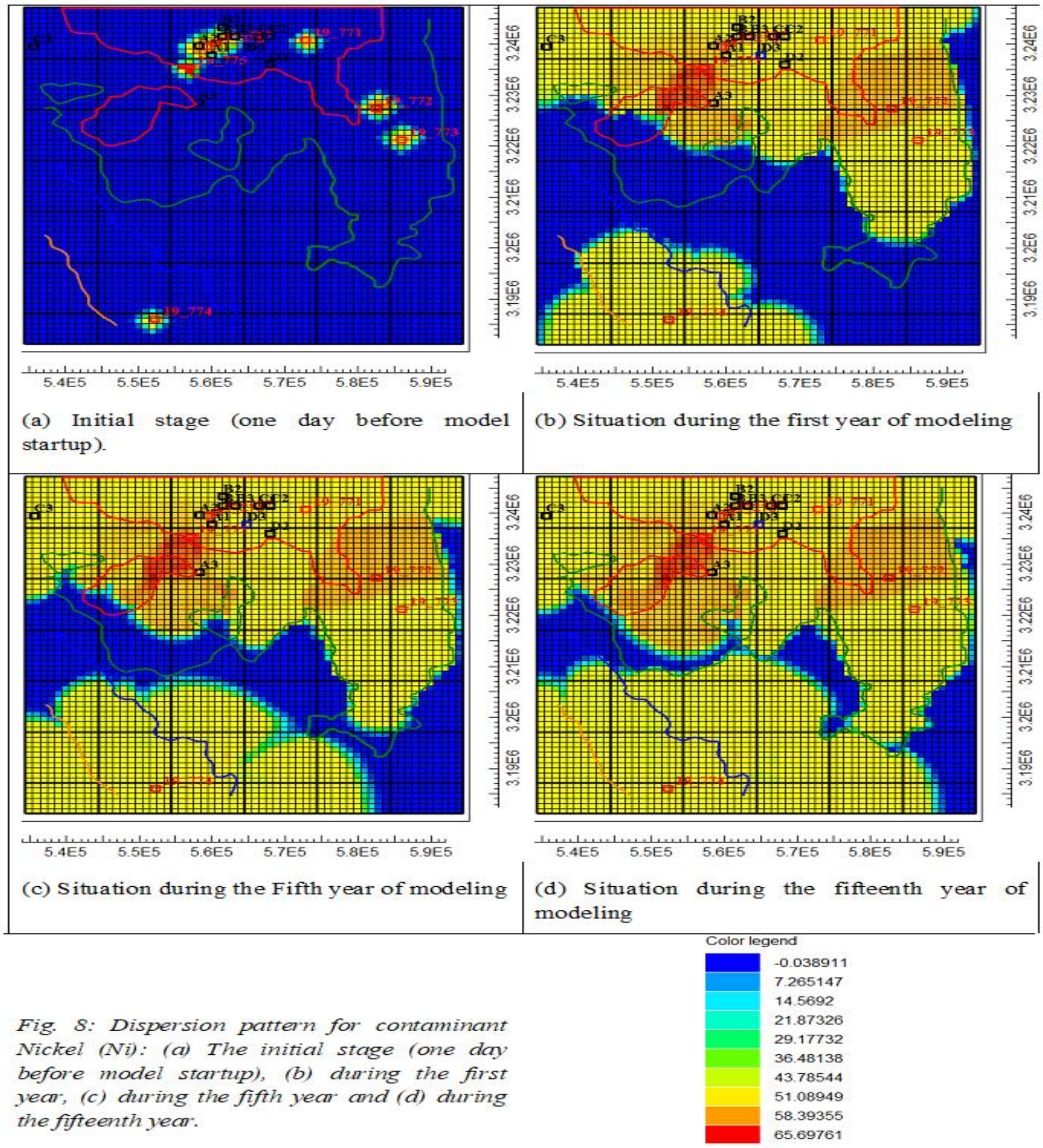


Fig. 8: Dispersion pattern for contaminant Nickel (Ni): (a) The initial stage (one day before model startup), (b) during the first year, (c) during the fifth year and (d) during the fifteenth year.

Note that the safe concentration is 0.004 ppm which is even not encountered in this scale.

Conclusions

The chemical analysis results and statistical analysis indicate that at least five contaminants in the wastewater of oil ponds are of concentrations that don't conform with Libyan standards for drinking water. These contaminants are: oil and grease, Zn, S, Al and Ni and to a lesser extent Cd with some samples lying within the safe concentration range. The results of Zinc (Zn) and Ni represent very high concentration levels compared to the standard levels.

Groundwater flow modeling indicates that pollution by the five contaminants is immediate and continues steadily with time to cover almost the whole area in about 20 years.

Some of the chemical elements present in the water associated with the oil in the study area were at the permissible limit according to the international and local standard specifications, so the focus should be on the accompanying chemical elements of oil, which is considered the most harmful components to the environment of the study area.

Recommendations

In view of the huge environmental, economic and health damage resulting from these oil ponds, work must be done to end, close or change their course so that the sites of these oil ponds are at a distance of at least 150 km from the study area.

Work must be taken to continue monitoring groundwater wells and inspecting them periodically by taking samples and analyzing them for the purpose of controlling any increase in pollutant concentrations beyond the permissible limits.

Local and foreign oil companies must strictly follow environmental protection systems and contribute in providing technical and material assistance in closing these oil ponds or limiting their presence, especially those oil ponds very close to the study area.

Many foreign and Arab companies have submitted several proposals to the Libyan Oil Corporation to get rid of these ponds and moreover to take advantage of these oil ponds to recycle their contents and extract from them several useful materials such as the different oils used for automatic vehicles and others, but these projects on industrial environment is not yet implemented for unknown reasons.

The study area is considered an arid region with a dry climate and little rain throughout the year. If these oil ponds of large size are reused (the method of separating water from oil), a very large amount of water with acceptable chemical, physical and microbial characteristics, they will represent an important water resource that can be used in agriculture, industry, public services and other needs of the study area.

The Public Authority for Agriculture in the study area must cultivate or use the method; pollutants absorbing plants, so that plants that have the ability to absorb oils, salts and others must be multiplied and raised in their roots, leaves, or stems, and then they perform vital operations in order to break, destroy and then get rid of these pollutants, such as wild reed plant, American alfalfa plant, squid plant and sunflower plant. The method of cultivation must be in the form of terraces as this happens when agriculture is done in mountainous areas.

The state and the competent authorities must encourage environmental organizations, civil organizations and researchers to develop methods for detection and reduction of these pollutants and to find methods and scientific means to get rid of them permanently, by using several modern means and methods and various techniques.

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