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Evaluation of Groundwater Contamination in Misurata City, Libya

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Abstract: This research examines both groundwater quality and hydrogeological characteristics of the Misurata locality on the Mediterranean Sea in Libya. The area is characterized by different land elevations, while its semi-arid climate exists with geological formations that span from the Miocene to the Quaternary periods. The water resources in this area experience problems because of excessive groundwater pumping, which causes saltwater to enter drinking water. Fifty groundwater samples were collected from wells across Misurata to perform chemical tests and contamination evaluations. The laboratory tests evaluated nitrates and chlorides, phosphates, and heavy metals (cadmium, lead, and zinc) against drinking water and irrigation water standards.The research data demonstrated that agricultural waste and wastewater entry into the ground caused nitrate and phosphate contamination to rise in the groundwater throughout Misurata, generally the southeastern and central parts have shown the highest contamination levels. The chloride measurement demonstrated that seawater intrusion followed the same pattern as other Libyan coastal aquifers, which experienced the intrusion due to excessive pumping. The industrial sections of the city displayed high values of Cadmium and lead concentrations, which endangered both environmental stability and human health. The zinc measurements in all wells exceeded established international limits because established that industrial activities which generate metal processing waste and air pollution lead to high zinc concentrations in surface water (IRC, 2014). The zinc measurements in all wells showed a consistent pattern throughout the entire study.The groundwater contamination in Misurata results from industrial operations and excessive groundwater extraction with an inadequate wastewater treatment practices. This research demonstrates that proper water resource management for drinking and agricultural requires a groundwater system with strict well management rules and ongoing water quality checks and public awareness programs.

Keywords: Groundwater, Misurata, Contamination, Heavy Metals, Seawater Intrusion

Introduction:

Human activities result in water body pollution because toxic substances build up and temperatures change and natural resources get extracted. The altered water quality makes it impossible for humans to use water for drinking purposes and industrial operations and agricultural farming (Abdel-Jawad, 1995). North African hydro-environmental research shows that uncontrolled urban development without adequate wastewater treatment systems has upgraded elevated the danger of aquifer contamination in various coastal areas (Mahgoub *et al.*, 2017).

The 1.8 million km² area of Libya faces an immediate water emergency because its 90% desert territory. The General Water Authority (2006) stated that the groundwater sources produce 95% of Libya's total water supply. The nation needs permanent solutions to manage its water resources properly. The evaluation of groundwater contamination serves as a fundamental approach to establish its fitness for residential and industrial water usage. The contamination of groundwater occurs through multiple sources which include sewage leaks and waste dumping sites and agricultural fertilizers use and saltwater intrusion into connected aquifer systems. Protecting groundwater is the highest priority because it provides drinking water to all Libyan citizens and research participants. The lack of permanent rivers in Libya makes groundwater management more complicated because the country relies on dry valleys (Wadis) which experience short periods of water flow during rainy seasons. The World Health Organization defines water pollution as any human-induced alteration that impacts water quality or state whether it occurs directly or indirectly. Research conducted worldwide shows that coastal aquifers in dry regions experience rapid deterioration because of increasing water consumption and urban development and decreased groundwater replenishment from climate change (Fetter, 2018).

The increasing volume of wastewater and untreated sewage has led to major contamination of aquifers, as it seeps through earth fissures. The infiltration process has made residential areas the main source of pollution, as they generate large amounts of liquid and solid waste. The research fulfills multiple operational objectives through its assessment of groundwater quality in the studied area and its verification against Libyan and international regulatory standards.

The research investigates the origins of groundwater contamination by examining environmental factors and human activities that degrade water quality. The research establishes which water sources, both shallow and deep aquifers in this area, meet the necessary standards for residential and agricultural use. The research establishes operational strategies to stop groundwater contamination spread and reduce its environmental impact through its experimental results. The UNEP (2022) and Lapworth *et al.* (2017) report that unregulated wastewater discharge is the main driver of aquifer degradation in developing countries, as shallow alluvial aquifers allow pollutants to spread quickly.

Study Area

The city of Misurata lies near the Mediterranean coast, at the location depicted in Fig.1, with coordinates 15.16°E longitude and 32°N latitude. The city is located about 210 kilometers east of Tripoli. The area of study is morphologically characterized by rather flat ground surfaces that gently descends from southeast to north, while sand dunes extend toward Wadi Al-Kamamin in the northwestern section of the area which falls within a semi-arid climate zone. The study area is desected by generally dry valleys, with Sabkht Tawergha and Qasr Ahmed follow the eastern coastline. (Al-Sharkasi, 2006).

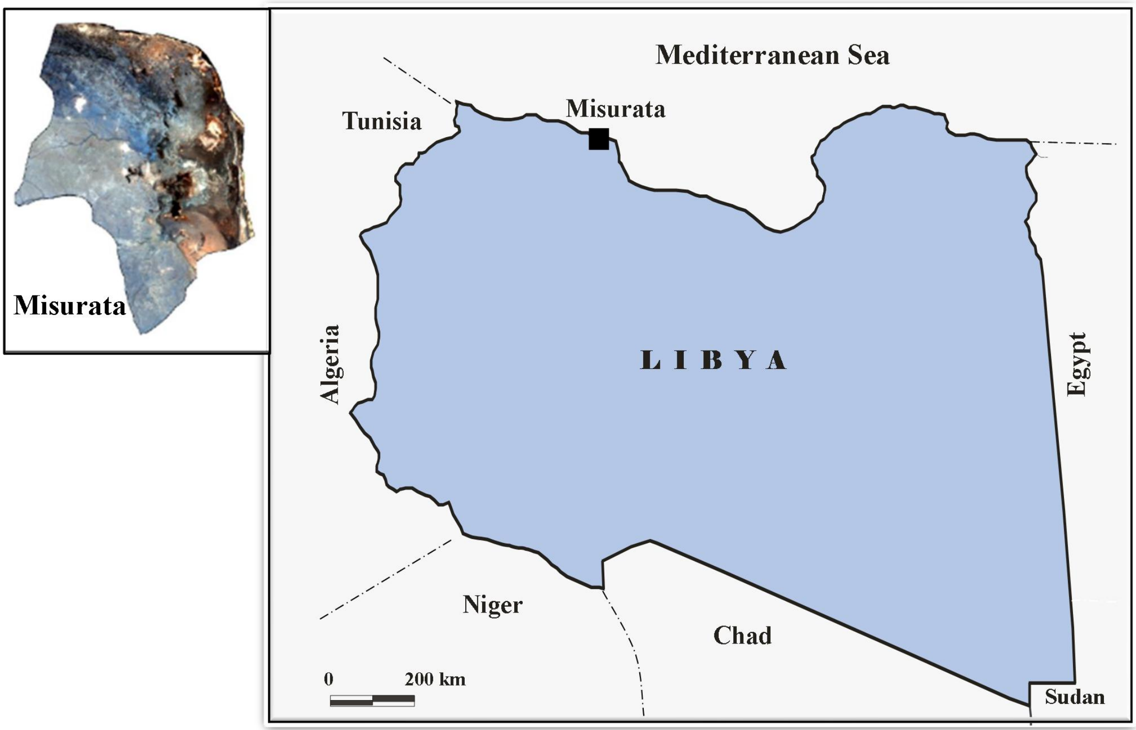

Fig. 1 Location map of the study are, Misurata city.

Methods of Study

The aim of this research is to integrated the existing studies, with academic publications in scientific journals which provide essential information. The research team has performed data compilation followed by data processing and interpretation to accomplish the data collection process. 50 water samples were collected from well sites of the entire study area. Using the GPS system in order to record the exact positions of the wells as presented in Fig.2.

The research team employed a specialized graduated tape to measure groundwater levels at each well site. The research team obtained water samples from their designated collection points for laboratory testing. The research team stored the samples in clean containers which they labeled with well names and locations before placing them in appropriate storage conditions until analysis. The Brega Oil Company laboratories performed tests to evaluate chemical indicators which show the extent of groundwater contamination. The laboratory conducted three different tests as part of their analytical work. The laboratory conducted chemical tests to measure nitrates and chloride and phosphorus and chlorate concentrations in the water samples. The laboratory performed heavy metal tests to confirm the presence of cadmium and lead and zinc in the samples.

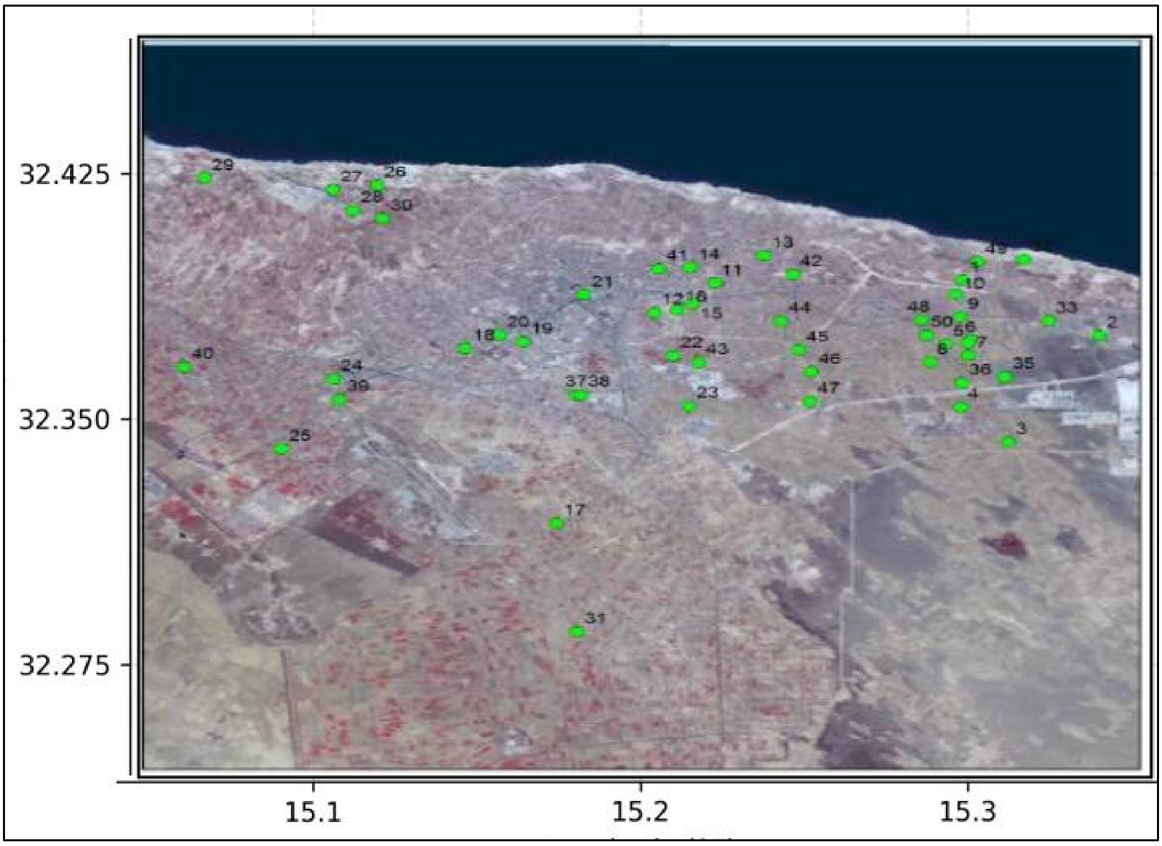

Fig. 2 Water sample locations in Misurata city

Geologic Setting

Rock layers beneath Misurata City hold different amounts of water depending on how porous or permeable they are. Because water moves through these layers, understanding their structure becomes essential when mapping underground flow patterns. Hidden beneath lie layers formed during Cretaceous times - layers stacked one after another in time and space. Westward directions show deeper burial, reaching about 200 meters underground where ancient deposits stretch further down. The area rests upon the Sirte Basin, a stretch of folded earth shaped by old sediment patterns. Knowing exactly which rock type does what matters a lot for tracking where groundwater appears or vanishes. Above older rock layers in northeastern Libya, sand and gravel from recent epochs sit loose and full of pores, allowing rainwater to seep through quickly when it rains (Hallett, 2002; Salem & El-Tomi, 2013).

The geological structure of Misurata exists in the Sirt sedimentary basin because it contains sequential Cretaceous rock layers from Lower to Upper Cretaceous formations which extend 200 meters beneath the surface to the west of the city (Fig.3). The area shows occasional Miocene rock formations (Fig.4) which Quaternary deposits have covered up. The geological formations in this area developed during the Tertiary and Quaternary periods, according to Mann (1975). The researchers obtained shallow aquifer samples from Miocene and Quaternary rock formations.

Research on coastal sedimentary basins shows that alternating layers of calcarenite and fine-grained lagoonal deposits create flow paths that make these aquifers more susceptible to surface contaminants and saltwater intrusion (Bear & Cheng, 2010).

Al-Khums Formation (Miocene)

The formation which appears in western Misurata consists of yellow to dark crimson limestone layers that contain manganese traces. The rocks show high porosity together with significant fracturing which makes them suitable for groundwater recharge (Al-Jadidi, 1986).

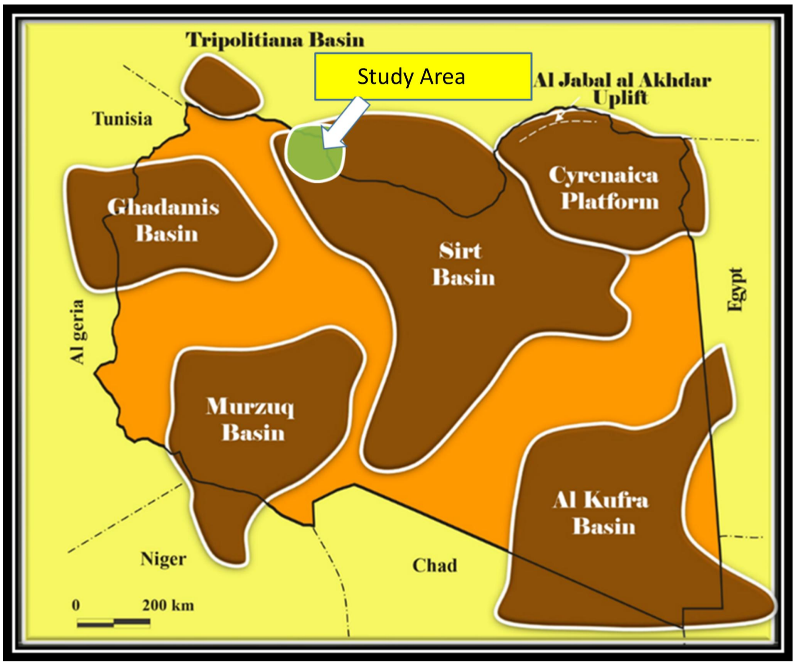

Fig. 3 Distribution of Sedimentary Basins in Libya, where Misurata is located at the northwestern edge of the Sirt Basin (Hassan & Kendall, 2014).

Quaternary Deposits

The Gargaresh Formation extends along the coastal boundary of the study area, with calcarenite rocks containing medium-sized fossil grains and occasional sandy silt layers (Fig 4). The porous sediments allows rainwater to enter the ground which creates freshwater lenses that extend above the seawater table. The formation contains historical shoreline data which makes it vital for studying past coastal transformations (Mann, 1975). The Aeolian Deposits consist of uniform sand dunes that extend parallel to the coastline. The main composition of these dunes consists of medium to fine quartz-rich sand grains. The loose structure and large grain size of these deposits create high permeability, allowing groundwater recharge but leading to soil instability throughout the area (Mann, 1975). The Water-Aeolian Deposits extend across broad areas of the study site through their sandy silts which develop calcareous crusts at irregular intervals. The crusts develop through wind and water erosion which primarily affects low-lying wadi and drainage areas that collect sediments (Khouja, 2002). The eastern part of Misurata consists primarily of Sabkha Deposits. The deposits consist of brown clay-sandy sediments containing sodium chloride and gypsum, and clay layers with salt deposits and blue-gray gypsum. The surface evaporation of rainwater creates salt crusts, which make these areas unsuitable for agricultural use and water extraction (Mann, 1975). The Wadi Deposits in southern wadis consist of well-sorted sands and gravels. The transported materials demonstrate extensive movement patterns that enhance groundwater recharge through seasonal water infiltration (Mann, 1975).

Surface Features

The inland wind penetration into Misurata shapes its climate, as the city lies on flat terrain that extends toward the Gulf of Sirte. The 17.5 km-long calcarenite fossilized hills in the northwest coastal area rise 60 meters above ground, protecting the area while directing rainwater toward the sea (Fig. 5). The dune chains extend in parallel lines at 50 meters high and are used to store shallow freshwater, but now hold saltwater because people extracted excessive water from the area. The dunes have decreased in size because people have been extracting sand from them for building projects. The eastern section of the region contains extensive salt flats which include Sabkhat Tawergha with its 2,700 km² surface area that becomes unreachable during wadi-borne rainwater floods. The southern section of the region contains sporadic wadis which create agricultural and grazing areas through Wadi Suf Al-Jin and Wadi Al-Samih

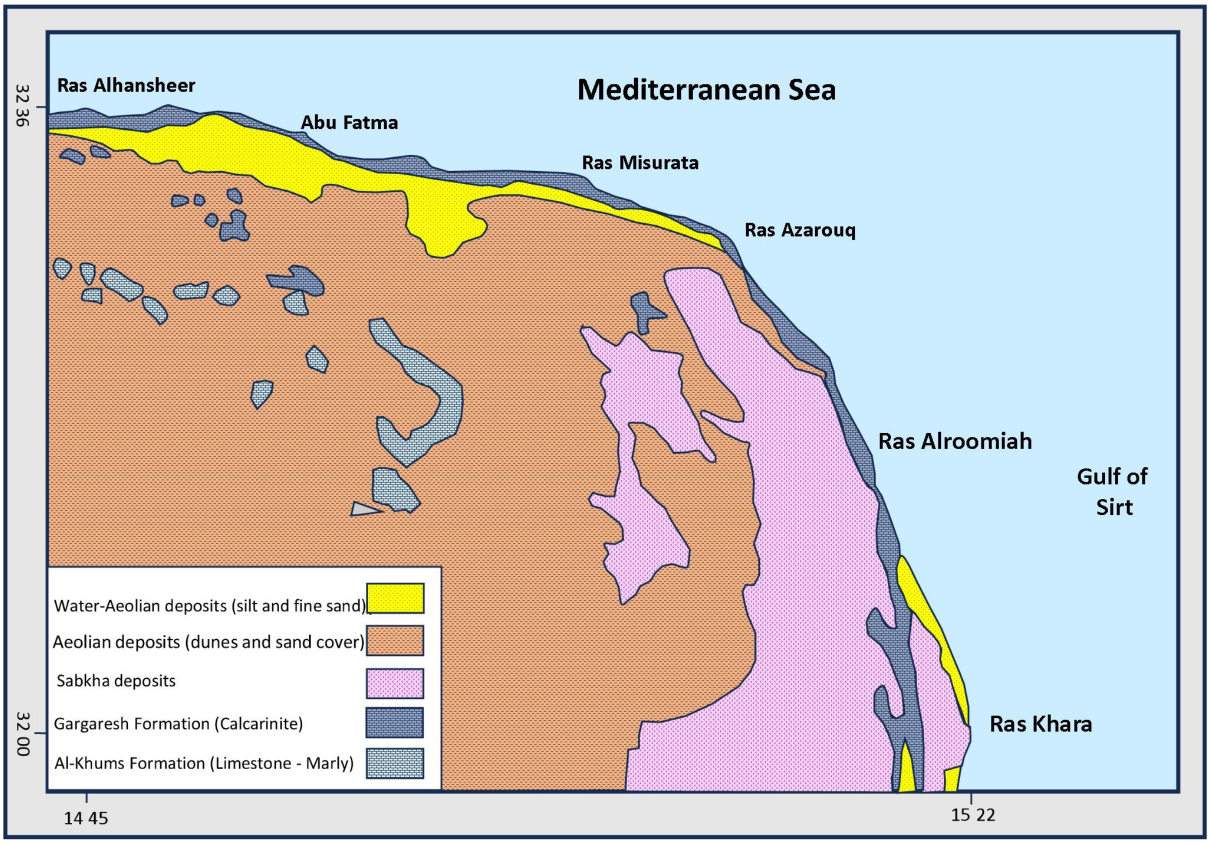

Fig 4. Geological map of Misurata Municipality (Modified from the Industrial Research Center map, Misurata sheet, 1975)

Water Availability and Sources

Human beings need water as their basic resource to establish permanent settlements. The lack of clean water leads to significant difficulties because water serves as the essential component for producing drinking water, farming, and industrial operations, and multiple essential activities. Human settlements emerged in regions with sufficient water resources, including the Nile River basin and Mesopotamia.

Libya's entire water resources depend solely on surface water. The region faces difficulties in using surface water resources because it lacks adequate systems to manage rainwater and seasonal streamflow. The region depends on rainfall for its surface water and groundwater, as rainfall is the primary water source. The Misurata region receives sporadic, unpredictable winter precipitation in December and January. The annual precipitation in this area reaches 281 millimeters with winter precipitation accounting for half of the total amount. The weather patterns in this area develop from Mediterranean and Atlantic low-pressure systems, which produce cyclonic systems.

The Libyan General Water Authority conducted hydrological surveys which showed that coastal basins stretching from Misurata to Tawergha experienced a 12–18% decrease in recharge rates because of reduced precipitation and rising evapotranspiration rates (GWA, 2010). The hydrological characteristics of this region include wadis which function as seasonal water streams. The wadis begin their path in the southern highlands before they proceed to the eastern lower part of the region, which reaches west of Sabkha Tawergha. The study area consists of four main wadis, which are Wadi Umm Al-Jirfan, Wadi Maimoun, Wadi Sasso, and Wadi Souf Al-Jin. The surface water features in this region do not contribute significantly to water resources because the area experiences both dry conditions and unpredictable rainfall patterns.

Groundwater in Misurata

The region obtains its water supply from groundwater that collects within sedimentary rock formations. The rock formations collect water from rainfall and wadi streams which eventually fill the groundwater system. The movement of groundwater depends on rock permeability and the power of hydraulic pressure. The study area contains aquifers that operate as part of Libya's northern renewable groundwater systems but are subject to excessive use (Fig.6). The high per capita water consumption of 1,295 liters/day has caused water table depletion and saltwater contamination in coastal regions.

Misurata coastal aquifers are experiencing increasing seawater intrusion due to prolonged pumping and declining recharge rates, according to recent hydrogeological assessments and numerical modeling studies across the Mediterranean region (Custodio, 2010; Werner *et al*., 2013).

The Quaternary aquifer operates as the surface aquifer and Industrial Research Center monitoring data shows increasing salt contamination in this layer throughout the eastern part of Misurata since the mid-1990s (IRC, 2016) which extends along the northern coastline. The aquifer becomes unusable for drinking water because seawater contamination spreads widely due to excessive water extraction. The Industrial Research Center documented a 40% increase in chloride concentrations in Quaternary aquifer wells located east of Misurata between 1995 and 2015, according to their local research (IRC, 2016).

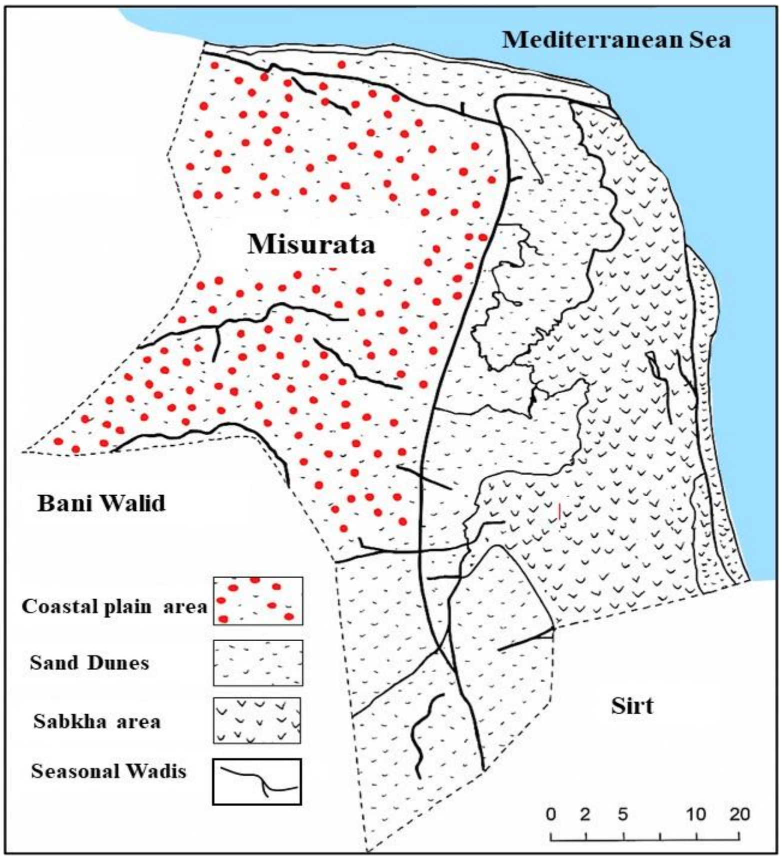

Fig. 5 Surface geological features in Misurata city (Modified and reproduced from Industrial Research Center, 1975).

The Mizdah-Tagharna Aquifer extends across three separate regions which include Tawergha and Wadi Sasso and Dafniya. The aquifer operates as an underground water storage system that extends across various depths in this territory. The Tawergha Spring used to extract water from this aquifer but farmers now obtain water through deep wells for their irrigation needs. The aquifer water needs treatment because its high salt content prevents human consumption without processing, according to Mann (1975).

The Ain Tabbi-Kikla Aquifer operates as a deep sandstone water source that provides Misurata with its primary water supply. The facility treats water from eight deep wells in Tawergha before distributing it to consumers. The production rates and water temperature readings depend on the depth of the wells. The Kikla Aquifer generates 200 cubic meters of water per hour which exceeds the output of the Quaternary aquifer (11 cubic meters per hour). The shallow aquifer contains extremely high total dissolved solids because of seawater contamination which results in severe water quality deterioration (Mann, 1975)

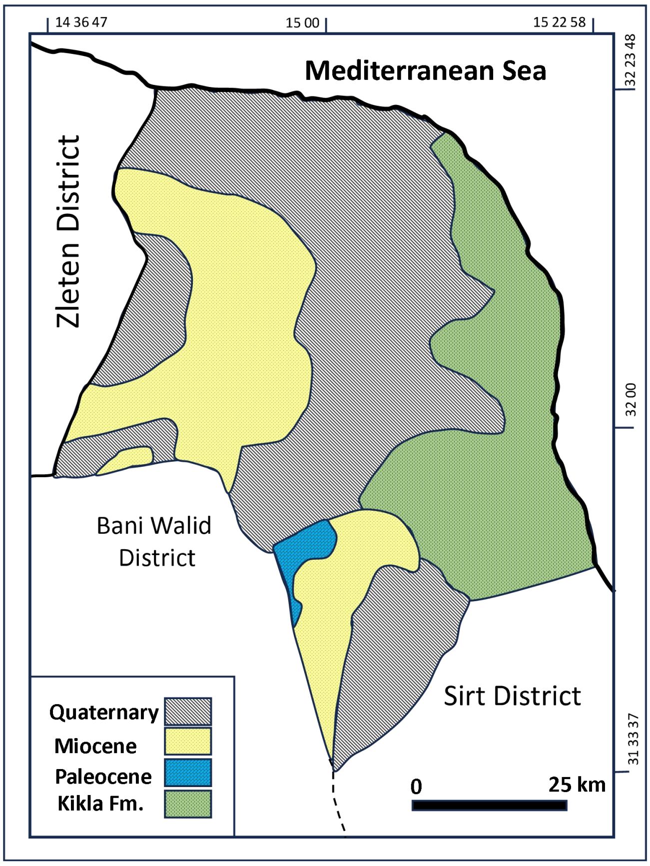

Fig 6. Map showing the distribution of groundwater reservoirs in Misurata Municipality (Reproduced after Asoul, 2007)

Alternative Water Sources

The city of Misurata has multiple alternative water sources to meet its rising water demand. The Desalination Plant at the Steel Complex near Misurata Port produces 440 cubic meters of treated seawater per hour to support the city's water supply. The central treatment facility in Misurata operates at maximum capacity, processing 24,000 cubic meters of wastewater daily. The treatment facility produces more wastewater during periods of rainfall. The Great Man-Made River Project transports 85,000 to 90,000 cubic meters of fresh water to Misurata daily through deep southern aquifers that formed during the Pleistocene humid period (Khouja, 2002).

Results and Discussion

The research team collected 50 groundwater samples from wells spanning the entire study area. The Brega Oil Company performed water testing at its Tripoli-based facilities. The research team used the obtained data to create visual maps which showed which wells satisfied drinking water and agricultural standards through different visual indicators. The research team identified multiple pollution sources across the area and developed strategies to manage and control groundwater contamination.Research studies in arid cities have shown identical contamination patterns which result from industrial clusters and unregulated waste disposal that increase heavy-metal concentrations in shallow aquifers thus requiring ongoing geochemical monitoring (Zhang *et al*., 2018).

The Libyan national standards for drinking and irrigation water together with elemental and heavy metal analysis results from wells across the study area appear in Tables 1 and 2. The tested elements in Table 3 show different concentration levels based on the data.

The research team found that water samples contained elevated levels of nitrate and phosphate. The water samples contained low levels of chloride and zinc; water quality evaluation depends on chemical and heavy-metal test results from groundwater samples collected from various wells across the study region.

The data presented in Table 5-3 enable researchers to identify contamination origins and determine the suitability of groundwater for human consumption and agricultural use.

Table 1. Libyan Standard Specifications for Drinking Water

Element	Concentration (PPM)
Lead	0.005
Cadmium	0.003
Zinc	5
Nitrate	45
Phosphate	0.1
Chloride	0.7

Table 2. Libyan Standard Specifications for Irrigation Water

Element	Concentration (PPM)
Lead	0.1
Cadmium	0.01
Zinc	2.0
Nitrate	5 – 30
Phosphate	2
Chloride	1.5

Table 3. Results of 50 Groundwater Well Samples distributed in Misuratra city, collected in January 2023.

Site	Sample Number	Lead (PPM)	Cadmium (PPM)	Zinc (PPM)	Nitirat (PPM)	Chloride (PPM)	Phosphate (PPM)
Saur Saoad	1	0.0563	0.0117	<0.1	8.1	0.03	330
Qasr Ahmed	2	0.0362	0.0191	<0.1	7.04	0.32	350
Al-Naseem Factory	3	0.0521	0.0219	2.929	9.88	0.04	370
Citizen House	4	0.0316	0.033	<0.1	28.05	0.04	340
Al-Shomouh School	5	0.0259	0.0459	<0.1	38.15	0.02	330
Al-Oqeeb	6	0.023	0.0538	<0.1	32.15	0.02	350
Abi Al-Haytham Mosque	7	0.0425	0.069	<0.1	12.77	0.04	360
Citizen House	8	0.0472	0.0707	<0.1	33.1	0.03	360
Zaid Bin Thabit School	9	0.0627	0.0846	<0.1	38.7	0.04	360
Al-Sawati	10	0.0591	0.1004	<0.1	33.5	0.02	180
Qarara	11	0.0544	0.1022	<0.1	33.2	0.05	360
Al-Ruwaisat	12	0.0674	0.1136	<0.1	22.95	0.07	370
Al-Oruba School (Al-Ramlah)	13	0.0575	0.1188	<0.1	41	0.02	370
Jazeerat Eldem	14	0.0738	0.1282	<0.1	36.35	0.06	350
Ras Al-Touba	15	0.1018	0.1355	<0.1	32.9	0.02	390
Al-Ruwaisat Second Ring Road	16	0.1155	0.1385	<0.1	34.6	0.02	140
Karzaz	17	0.0961	0.1424	<0.1	33.75	0.04	280
Zamoura	18	0.0726	0.1519	<0.1	35.5	0.04	290
Maqasba	19	0.0938	0.1616	<0.1	32.45	0.07	190
Awlad Abu Shaala	20	0.0786	0.1768	<0.1	39.45	0.04	350
Al-Ruwaisat	21	0.0722	0.1842	0.5645	28.7	0.05	360
Ruwaisat	22	0.1021	0.1839	<0.1	36.85	0.02	200
Tareak Elmoujmedat	23	0.1362	0.1875	0.3128	34.1	0.02	220
March 6 School	24	0.1319	0.1971	<0.1	28.15	0.06	195
Jazeerat Al-Zabbati	25	0.1133	0.2072	<0.1	28.05	0.02	200
Aljazeera	26	0.1227	0.2153	<0.1	22.98	0.08	144
Bourj Misurata	27	0.1263	0.2255	<0.1	31.9	0.02	300
Jazeerat Elmougaouba	28	0.1152	0.2375	<0.1	37.35	0.02	165
Al-Suwaua	29	0.105	0.2358	0.0292	29.6	0.03	140
Al-Shawahda	30	0.1337	0.2504	<0.1	39.45	0.02	350
Karzaz	31	0.1622	0.2525	<0.1	36.55	0.04	340
Sea Road	32	0.1562	0.2585	<0.1	44.7	0.01	16
Fuel Station Qasar Ahmed	33	0.1652	0.2691	<0.1	28.35	0.05	340
Al-Shafshafa	34	0.1618	0.2761	0.0222	7.2	0.12	205
Al-Thaqeel Martyrs Club	35	0.1457	0.2775	<0.1	5.95	0.05	205
Al-Taam Al-Asil Restaurant	36	0.1543	0.3007	<0.1	4.365	0.08	340
Next to the Faculty of Science	37	0.1539	0.3029	<0.1	7.35	0.01	300
Qazir Bridge	38	0.1517	0.3265	<0.1	8.15	0.03	330
Airport Road	39	0.1639	0.3397	<0.1	8.45	0.06	148
Al-Sidri School (Al-Ghiran)	40	0.1686	0.3428	<0.1	8.7	0.02	280
Sharah Eldem	41	0.1846	0.3481	<0.1	9.25	0.05	300
Al-Ramlah	42	0.1896	0.3543	<0.1	7.875	0.03	205
Al-Ruwaisat	43	0.1732	0.3569	<0.1	8.2	0.04	300
Al-Zarouq	44	0.1717	0.366	<0.1	9.5	0.38	330
Jazeerat Al-Skirat	45	0.1847	0.3806	<0.1	4.8	0.05	340
Al-Skirat	46	0.1594	0.3812	<0.1	3.49	0.01	350
Al-Sakhra Club	47	0.1633	0.3907	<0.1	8.3	0.12	205
Qasr Ahmed	48	0.1664	0.394	<0.1	2.7	0.05	300
Al-Hasyan Area	49	0.1554	<0.1	<0.1	2.79	0.06	126
Al-Raeidat	50	0.1487	<0.1	<0.1	8.55	0.09	360

Phosphate Analysis

Water bodies experience their main pollution threat from phosphorus compounds which damage aquatic ecosystems. The compounds in soil maintain their chemical stability for extended periods which leads to health problems for humans and animals. Agricultural waste that enters water streams due to excessive phosphate fertilizer use in Libyan agricultural areas (Al-Jazwi, 2011) pollutes water by promoting excessive algal and microbial growth (Islam & Amara, 2006). The World Health Organization has established 5 mg/L as the maximum permissible level of phosphate in drinking water. Al-Maghrebi, M. 2013. Phosphate Transport in Shallow Aquifers of Eastern Libya. The contour map in Fig.8 displays the distribution of phosphate concentrations across Misurata city. The phosphate levels in groundwater wells in Misurata city reach high levels throughout its southeast and southwest regions.

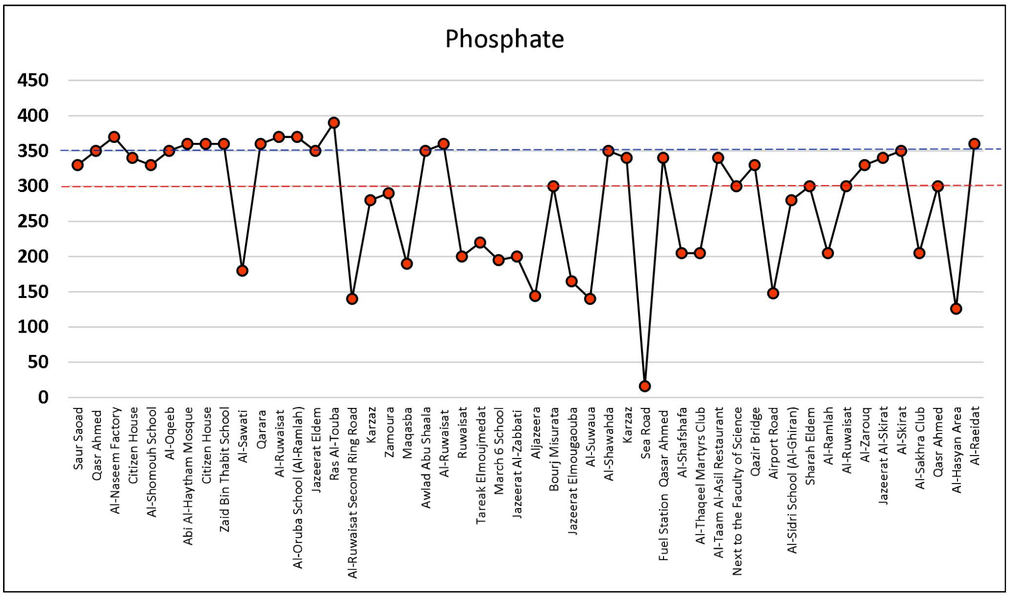

Fig 7. Phosphate Concentration in the50 Sample. The red line represents the maximum limit for drinking water, while the blue line represents the maximum limit for irrigation water.

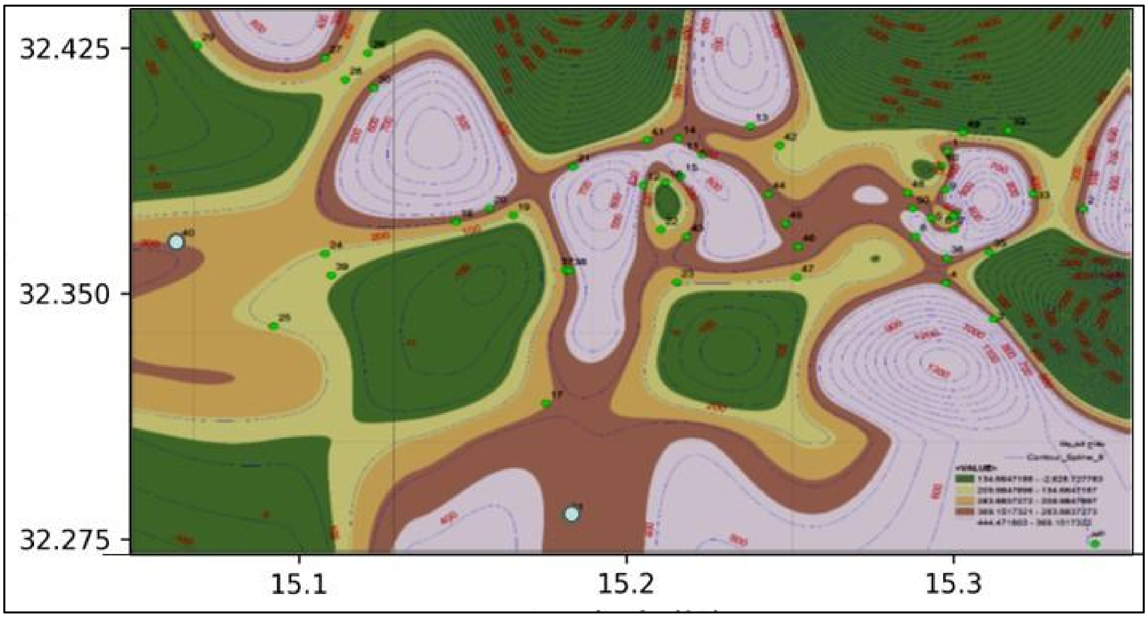

Fig 8. Contour map showing phosphate (PO_4^{3-}) concentrations across Misurata City.

Chloride Analysis

The combination of groundwater with seawater or fossil water results in elevated chloride levels which create a hydrochemical signature that appears along the Gulf of Sirte coastline because pumping activities create strong salinity gradients through upconing (El-Baruni & El-Hashmi, 2008) that accumulate in soil and contaminate water sources. The water becomes salty when chloride levels exceed 100 mg/L, as concentrations above this level can harm health issues. The U.S. Public Health Service, along with the American Academy of Engineering Sciences and the World Health Organization, determined 250 mg/L as the maximum allowed chloride content in drinking water (Alyan *et al*., 1994). The Gulf of Sirte region hydrochemical assessments show distinct ionic patterns, including high chloride, sodium, and magnesium concentrations, along with low calcium and bicarbonate levels, indicating that seawater intrusion is actively entering coastal groundwater systems (El-Ghadi, A. 2014).

The chloride concentration map in Fig 10 shows that Misurata's northern and northeastern areas have high chloride levels. The coastal location of this phenomenon makes seawater intrusion into the groundwater aquifer the most probable explanation. The chloride levels at Well No. 3 operating behind the Nasim Factory show high values in the eastern part of the city. The high chloride levels in this area might result from over-extraction of groundwater.

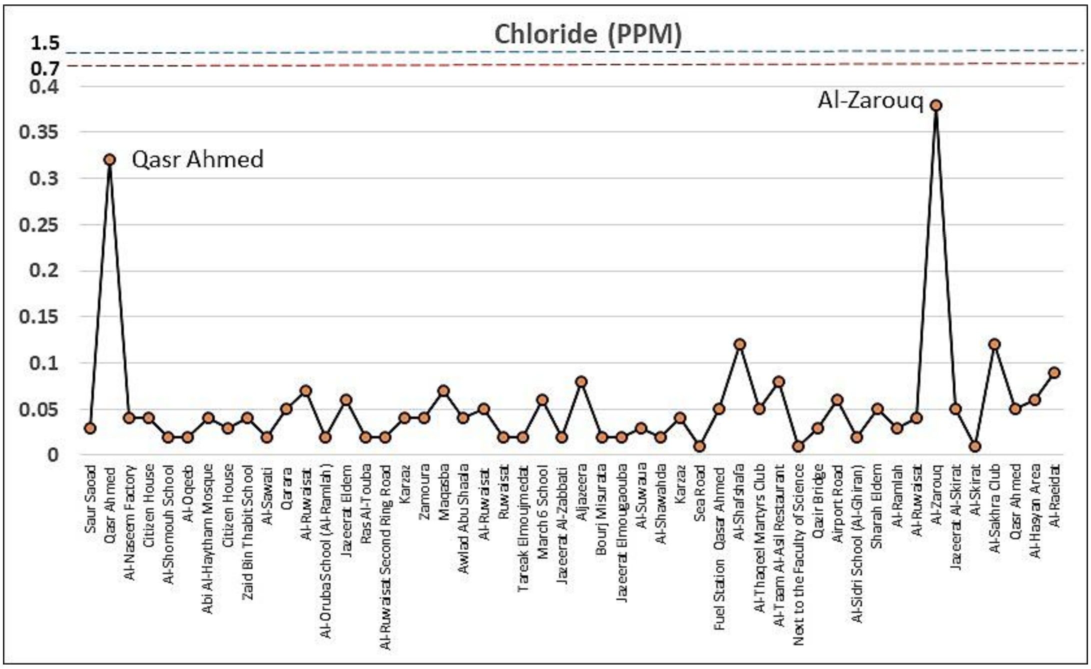

Fig. 9 Chloride concentration in the50 Sample. The red line represents the maximum limit for drinking water, while the blue line represents the maximum limit for irrigation water

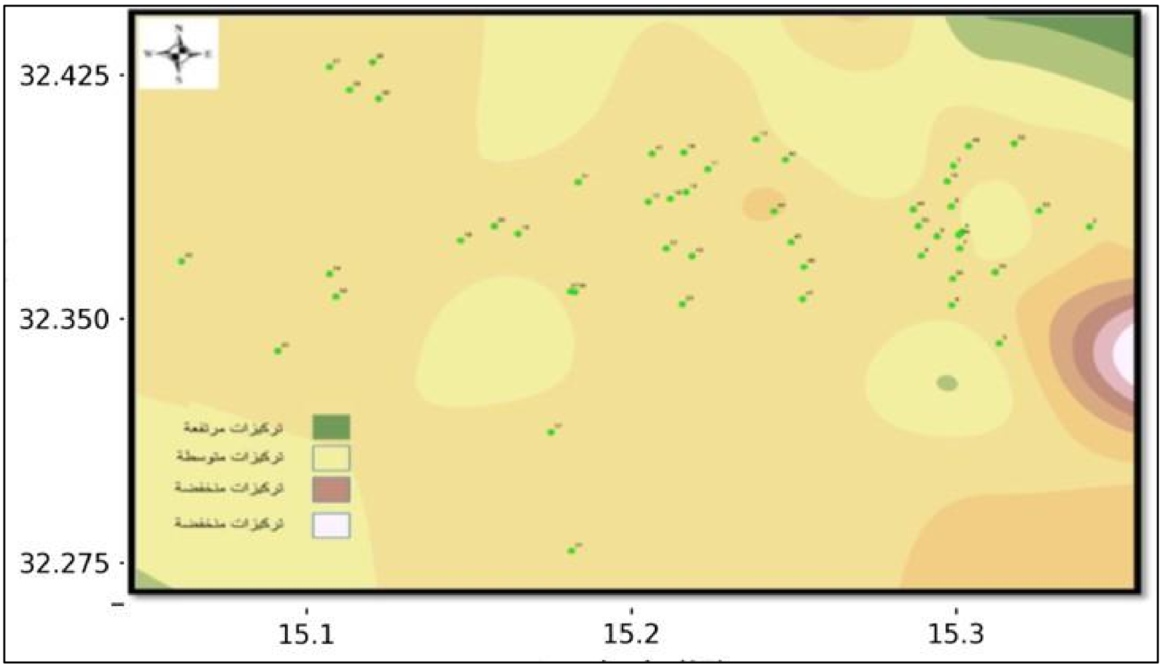

Fig. 10 Contour map showing chloride (Cl^-) concentrations across Misurata City.

Nitrate Analysis

The occurrence of nitrates in groundwater poses a significant threat to human health, according to Alshomou's School in Alaqeeb, Zaid bin Thabit School, Alsawaty, Qararah, Alruwaisat Muwatin, Alorouba School (Alramlah), Jazirat Aldam, Ras Altoubah, Alruwaisat Second Ring Road, Zamoura, Maqasbah, Awlad Abu Sha'alah, Mujammadat Road, 6th of March School, Alzabbati Island, Old Island, Alsawawah, Alshawahidah, Karzaz, Sea Road. The FAO (2019) reported that North African regions are experiencing increasing nitrate contamination due to fertilizer overuse and poor sewage management in newly developed urban areas.

The excessive consumption of nitrates results in methemoglobinemia which primarily affects infants. The data in Fig 11 shows multiple sites where nitrate levels surpass the established safety standard of 30 mg/L. The following locations recorded nitrate levels above 25 mg/L.

The Sea Road area recorded the highest nitrate concentration at 44.7 mg/L. The following locations have nitrate-free groundwater according to their nitrate pollution status: Sour Saud Muwatin, Qasr Ahmed Residential Area, Behind Al-Naseem Factory, Althaqeel Martyrs Club, Faculty of Science, Aqzeer Bridge, Airport Road, Alshoura School, Alghiran, Alamlrah, Alzarrouq, Alsakeerat, Qasr Ahmed, Alhassiyan, Alraeidat.

The entire low-concentration zone spans a single geographic area, starting at Airport Road and extending through Aqzeer and Karzaz, then reaching the eastern parts of Misurata, including Althaqeel, Alraeidat, Alsakeerat, Alzarrouq, Qasr Ahmed, and Alramlah (Fig.12).

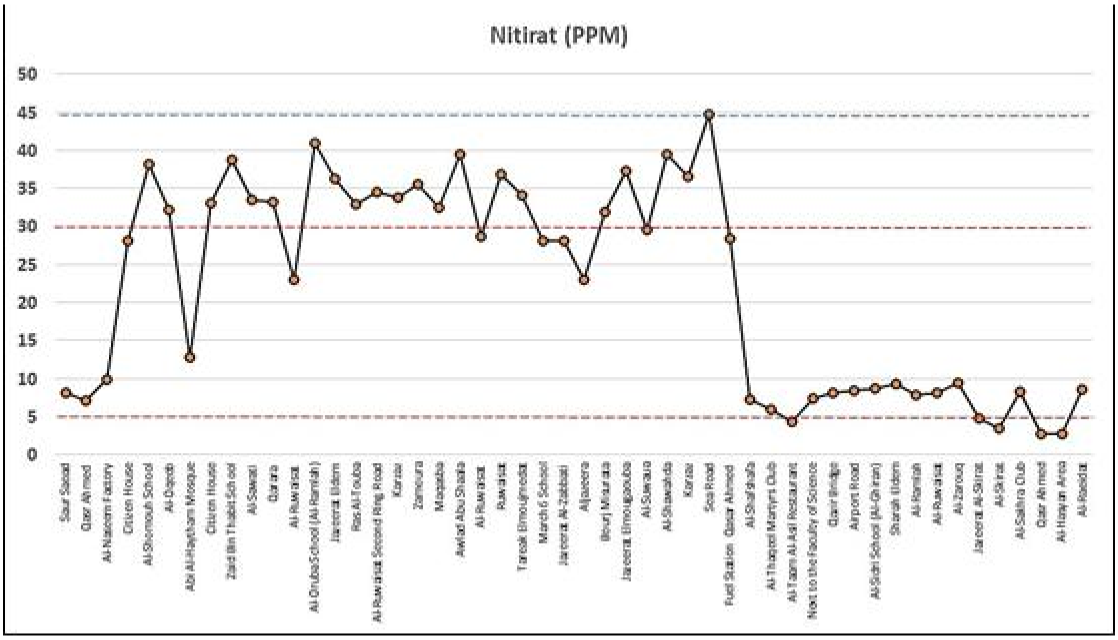

Fig. 11 Nitrate concentration in the 50 samples. The red lines represent the permissible range for drinking water, while the blue line indicates the maximum allowable limit for irrigation water

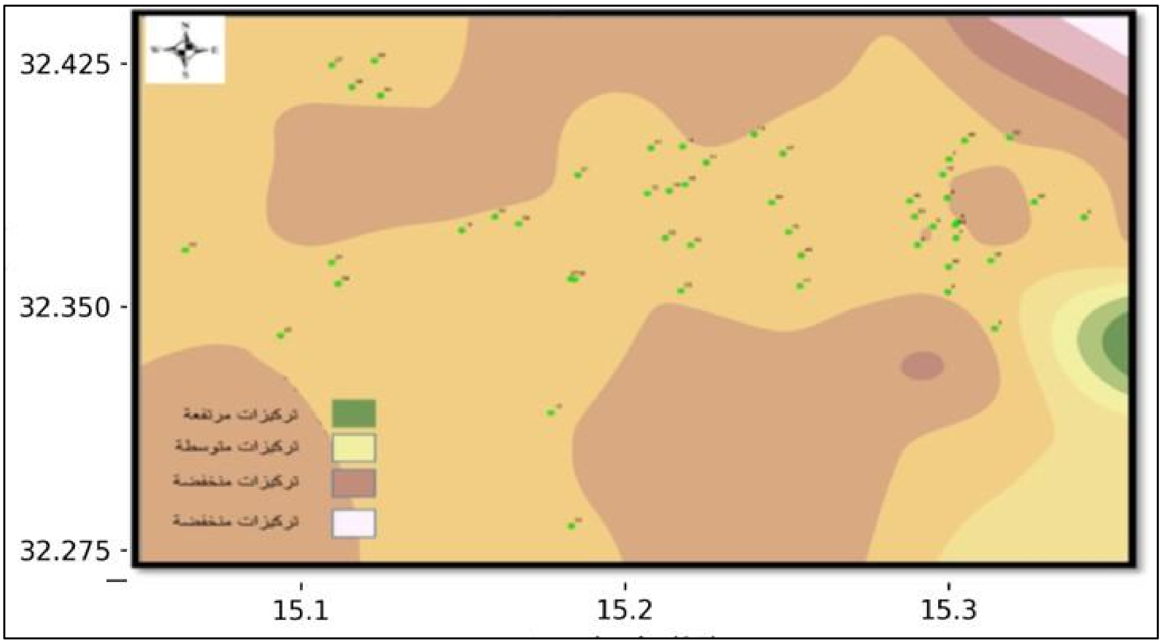

Fig. 12 Contour map showing nitrate (NO_3^-) concentrations across Misurata City.

Cadmium Analysis

The toxic substance cadmium persists in the environment for extended periods, causing significant ecological damage and posing serious health risks to people. The human body stores cadmium from all exposure points, which causes kidney damage, bone loss, multiple other medical conditions.

The three microgram per liter drinking water standard is exceeded by cadmium concentrations across all parts of eastern Misurata, as shown in Fig13. The cadmium levels in Agzeir Bridge, Airport Road, Al-Shura School in Ghairan, Damm Street, Alramla, Alrwaisat, Alzarouq, Skerat Island, Alskerat, Alsakhra Club, Qasr Ahmed exceeded safe limits. The highest measured cadmium level reached 0.394 mg/L at Qasr Ahmed. The leading cause of environmental cadmium elevation stems from mining operations, smelting activities, industrial waste discharge into the industrial zone, which contains multiple facilities including the Libyan Iron and Steel Company, the steam power plant, Misurata Port, Brega Oil Company storage units, workshops, paint factories, scrap-smelting sites located along Heavy Transport Road, and Alhamiya Road. The combination of industrial operations, insufficient waste management practices has led to cadmium contamination in groundwater systems.

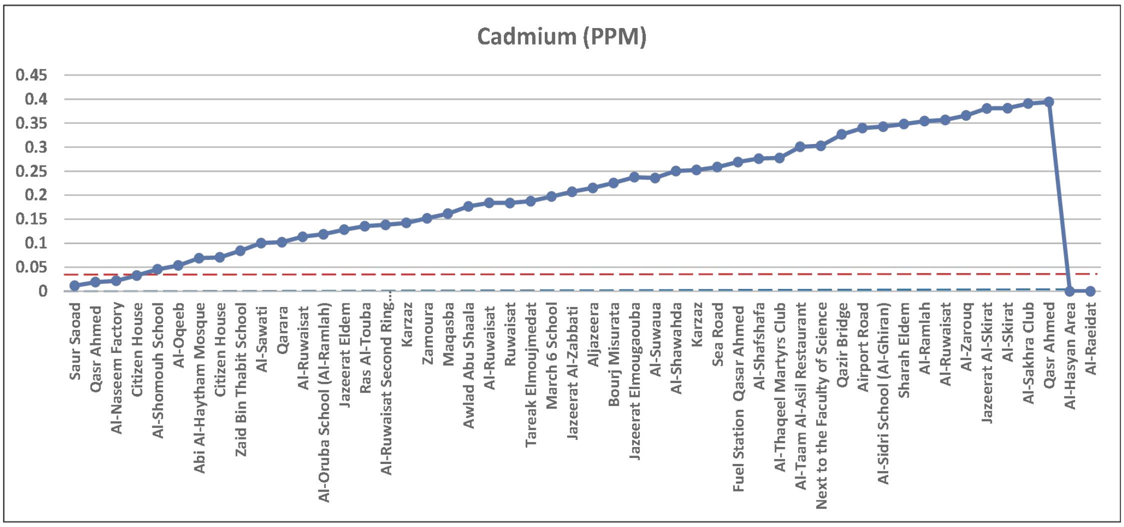

Fig.13 Cadmium concentration in the 50 samples. The red line represents the permissible drinking water value, while the blue line indicates the maximum allowable irrigation water limit.

The southeastern section of Misurata contains the highest cadmium levels, according to Fig 14. The northeastern section of the city shows cadmium concentrations similar to those in the southeastern area. The northern sections of Misurata contain the lowest cadmium levels in the city.

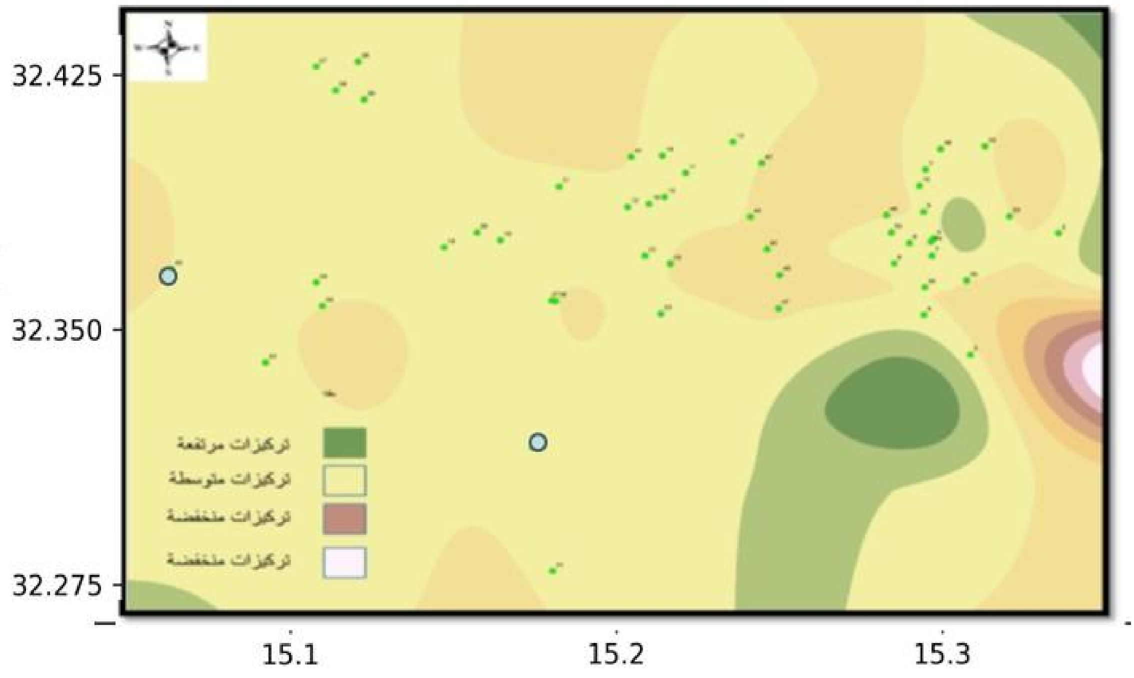

Fig. 14 Contour map showing Cadmium (Ca) concentrations across Misurata City

Lead Analysis

The detection of lead in drinking water poses a significant health risk, as multiple Libyan public health studies have shown elevated lead exposure in coastal cities with deteriorating water distribution systems and industrial zones that contaminate shallow aquifers (EGA, 2020). Lead exposure through toxic substances damages a child's brain development and triggers cardiovascular and renal diseases in adult populations. The toxic effects of lead become dangerous even at low concentrations. The main sources of lead contamination in drinking water stem from industrial activities and failing plumbing systems.

The test results in Fig 15 show that multiple wells throughout Alrwaisat Second Ring Road, Tajmida Road, 6 March School, Alshawahda, Karzaz, Coastal Road, Qasr Ahmed Fuel Station, Al-safshafa, Shuhada Althaqeel Club, Altaam Alasil Restaurant, Faculty of Science, Airport Road, Damm Street, Alzarouq, Alskerat, Qasr Ahmed, Alhasyan, Alareidat show elevated lead levels. The main factors that lead to water contamination in water sources include metal smelting activities, gasoline and coal combustion, and lead-based materials used in plumbing systems, and well and pipe connections. The breakdown of these materials can lead to lead leakage when they corrode or deteriorate.

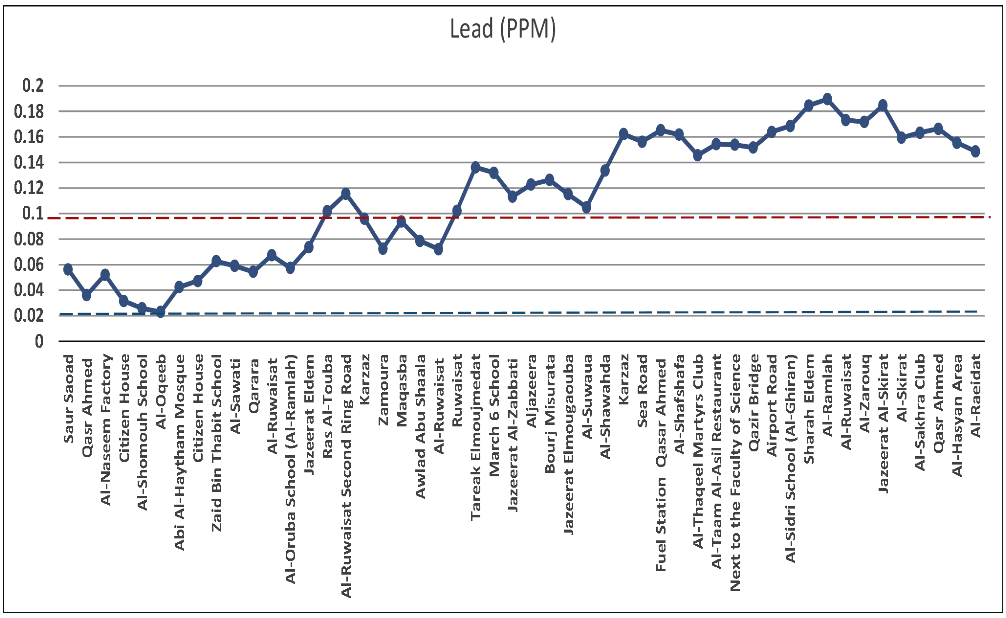

Fig. 15 Lead concentration in the 50 samples. The red line represents the permissible value for drinking water, while the blue line indicates the maximum allowable limit for irrigation wate

Zinc Analysis

Zinc serves as a vital trace element but its elevated presence in industrial Libyan districts creates environmental problems because particulate emissions from metallurgical operations and unregulated scrap processing deposit zinc into recharge zones (IRC, 2015). Elevated zinc levels in groundwater pose water-quality issues that threaten human health. Drinking water with high zinc levels leads to gastrointestinal problems that cause nausea, vomiting, diarrhea, and produce an unpleasant taste. The zinc concentrations in groundwater samples exceeded 0.1 mg/L in more than 90% of the collected water samples, according to Fig 16. The zinc concentration in the study area is consistent across locations. The main environmental sources of zinc contamination stem from coal-fired power plants and waste incineration facilities and steel production facilities. The operations need environmental protection systems to prevent zinc contamination of groundwater sources.

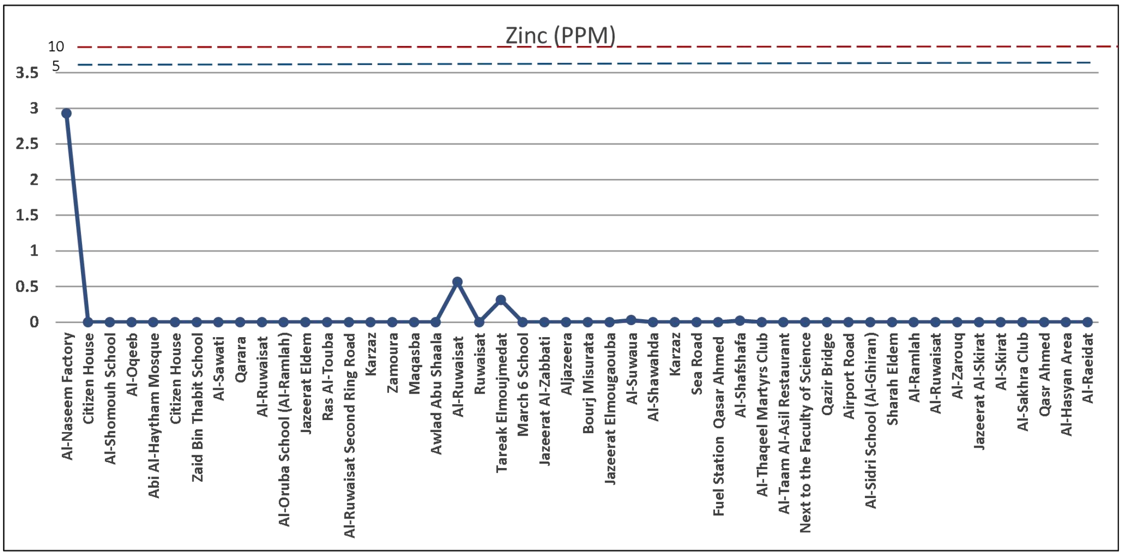

Fig. 16 Zinc concentration in the 50 samples. The red line represents the permissible value for drinking water, while the blue line indicates the maximum allowable limit for irrigation water

Conclusions and Recommendations

The analyzed water sample displayed groundwater quality that had been severely deteriorated throughout the entire study area. The hydro-chemical survey has demonstrated different values of phosphate, nitrate, cadmium, and lead. The highest heavy metal concentrations were detected in the eastern well sites of the study area, which is definitely due to industrial activities that most likely caused the contamination. The water quality distribution in the study area shows how unregulated groundwater discharge without rules, which has caused water resource degradation. The two leading causes of higher nitrate levels in different areas are wastewater contamination of groundwater systems and agricultural fertilizer use. The eastern part of the city shows high chloride levels because its aquifer system experiences seawater intrusion which produces saltwater. It should be wise to recommend a comprehensive roles and long term mentoring strategy to handle groundwater resources. Regular water-quality monitoring programs will generate reliable data that reflects the current state of groundwater resources.

The implementation of efficient decision-making depends on municipal laboratories obtaining advanced analytical equipment and creating a single platform for water quality information. The protection of private wells requires stronger regulations, as these measures safeguard both environmental resources and public health. The development of an integrated system for managing water shortages and groundwater pollution requires government entities to work with academic institutions and research centers. The public needs to learn sustainable water practices through educational outreach programs which teach them about drinking water and irrigation requirements. The implementation of groundwater governance requires synchronized policy implementation, industrial effluent reporting requirements, and extended monitoring systems that detect aquifer chemical changes before they become significant, according to regional water-security strategies (UNEP, 2021).

The most successful approach to integrate aquifer management requires ongoing groundwater modeling, extensive monitoring systems, and strict control measures for large-capacity wells, in line with international water-resource strategies (Giordano, 2009; MacDonald *et al*., 2021).

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