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Genetic and environmental factors in the spread of some genetic diseases in polluted areas of southern Iraq / Review Article

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Abstract

The southern governorates of Iraq, particularly Basra, Nasiriyah, and Muthanna, are witnessing an alarming increase in the rates of genetic diseases. This is the result of a complex interaction between genetic factors and long-term exposure to environmental pollutants such as heavy metals (lead, mercury, cadmium) and perfluorooctanoic hydrocarbons (PAHs). Recent studies have shown that this interaction is not limited to a direct causal relationship, but rather includes disturbances in DNA repair mechanisms and alterations in gene expression resulting from environmental stress. Genetic factors, such as high rates of consanguineous marriages (reaching more than 45% in some areas of Basra), indicate a significant role in the spread of recessive diseases such as sickle cell anemia and thalassemia, especially in light of the weakness of premarital genetic screening programs. It was found that less than 20% of couples in these governorates underwent genetic testing, leaving large numbers of carriers of genetic mutations unidentified. On the environmental level, the concentration of heavy metals and industrial activity associated with oil extraction contribute to DNA damage and the accumulation of genetic mutations through what is known as oxidative stress. Hydrocarbons also have a direct effect on gene expression through epigenetic modifications, such as the inhibition of genes responsible for DNA repair (MLH1, BRCA1). An explanatory model concluded that the emergence of genetic diseases is not caused by genetic mutations alone, but rather requires environmental triggers for their activation, as congenital malformations and childhood cancers have increased in areas close to pollution sites in Basra and Dhi Qar. In light of these challenges, the National Environmental Genetic Monitoring Plan in Iraq proposed the establishment of genetic testing and field environmental monitoring centers and linking them to a smart database based on geographic information systems and artificial intelligence, this

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system is expected to contribute to mapping genetic and environmental risks and guiding health policies for prevention and early intervention.

Keywords: Environmental Pollution ,Genetic Diseases, Epigenetic Modifications , Genetic Monitoring

1. Introduction:

Genetic diseases are a growing health challenge in many regions of the world, particularly in environments suffering from chronic environmental pollution. In southern Iraq, i.e., the governorates of Basra, Dhi Qar, and Muthanna, alarming evidence is building up regarding the association between long-term exposure to environmental pollutants, i.e., heavy metals (such as lead, mercury, and cadmium) and polycyclic hydrocarbons (PAHs), and the high incidence of genetic disorders. This threat is added to by social habits such as consanguineous marriage and absence of robust genetic protection infrastructure, which increase the chances of harmful genetic mutations or cumulative environmental effects on DNA. Recent studies (Ali *et al.,* 2023; Al-Mayah *et al.,* 2024) also indicate that the relationship between environmental exposures and genetic predisposition is not a simple causal relationship but a complex interaction that leads to disruption of DNA repair or dysregulation of gene expression as a consequence of environmental insults.

2. Contributing Genetic Factors

The genetic factors are a main reason for the prevalence of some genetic diseases in south Iraq, especially in view of the intersection of environmental conditions and social customs. It is noted that the interaction between consanguineous marriages and the lack of genetic screening programs is a reason for the high rate of recessive diseases, especially in governorates that suffer from chronic environmental pollution

2.1 Consanguineous Marriage: Consanguineous marriages, especially first-degree relatives (such as cousins), increase the likelihood of recessive alleles occurring in offspring. Recessive alleles are often not apparent in their carriers, but their pathological effects are manifested when two identical copies of the mutant allele meet in the child. These mutations can cause serious illnesses in children.

Some diseases associated with consanguineous marriages, which are common in southern Iraq, include:

Thalassemia: A defect in hemoglobin formation that leads to chronic and severe anemia.

Sickle cell anemia: Mutations in the beta globin gene lead to an abnormal shape of red blood cells, causing blockage of blood vessels and chronic pain.

Genetic metabolic diseases such as phenylketonuria (PKU): a disorder resulting from a defect in the enzyme phenylalanine hydroxylase, leading to the accumulation of phenylalanine and brain damage. Maple syrup urine disease (MSUD): a defect in the breakdown of branched-chain amino acids (leucine, isoleucine, and valine), leading to rapid neurological damage if not diagnosed early.

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A study by Hasan *et al.* (2024) indicates that the rate of consanguineous marriages in some areas of Basra Governorate exceeds 45%, one of the highest rates in the Middle East. This high rate is associated with significantly higher rates of rare and fatal genetic diseases, especially among newborns. Contributing factors include cultural and social heritage, a lack of genetic awareness, and weak health education programs in schools and communities.

2.2 Lack of Genetic Screening Programs: Premarital genetic screening programs aim to determine whether both partners carry a mutation in the same gene, increasing the likelihood of giving birth to a child with a recessive genetic disease. These programs are among the most successful prevention strategies at the public health level and have proven to succeed in countries such as Saudi Arabia, Lebanon, and Cyprus. Despite initiatives by the Iraqi Ministry of Health to implement premarital screening programs, several challenges impede their success, including government failure to support genetic labs, the availability of a limited number of capable labs to conduct precise genetic testing, low levels of community awareness of the importance of the tests, and the absence of legislation mandating premarital genetic testing.

It was reported, by Jasim & Abdul-Razzaq (2023) through a survey, that less than 20% of newlyweds in Dhi Qar and Muthanna governorates were tested premaritally for genetic disorders. This less than 20% represents thousands of undiagnosed marriages among carriers with the same mutation, which results in children being born with serious genetic diseases. The interaction of high consanguinity marriages with the inefficiency of genetic screening programs is among the genetic determining factors for explaining the prevalence of inherited illnesses in southern Iraq. Besides that, they are often exposed to environmental pollutants such as industrial and petroleum pollution, which contribute to the health impact on the population, particularly on future generations.

3. Environmental Pollutants and Their Genetic Effects

3.1 Heavy Metals and Their Effects on DNA: Heavy metals such as lead (Pb), mercury (Hg), and cadmium (Cd) are poisonous environmental pollutants that prevail in huge amounts in southern Iraq due to various factors, including ongoing wars, drilling operations of oil wells, and natural gas flaring (Al-Shammari *et al.,* 2024). Heavy metals are environmental stressors with the capacity to directly influence the genetic material and pose a long-term genetic health risk.

Recent evidence indicates that exposure to these metals triggers oxidative stress, which aims at targeting DNA molecules for degradation, disrupting DNA strands through the production of reactive oxygen species (ROS) (Fakher *et al.,* 2023). This damage interferes with normal gap and substitution repair and thus leads to the accumulation of genetic mutations.

As reported by Fakher *et al.* (2023) Long-term exposure to these metals has a tendency to cause chromosomal alterations, as well as "silent" mutations that are not manifest in the carrier but are activated and become deleterious upon mating of carriers of these mutations. This increases the risk of genetic diseases that are recessive and affects the healthiness of future generations.

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3.2 Polycyclic Aromatic Hydrocarbons (PAHs): Polycyclic Aromatic Hydrocarbons (PAHs) are highly toxic organic substances with carcinogenic activities. They are present in elevated amounts in southern Iraq's environment, particularly in Basra soil and water surrounding oil refining processes and intensive industry (Al-Khafaji et al., 2023). PAHs also have the ability to cause somatic and germline genetic mutations, and these may lead to hereditary disease as well as cancerous tumors through direct action on genetic material. Besides, these chemicals affect gene expression by altering epigenetic marks, such as DNA methylation, that alter normal gene expression patterns and influence growth and reproduction. Al-Khafaji *et al.* (2023) reported in a study that evidence existed that long-term exposure to PAHs leads to reduced sperm count and impaired male fertility in contaminated areas, which increases the possibility of assortative mating and, thus, a higher risk of genetic disease among affected populations. Recent studies show that environmental pollutants in the southern part of Iraq, and particularly heavy metals and PAHs, not only affect genetic health but also extend their influence to public health by directly and indirectly affecting DNA damage and gene expression. Such observations require formulation of scientific, environmental, and health surveillance and control policies to monitor the effect of such pollutants and reduce their spread.

4. Genetic-Environment Interaction: An Explanatory Model

The relationship between genetic and environmental determinants is a complex model of interactions, influencing the health of individuals and populations, particularly in areas such as southern Iraq, which are subjected to unprecedented environmental pressures and elevated rates of genetic disease.

4.1 The Individual and Cumulative Effect of Genetic and Environmental Factors

Their interaction can be imagined as follows:

A- **Gene-Environment Interaction and Its Effect on Health:** It has been discovered that a World Health Organization (WHO, 2024) research finds that genetic mutations which are able to silently persist among individuals become evident under the influence of their pathological action only when faced with stressful environmental conditions such as chemical pollution, heavy metals, or chronic oxidative stress. This shows that the environment acts as an environmental stressor which activates underlying genetic diseases and aggravates their intensity.

Table 1: Interaction Between Genetic and Environmental Factors in Southern Iraq

Factor	Individual Effect	Cumulative/Synergistic Effect
Consanguineous marriage	Transmission of recessive alleles causing genetic disorders	Increased expression of mutations under oxidative environmental stress
Heavy metal pollution	Silent mutations and oxidative DNA damage	Amplification of pre-existing genetic damage and mutation accumulation

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Lack of genetic screening	Failure to identify carriers of genetic mutations	Continued transmission of hereditary mutations across generations

A recent study by Al-Haidari *et al.* also showed that (2023) In southern Iraq, simultaneous exposure to environmental pollutants such as heavy metals and oil pollution enhances the expression of genetic mutations, leading to increased incidence rates of diseases such as sickle cell anemia, thalassemia, and hereditary metabolic diseases. The study confirmed that these environmental conditions also affect gene regulation through epigenetic mechanisms, increasing the complexity of the disease and making it more difficult to treat.

B- **Brief Explanatory Model:** The explanatory model below shows how the simple occurrence of a genetic mutation alone is not sufficient to cause a disease. Rather, it must combine with certain environmental factors to induce such mutations. This can be seen by:

1- The incidences of genetic diseases being high in environmentally polluted areas.

2- The difference in severity of the diseases across different regions as per the intensity of pollution.

3- The difficulty in predicting the occurrence of a disease based on genetic alone and not environmental factors.

C- **The Application of the Model in Awareness and Prevention:** The comprehension of such an interaction requires:

1- Given priority to the elimination of environmental pollution as part of efforts to prevent genetic diseases.

2- Strengthening genetic screening programs, including environmental parameters.

3- Developing awareness campaigns based on the risks of combined exposure to genetic and environmental factors.

5.Case Studies: Basra and Nasiriyah as Examples

5.1 Case Studies in Basra Governorate: Basra Governorate is one of the most exposed areas in Iraq to environmental pollution, particularly by soil and water contamination with oil waste, heavy metals, and radiation due to previous wars. Several field studies and scientific research showed a clear increase in the rate of birth defects and leukemia compared to other Iraqi governorates. In a 2018 study by Al-Sabbak *et al.,* published in the journal Environmental Science and Pollution Research, the researchers measured increased levels of congenital anomalies in proximity to oil fields and heavy metal pollution areas in Basra, where birth defects increased up to three times the nation's average. Al-Sabbak, M. *et al.* (2018). Another study published in 2021 in the Journal of Cancer Epidemiology by Hussein et al. A catastrophic increase in childhood leukemia has been registered in Basra, where prolonged exposure to pollutants such as depleted uranium and heavy metals has been associated with high incidence rates. Hussein, A. M., & Al-Azzawi, B. S. (2021).

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5.2 Case Studies in Nasiriyah (Dhi Qar Governorate): Studies have indicated that areas in the south of Iraq, such as Nasiriyah, which have experienced extensive environmental pollution with chemicals and oil residues have seen an increase in genetic diseases such as sickle cell anemia and hereditary anemia, particularly in families living in environmentally polluted areas. A 2019 field research carried out by Kadhim *et al.* and published in the Environmental Toxicology and Pharmacology journal demonstrated a clear relationship between soil and water contamination with oil wastes and the high rates of incidence of sickle cell anemia in Dhi Qar Governorate. The study confirmed that chronic exposure to toxic petroleum compounds affects the genetic health of the population and causes an increase in the genetic expression of genetic diseases (Kadhim, M. A., Al-Saadi, Z. A., & Al-Maliki, A. S. (2019).

Additionally, a health report issued by the Iraqi Ministry of Health in 2020 confirmed that the occurrence of inherited anemia (thalassemia) in the Nasiriyah region is much higher, especially in families living in regions near oil dumps and industrial waste, indicating the interaction of genetic factors with the negative effect of a polluted environment.

These studies and investigations uncover that the environmental pollution in southern Iraq, particularly in Basra and Nasiriyah, is a key factor in increasing the incidence of genetic diseases and congenital anomalies by its impact on the integrity of the DNA of the population. The pollution amplifies the impact of the background genetic elements such as consanguineous marriage, calling for urgent health

6. Epigenetic Modifications and Their Impact in Contaminated Areas in Southern Iraq Recent literature indicates that environmental pollution not only affects DNA sequences but also induces epigenetic changes, such as DNA methylation pattern changes and histone chromatin structure changes, that affect gene expression without altering the gene sequence itself. In southern Iraq, a recent study by Al-Zubaidi *et al.* (2023) illustrated that the expression of DNA repair genes (MLH1, BRCA1) was markedly reduced in children born in oil-contaminated areas of Basra as a result of epigenetic changes. This epigenetic silencing has been incriminated in high rates of congenital malformations and cancers.

Recently, in a clinical study conducted at Al-Batoul Children's Hospital in Thi Qar, molecular investigation of thalassemia- and sickle cell anemia-related mutations was investigated in patients residing in areas close to oil dumps. The results showed that more than 60% of affected children carried recurring mutations associated with a specific location (hotspot) of the HBB gene and that the gene expression level of those mutations fluctuated according to exposure to the environment. Those fluctuations were correlated with clinical indicators such as low hemoglobin concentration, frequent blood transfusions, and the presence of associated organic abnormalities (cardiac/liver abnormalities).

7. Genomic technology-based preventive and diagnostic systems

With the advent of whole-genome sequencing (WGS) and epigenetic study, it is currently possible to devise accurate tools to identify the interaction of environmental and genetic

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factors. WHO-EMRO (2024) recommended the integration of gene expression analysis and methylation detection techniques into national public health initiatives for highly polluted areas, southern Iraq, to identify most at-risk populations. Joint projects are being pursued in the University of Basra and the University of Thi Qar for the establishment of a genetic database of the population of the industrial areas, with known genetic mutations and environmentally induced epigenetic changes.

The piece would be more effective with a geo-genetic risk map that links pollution sites to the occurrence of genetic disease, based on statistical data from the Iraqi Ministry of Health and air and water pollution maps. This approach was utilized in a recent 2024 paper by Mahdi *et al.,* where the authors created a genetic/environmental risk map in Basra using GIS tools and cumulative risk models. The map revealed significant overlap between high lead and cadmium and high β-thalassemia and G6PD mutations.

To study the relationship between environmental and genetic factors in the governorates of Iraq, comparison tables can be formed with the following factors in Table 2 :

Table 2 : (Geographic Distribution of Major Pollutants, Prevalent Genetic Disorders, and Potential Gene–Environment Interactions in Iraq)

Province	**Major Pollutants**	**Prevalent Genetic Disorders**	**Possible Gene–Environment Interaction**
Basra	Oil residues, heavy metals	Leukemia, birth defects	Pollution-linked DNA mutations and epigenetic alterations
Dhi Qar	Oil waste, industrial effluents	Sickle cell anemia, thalassemia	Inherited disorders exacerbated by oxidative stress
Muthanna	Agricultural chemicals	Congenital malformations	Maternal exposure affecting fetal gene expression
Baghdad	Traffic emissions, urban waste	Autism spectrum disorders, cancers	Air pollutants linked to neurodevelopmental genes

These tables serve as a foundation for identifying geographic hotspots of gene–environment interactions and formulating targeted health interventions.

About National Plan for Environmental Genetic Monitoring in Iraq in Table 3

Table 3 : Proposed Framework for a National Gene–Environment Surveillance Plan in Iraq

Component	**Description**
Objective	Establish a national system to monitor and link genetic disorders with environmental pollutants
1. Genetic Screening Centers	Establish centers in major provinces to perform genetic testing and detect hereditary disorders
2. Environmental Monitoring Units	Deploy ground-based and satellite tools to track pollutants like oil, heavy metals, radiation
3. Integrated Database System	Link genetic health data with environmental exposure records using AI and GIS technologies

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4. Public Health Alerts	Issue alerts and health advisories when pollution-genetic risk correlations are detected
5. Research & Training Programs	Fund interdisciplinary research in environmental genetics and train medical/public health staff
6. Community Engagement	Engage local communities for awareness, data collection, and early disease reporting

8. Why is this model important for Iraq?

Southern Iraq, and in particular Basra and Nasiriyah, is suffering from chronic pollution as a result of oil activity. In the absence of a national system linking genetic health and environmental pollution, it is impossible to pinpoint the precise causes of increasing genetic disease. This model will allow for the mapping of environmental genetic risk and provide guidelines to decision-makers to reduce disease levels and improve population health. The Iraqi National Environmental Genetic Monitoring Plan is a strategic model that aims to link genetic change in the population to long-term exposure to environmental contaminants, particularly where there is intensive industrial and oil activity, such as in Basra and Nasiriyah governorates. This plan depends on establishing specialized genetic testing facilities in principal governorates that will conduct state-of-the-art analyses for detecting mutations or genetic diseases related to environmental factors. At the same time, there are going to be environmental monitoring stations established, relying on the newest technologies such as satellites and drones for monitoring the levels of pollutants in air, water, and soil. This data will be linked through a national database system with artificial intelligence and geographic information systems (GIS) to analyze patterns and predict areas of genetic risk. By issuing proactive health alerts, the plan aims to curtail the spread of genetic diseases linked to pollution. It also provides for training of health professionals and scientific research in environmental genetics and public health. Community engagement is an essential part of the design for proper data collection and to bring awareness to the community. Through this complete model, Iraq will be in a position to establish a new generation of environmental monitoring through genetic markers for the improvement of the health and environment system's efficiency and the reduction of chronic and hereditary diseases.

9. Conclusions:

1- Genetic/environmental interactions in southern Iraq are largely accountable for the prevalence of genetic disease.
2- Consanguinity and absence of genetic screening provide a fertile ground for the spread of recessive mutations.
3- Heavy metals and PAHs cause DNA damage and gene expression alterations that lead to chronic and inherited disease.
4- Environmental genetic mapping enables the linking of pollution sites with disease incidence, enabling focused health intervention.

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5- The National Environmental Genetic Monitoring Plan is a novel model that incorporates genetic and environmental data in order to protect the public health of Iraq.

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