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## Prediction of Flood Occurrences Using Rough Sets Theory (Case Study: Halilrood River)

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### Expanded Abstract

#### Introduction

Flooding, as overflow of water, brings massive biological and economic problems all around the world and disrupts the lives of many people. Based on several effective factors in flood occurrence as well as unknown relationships between parameters, researchers have used various methods to forecast flood events over the past decades. An investigation of the conducted studies on flood forecasting revealed that most studies have used measured data such as river flow, temperature or moisture for the forecasting. These data are collected over several years. Indeed, the point common to all studies is use of data model for model training and flood forecasting. However, the issue that has received less attention is the presence of uncertainty in the data used for extracting flood occurrence model. Taking uncertainty into account, due to high data volume used for model extraction, improves the results.

The current research aims to investigate the relationship between flood occurrence and effective parameters by selecting rough sets theory as well as taking into account the uncertainty present in the data during the forecasting process. Moreover, following the extraction of these relationships, some rules are extracted which, in addition to their simplicity, present the simultaneous effects of the effective parameters on flood occurrence. Then, using the existent relationships in this theory, the correlation between the parameters is investigated in multiple form and the most efficient rules for identifying the most probable conditions of flood occurrence are obtained.

For this purpose, the parameters of four years (2003-2007), related to Jiroft Dam, are used for analysis and extraction of the rules. In this way, first, data processing is performed and intervals of flood occurrence are separated from each year. Then, data discrete manufacturing is performed followed by data approximation and data reduction; the most probable rules are then extracted for flood occurrence by identifying effective core features. The region under study for the current research is Halilrood River located in southeast part of Iran, Kerman province.

#### Materials and Methods

Nowadays, flood occurrence is one of the major issues associated with natural disaster management. Accordingly, the current research proposes a method for prediction of flood occurrence on a daily basis by using rough sets theory to both manage its risk of occurrence and analyze the uncertainty obtained from the used data.

Given that the extraction rules using rough sets theory is done only through previous data analysis, data selection has high sensitivity. The parameters used in this study are including precipitation, minimum daily temperature, evaporation, and recorded river flow. Application of rough sets theory and simultaneous model extraction of effective parameters in flood occurrence are among the main objectives of the current research. Among the data of four years (2003-7), the monthly data obtained from hydrometer devices installed at the entrance of Jiroft Dam are selected for the time period of 2003-2007 in this analysis. In this way, first, data processing is performed and intervals of flood occurrence are separated from each year. Then, data discrete manufacturing is performed after data approximation and data reduction; the most probable rules are then extracted for flood occurrence by identifying effective core features. Finally, the data related to 2009 is used to evaluate the power of the extracted rules.

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Rough sets theory, proposed in 1980 by Pawlak, is a powerful mathematical tool to deal with uncertainty and ambiguity of data. It relies on analysis of data tables. These Tables may be obtained from measurements or by experts. The approximation synthesis of the concepts from the acquired data is the main objective of the rough set analysis. It also provides some methods to reduce imprecise or redundant data in databases. The process of eliminating redundant data is performed based on training without losing basic data from database. As a result of data reduction, a set of tabloid and meaningful rules is extracted, which makes the process of decision-making easier.

### Results and Discussion

In the first stage, including data selection, all data of the years 2003-7 were annually and completely selected for processing. In the next stage for data discrete manufacturing, since it is impossible to put all data in information system table due to different average evaporation and minimum temperature for different seasons of the year, the data were selected based on different seasons and then they were prepared as four tables of information system. After data selection, data discrete manufacturing was performed by taking their average into account. In the next stage, in order to evaluate the data, Lower and Upper Approximations of each information system were individually calculated. Given that the current research aims at extraction of flood occurrence rules, only the information systems can be selected for the next stage that are able to have maximum approximation accuracy for Class 1 of decision.

The information systems of spring and winter were first mixed in this research for Reduction of Attributes which created an information system. Then, Reduction of Attributes for this new information system was performed using the discussed relations in rough sets theory, after which no attribute was eliminated; this may be attributed to a variety of situations as well as high volume of data in this system. In order to obtain simple decision rules, Reduction of Attributes was performed by dividing the new information system into the seasons as well as forming individual information systems for each month of spring.

Finally, the hydrology data of 2007 was used to evaluate the obtained rules. This data evaluation shows that there are 29 river flow occurrences with more than 10 m<sup>3</sup>/s discharge. The results obtained from data discrete manufacturing associated with flood occurrence of 2007 show 21 cases out of 29 floods based on the extracted rules for Class 1. The results show that 72% of the extracted rules are consistent with the cases of flood occurrence. This shows the ability of these rules in identifying the probable cases of flood occurrence. However, it should be mentioned that the powerful rules extracted by rough sets theory are based on lower approximation of Class 1; therefore, the elements forming the border or uncertainty are not used in these rules; however, border elements and upper approximation of Class 1 are used only for approximation rules. Using the values obtained from confusion matrix, Kappa value was calculated to be 0.84. In addition, an overall accuracy rate of 95% was obtained for the research results regarding the fact that this parameter also involves forecasting of flood non-occurrence. Moreover, based on the frequency, the overall accuracy has increased for more cases of flood non-occurrence than occurrence. Therefore, the uncertainties present in the data are identified and then eliminated from the process of rules extraction. This issue was one objective of this research which was obtained using rough sets theory.

### Conclusion

Flood occurrence as a natural disaster is a serious threat to social infrastructures and financial compensation of damage due to floods seems impossible. Given that this phenomenon depends greatly on several factors, many researchers have attempted to forecast flood over the recent years. In many cases, the researches employ flood occurrence model for forecasting by using the previous data. One considerable point common to those researches is that they do not consider the uncertainty present in high volume of the data used for identifying flood occurrence model. Moreover, some of these methods individually investigate the correlation between effective parameters and flood occurrence; then, the effect coefficients were calculated for them; it is necessary to compare all parameters with each other as well as to investigate them for forecasting due to complexity of natural phenomena and interdependency and simultaneous impact of various factors.

However, the current research, with data uncertainties and their elimination from the process, was to extract the rules and investigate the correlation between parameters and flood occurrences simultaneously by using rough sets theory. The results of the present research show that 72% of flood occurrences recorded in 2007 are consistent with the obtained rules. This indicates the ability of rough sets theory in extracting forecasting rules of natural phenomena occurrence which have the highest complexity. The results of this research can be utilized in crisis management planning and natural disaster control.

**Keywords:** flood forecasting, river flow, rough set theory.

## Assessment of Total Economic Loss by Potential Tsunami Threat in Chabahar Bay

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### Expanded Abstract

#### Introduction

Tsunami is a series of water waves caused by the displacement of a large amount of water as a result of underwater earthquake, volcano, landslide or other disturbances below water. The Makran Subduction Zone (MSZ) is one of the regions with the potential to generate tsunami event. Such an event has been occurred in 1985 and the region is capable of another one. In MSZ, the coasts of Chabahar Bay are at risk of tsunami. This bay is an important region from economic aspect for Iran and there are two important ports where make it strategic for economy and international trade. According to their location in the bay, in case of tsunami, there will be huge loss because of delay in ships schedule for import and export and to the ports facilities. Thus, the aim of this study is to estimate total economic loss from Makran zone tsunami for local economy.

According to a numerical simulation of tsunami based on a probable earthquake, all coastal zones in Chabahar bay with inundation map are considered in three assumed scenarios (weak, moderate and strong) which is shown in Figure 1.

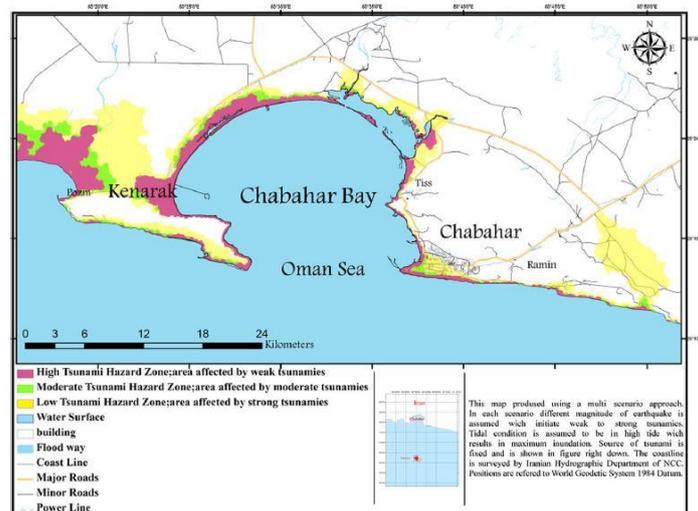


Fig. 1. Inundation area by tsunami area in Chabahar Bay in worst scenario

To have a better view of total economic loss, we estimate TEL for two scenarios. In worst scenario with earthquake magnitude of about 9.1 Richter and maximum inundation, all sectors will be affected by tsunami but in best scenario with earthquake magnitude of about 8.1 Richter only human life casualties and two damaged trade ports will be the significant items. Although we have tried to consider as much as possible items, but because of lack of data, the Total Economic Loss (TEL) is minimum loss to Chabahar bay.

Marine hazard costs are categorized in three groups including direct costs, indirect costs and hidden costs. In

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this study, we have applied Probable Maximum Loss (PML) to estimate total costs. The damage of tsunami could be considered in four sectors including: social sector, infrastructure, productive, and cross-sector.

### Material and Methods

Among all the mentioned sectors, buildings are more vulnerable to tsunami which PTVA model is used for that. This model was developed to provide first order assessment of building vulnerability and by calculating Relative Vulnerability Index (RVI) for each coastal zone building, the probable loss in residential zones in Chabahar Bay is estimated.

RVI for each building has been estimated as follow:

$$RVI = 2/3 (SV) + 1/3 (WV)$$

where SV is the standardized score for the structural vulnerability and WV is the standardized score for the vulnerability to water intrusion. For other sectors we have applied appropriate economic methods including damage cost and replacement cost approach and for those that there were no data and accurate documents, benefit transfer method have been used.

Each coastal region is divided into sub areas and in accordance with inundation map, via google map and other official documents, some of the buildings and their characteristics are provided. Then, with economic methods and PTVA model, economic loss for all sectors has been calculated.

### Results and Discussion

The purpose of this study is to estimate the total economic loss of probable tsunami in Makran zone and especially in Chabahar bay in Iran. As this bay is very strategic for international trade and fishery in south part of Iran, the costs of marine hazards like tsunami are economically important. To do this, the affected sectors are categorized into four items including social sector, infrastructure, productive, and cross-sectoral. In social sector, housing is the most vulnerable and important item which needs additional consideration. Thus, the special model for buildings are provided by Papathoma et al. in 2003 and by considering each building characteristics, the vulnerability index and the total loss could be estimated. The second important item is human life loss that is one of the most important costs in all marine hazards especially tsunami. In 2011 tsunami in Japan, about 15,000 people were lost or died which is a huge loss. Infrastructures and constructions in coastal areas are more fragile to tsunami and by stop their services, additional costs will be occurred after tsunami.

In Chabahar bay only in Chabahar province and Konarak province there is population and production firms. Because of that only the inundation map for these two regions are considered. Inside the bay, only one desalination plant is working and there are no residential places. These maps are shown in Figure 2.

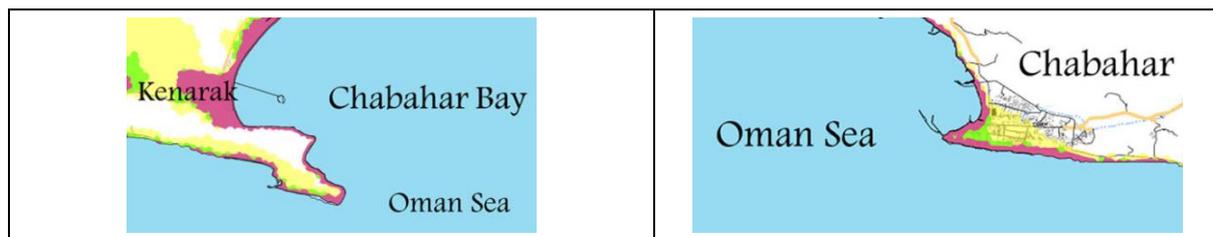


Fig. 2. Inundation map of tsunami in residential regions in Chabahar Bay

Table 1. Summary of damage and losses from probable tsunami in Chabahar bay

Sectors for damage	Total Impact (Damage and Losses) (\$ 2014)	Total Impact (Damage and Losses) (\$ 2014)
	In worst case	In best case
<b>Social sector</b>		
Housing	16,455,660	-
Health	18,000	18,000
Human life	500,000,000	250,000,000
Education	5,468,750	-
Culture and religion	16,900	-
<b>Infrastructure</b>		
Transports	1,321,370	-

Sectors for damage	Total Impact (Damage and Losses) (\$ 2014)	Total Impact (Damage and Losses) (\$ 2014)
	In worst case	In best case
Ports (50% damage)	450,000,000	450,000,000
Energy	622,525	-
Communication	1,414,430	-
Water and sanitation	3,859,957	1,278,985
Breakwater	6,338,683	4,282,218
<b>Productive sector</b>		
Fisheries and lobsters	121,090,836	121,090,836
Enterprises	308,456,107	-
<b>Cross-sectoral</b>		
Governance	201,000	-
Environment	1,305,057	1,305,057
<b>Total Impact</b>	<b>1,416,568,295</b>	<b>827,975,096</b>

### Conclusion

The total estimate of damages and losses from probable tsunami in MSZ in Chabahar Bay in two scenarios (worst scenario and best scenario) is summarized in table 1. As shown in table 1, in worst scenario human life lost and ports are the first and second items of economic costs. In this scenario the total impact is about US\$ 1.4 billion that can be destroyed if suitable risk management is not established in this area. In the best scenario total loss is equal to US\$ 828 million and the ports are the first target for damages of tsunami waves.

The total impact in best scenario is about US\$ 827 million which is still considerable. The second stage impacts can make low GDP growth and reciprocate of the needs. Although it is not possible to omit all damages and losses but by putting some rules for building construction and provide appropriate guide and evacuation map to residents and also give informational brochures to residents and tourists, we could diminish economic costs of tsunami in Chabahar Bay.

**Keywords:** Iran, Makran Subduction Zone, probable maximum loss, PTVA model, Tsunami.

## Investigation about the Appropriateness of Wheat Planted Areas in Iran with Wheat Yield and Water Demand by Virtual Water Approach

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### Extended Abstract

#### Introduction

The average annual precipitation in Iran is about 250 mm. This precipitation does not have regularly spatial and temporal distribution. More than 70 percent of total precipitation is not accessible due to evapotranspiration. Total renewable water resources of the country are estimated to be around 130 billion cubic meters. In spite of limitation in water resources, they are not used properly. Agriculture is considered as the biggest sector that uses around 90 percent of the total accessible water. Accordingly, any mismanagement of water usage in this section can make a remarkable damage to the water resources of the country. Paying attention to virtual water content of products is one of the methods to reduce water usage in this section by selecting proper agricultural products for each area.

Virtual water is a measure of the total water used in production of goods or services. The concept was initially used to illustrate the advantages to the nations of water deficit with other nations, rather than attempting to produce all goods locally. In the recent times the concept has been applied to argue against production of commodities with high embodied water content, or to argue against their export on the basis that these activities waste scarce water resources. Virtual water estimates have also been used as an indicator of environmental damage of certain production activities. Estimation of virtual water content of a product contains more than just considering water directly applied to growth or to the process. In the case of agriculture, it should also consider, for example, the water contained in production of fertilizers and pesticides used on farm, and the water used to grow and process grains fed to animals. Moreover, it must do so over the full lifespan of a plant, and also include all the water used at postharvest stages of production, including any inputs to those stages. Generally, water associated with transportation must also be included, but this usually turns out to be a small and negligible amount.

Given the remarkable demand all around the world, wheat is one of the most strategic agricultural products. Accordingly any decision towards changing the crop production may have distinct local, regional and global effects. On the other hand, with the dominance of conventional irrigation methods in Iran which impose remarkably higher stress on water resources in comparison with developed countries, an effort should be made to mitigate the pressure. To achieve a wheat farming template through which the optimized amount of water is needed to have the maximum potential crop, a survey should be run and the whole country should be classified in categories. The wheat farming priority then should be attributed to provinces where the most optimized conditions are observed. Wheat is the main agricultural product in Iran with its significance and remarkable consumption. Its farming in the areas with lower water consumption would cause a reduction of water usage in agriculture section. Wheat virtual water is equal to the amount of net water required for farming divided by produced wheat per hectare in each province.

#### Materials and Methods

In this paper wheat yield, the net water required for farming, irrigation water and farming area in each province has been investigated. By comparing these data for each province, proper areas for farming this important and strategic agricultural product is recommended. In order to evaluate the water demand in different areas CROPWAT software is used. Finalized data are shown through maps in GIS environment.

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## Results and Discussion

As it is seen in Figure 1, net water demand for wheat crop in central parts of Iran is higher than marginal areas. Minimal values are seen in Caspian Sea coastline.

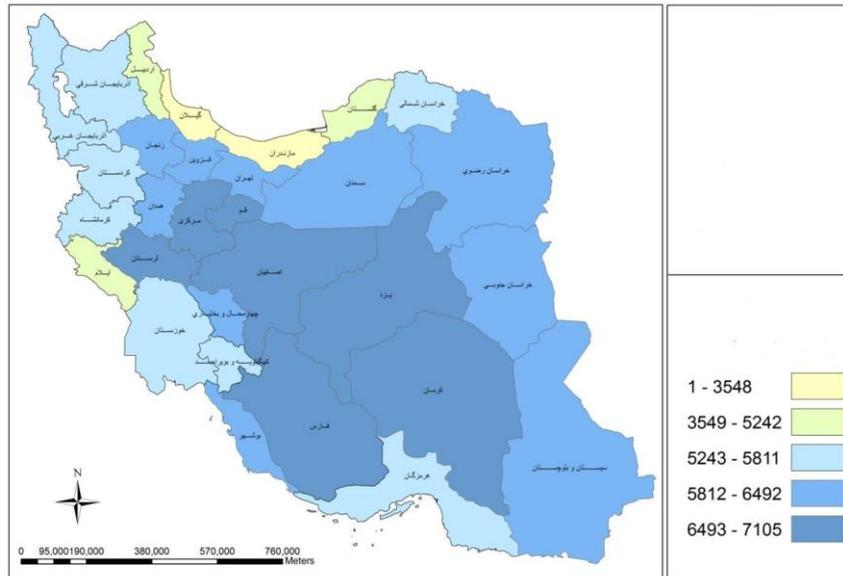


Fig. 1. Net water demand for wheat crop in different provinces of Iran

As it is seen in Figure 2, the highest values of irrigation need are observed in central and southeastern parts (Qom, Isfahan, Yazd, Kerman, Sistan and Baluchestan provinces).

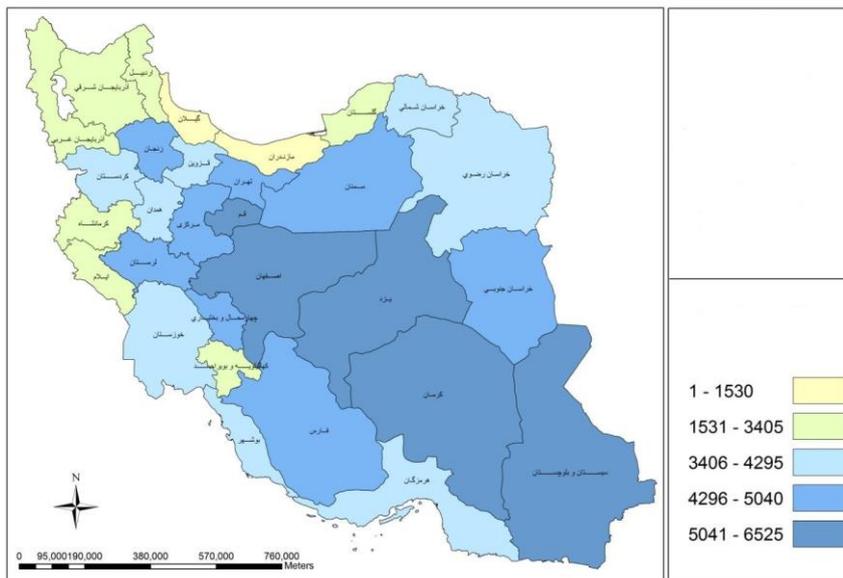


Fig. 2. Wheat irrigation need in different provinces of Iran

On the other hand, the lowest values are seen in north and northwestern areas (Guilan, Mazandaran, Golestan, Ardebil, East and West Azerbaijans, Ilam, Kohkilooyeh and Boyerahmad and Kermanshah provinces).

Besides water demand and irrigation need, wheat yield should also be taken into consideration. Wheat yield in different provinces of Iran is shown in this paper. As it can be seen, the lowest yield is observed in eastern provinces and also in Bushehr where there are remarkable water shortage and conventional irrigation methods. Wheat yield in provinces like Tehran and Kordestan are estimated to be more than five tons per hectare, while provinces like Qazvin, Hamedan, Zanzan and Hormozgan have wheat yields greater than four tons per hectare. As a rule of thumb, the farming priority should be made for provinces where the highest wheat yields are observed.

The largest wheat farms are located in Khuzestan Province. This province holds the 13<sup>th</sup> rank in irrigation need and 18<sup>th</sup> rank in wheat yield. Accordingly, any enhancement project should be stopped there. A similar status is seen in provinces like Fars, Khorasan Razavi and Kerman.

### **Conclusion**

According to the results of this research, there is no coincidence between the optimization of water demand, wheat yield and surface area of wheat farming in different provinces. This fact would be terminated in more water loss and stress. The largest wheat farming areas are located in provinces like Khuzestan, Fars and Khorasan Razavi where a remarkable irrigation demand is observed. Accordingly, a shift should be made towards northern and western provinces where less irrigation need is observed.

**Keywords:** farming, optimization, virtual water, wheat.

## Detection of Climate Changes by Mann-Kendall Analysis and Drought Indices (Case Study: Agh Gol Wetland, Hamedan)

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### Expanded Abstract

#### Introduction

Climate change is one of the most significant challenges in sustainable development that has negative effects on land and marine ecosystems. This phenomenon leads to imbalances that cause some effects including hydrological changes, increased soil erosion, increased runoffs and reduced groundwater aquifer feeding, and etc. The effects of climate changes over the past decade have significantly increased in Ecology and Hydrology Literature. Therefore, researches have been increased in this area with focusing on climate change. Furthermore, researchers know pressure on wetlands is likely due to changes in the hydrological regime directly and on temperature change and lands-use indirectly. The purpose of this study is to predict climate change important parameters in the study area and management planning for Agh Gol Wetland in the predicted conditions to be protected against drought in the coming years. Furthermore, knowing the drought years can provide better and more comprehensive management model for the study area.

#### Study area

Agh Gol Wetland is located in 34 degrees and 49 minutes in eastern longitude and 29 degrees and 2 minutes in northern latitude. This wetland as a Hunting Prohibited Area in Hamedan province in recent years was exposed to extra (ecological) pressure of sources as other water sources. This increased pressure led to drying up of the water body in the recent years. In this study, we tried to detect the characteristics, climatic and hydrological changes in addition to land-use and the factors influencing the revival of the dry wetland and present the strategies affecting the revival of this wetland.

#### Materials and Methods

This study was based on the data obtained from synoptic stations around Agh Gol wetland. To determine the severity of the drought, indices including SPI, RAI, and PNPI were used over the last 30 years.

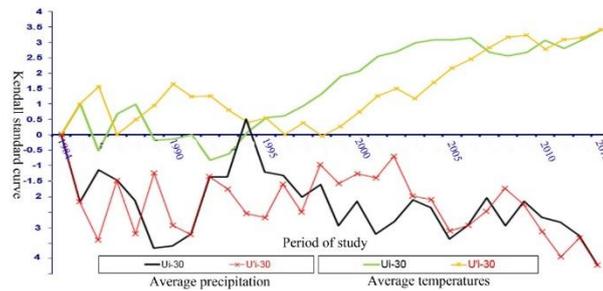
In this study Mann-Kendall graphical test was also used to show the trend of changes and calculation of time series in climatic parameters. In Mann Kendall graphical test each value in the time series is compared continuously and subsequently with the rest of the series values.

#### Results and Discussion

Kendall graphical test results in Figure 2 shows that with respect to collision of Diagrams  $u$  and  $u'$  for temperature indicator outside the critical range of  $\pm 1.96$  a significant trend for the temperature indicator can be recognized in Nozheh Station. The results and the trend of graph changes indicate the occurrence of mutation for temperature indicator in Nozheh station, in the years 2007, 2010, and 2012. Through 1999, the temperature indicator at the station has also shown a positive trend. On the other hand, with the analysis of rainfall indicator at this station the existence of a significant trend in the recent years is emphasized. The results indicate observation of a mutation in 2013. The rainfall index shows a negative trend at this station and it can be due to reduction of precipitation at the station in the recent years.

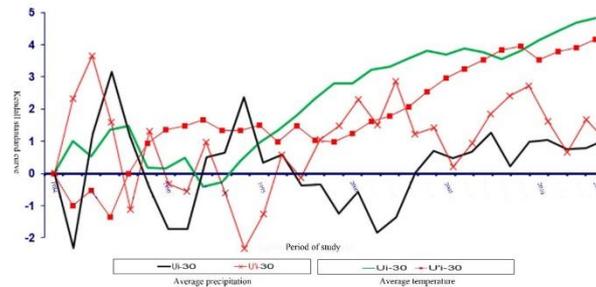
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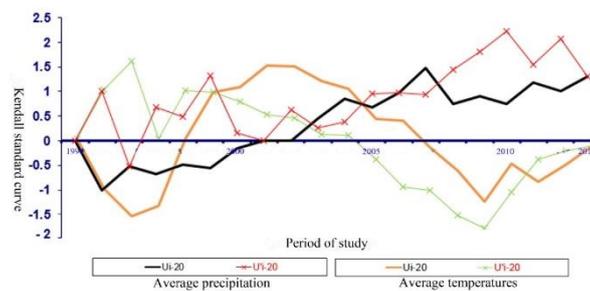
**Fig. 1. Graphical Kendall test, Hamedan- Nozheh weather station**

The results of the analysis of Kendall graph in Weather Station of Hamedan-Airport (Fig. 3) in the time period of the study (1984-2013) confirm a significant trend for temperature indicator with regard to cross of Line  $u$  from the critical point in  $\pm 1.96$ . The results show that in temperature indicator of Hamadan-Airport Station in the years 2008 and 2009 a mutation has occurred that can be a trigger for abrupt climatic change. Changes of Line  $u$  in this station have a positive trend given that the line in the range  $u > +1.96$  has experienced an upward turn and can confirm the existence of time series in Hamedan-Airport station.



**Fig. 2. Graphical Kendall test, Hamadan- airport weather station**

The results of Mann-Kendall model in weather station of Malayer in the period 1994 to 2013, due to inclusion of Line  $u$  for the two indicators of temperature and precipitation in the range  $\pm 1.96$  and failure to observe the trend due to placement of random series in data of this station does not show a significant trend for these indicators.



**Fig. 3. Graphical Kendall test, Malayer weather station**

Investigation of drought indices according to Figure 5 represents that based on RAI index in the the years 1985, 1990, 1995, 2001, and 2008, Hamedan- Airport Station has experienced very dry years and in the rest of the study period, the region has experienced moderate or mild drought.

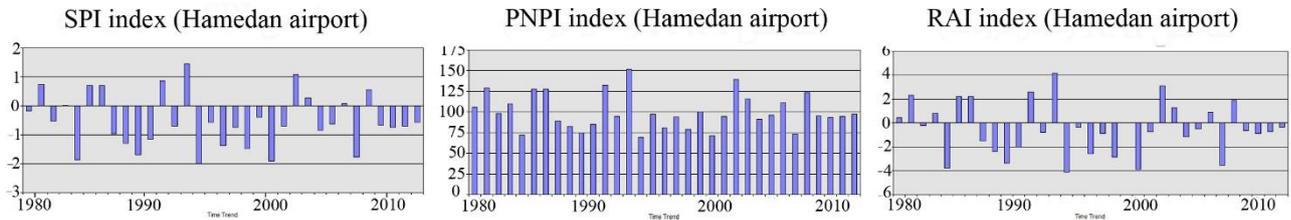


Fig. 4. Trends of changes of Drought Indices in Hamadan- Airport weather station

Investigation on the drought index in Hamedan- Nozheh station showed that for the years 2013, 2012 and 1999, the region has experienced severe dry years according to RAI index. In other years, the region has not been in satisfactory condition and has experienced years with relative drought.

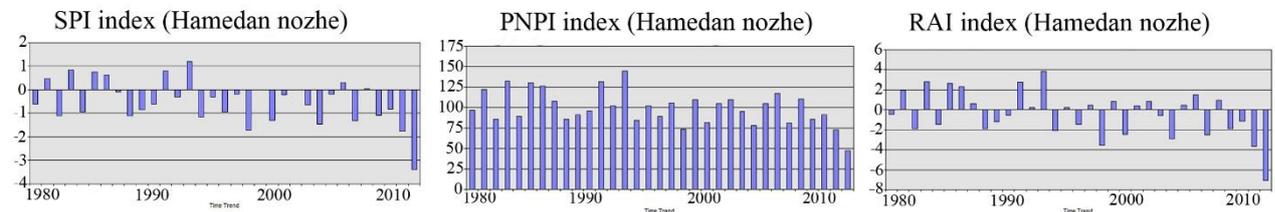


Fig. 5. Trends of changes of Drought Indices in Hamadan- Nozheh weather station

Evaluation trend of changes of drought in Malayer Station in terms of RAI index showed that in the years 1995, 1997, 1998, 1999 and 2008, the drought index has been in cute conditions. The rest years of the study period in this station are associated with normal or mildly drought.

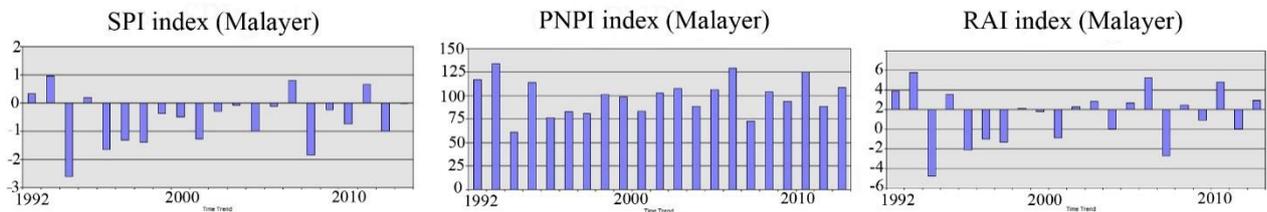


Fig. 6. Trends of changes of Drought Indices in Malayer weather station

## Discussion

The study area around the wetland, according to climatic statistics in meteorological stations in a 30-year period (1984-2013), did not have stable conditions. Thus, analysis of the climatic results emphasizes that in the years 1999, 2001, 2005, 2008 and recent years (2010- 2013) a significant trend of drought has been experienced in all analyses. The use of drought indices in this study suggests the tensions that the region has endured over a period of 30 years. Comparing these results with evaluation of the trend of changes and time course of changes and modifications indicated that the greatest changes occurred in the temperature indicator and precipitation variations usually appeared with a delay up to several years after the temperature mutations in the region. Therefore, by a careful planning and consideration of the interests of all concerned and influential parties we can present a comprehensive plan for the sustainable management. This is for control and mitigation of the effects of drought and climate change, in Agh Gol wetland, to witness dewatering of wetlands in the coming years. Presenting a sustainable agriculture program in accordance with the climatic conditions of the region may be contributed to regional stability.

**Keywords:** climate change, drought, hydrological regime, sustainable development, wetlands.

## Dust detection using improved TIIDI and applying MODIS sensor data

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### Expanded Abstract

#### Introduction

Thermal Infrared Integrated Dust Index (TIIDI) is one of the indices presented in this direction. The index operates based on four brightness temperature difference including Wavelengths 3.7, 8.6, 11 and 12 micrometer. According to the studies, BT<sub>D</sub> (BT<sub>12</sub>-BT<sub>11</sub>) is used for cloud detection. BT<sub>D</sub> (BT<sub>8.6</sub>-BT<sub>11</sub>) is the index for separation of dust from sandy surface and BT<sub>D</sub> (BT<sub>3.7</sub>-BT<sub>11</sub>) is employed for differentiation of dust from vegetation. It can also show dust intensity.

In general, according to Weather Meteorological Organization (WMO) protocol, dust phenomena are divided into four categories based on reduction in horizontal visibility:

1. Dust-in-Suspension: Its development is suspended, visibility of less than 10 km
  2. Blowing Storm: Reduced visibility from 1 to 10 km
  3. Dust Storm: Reduced visibility from 200 to 1000 m
  4. Severe Dust Storm: strong gust of wind with large dust particles and reduced visibility from less than 200 m.
- Yang by combining these three parameters created the TIIDI index.

$$TIIDI = (BTD_{BT32-BT31}) \times \exp(BTD_{BT29-BT31}/a) \times (BTD_{BT20-BT31}) \quad (1)$$

Dust  $BTD_{BT32-BT31} > 0, BTD_{BT29-BT31} < 0, BTD_{BT20-BT31} > 0 \rightarrow TIIDI > 0$

Sky without dust and cloud  $BTD_{BT32-BT31} > 0, BTD_{BT29-BT31} < 0, BTD_{BT20-BT31} > 0 \rightarrow TIIDI > 0$

Cloud  $BTD_{BT32-BT31} > 0, BTD_{BT29-BT31} > 0, BTD_{BT20-BT31} > 0 \rightarrow TIIDI < 0$

In Equation (1), if the  $BTD_{BT29-BT31}$  gets the positive value, 'a' would be 10 and otherwise it would be 5.

Based on the  $BTD_{BT29-BT31}$ , it has a small value for sky without dust and cloud, the index TIIDI gets less value for sky without dust and cloud than just dust.

Therefore, using this index appears reasonable according to topographic complexity that exists in west and southwest part of Iran. Because in these areas, there is a combination of mountainous terrains either with vegetation or with bare land and vegetation. Consequently, the suggested index by Yang is developed and customized. The modified method can estimate dust storm intensity with improved accuracy.

#### Materials and Methods

In this research, we used MODIS products including MOD021, MCD12Q1, MOD35, topographic map 1:25000 of Ilam (31°58' to 34°15' N, 45°24' to 48°10' E) and Khuzestan (29°57' to 33°00' N, 47°32' to 50°39' E) to obtain land cover types. We also used meteorological data of the two provinces during the period 2005-2012 to implement the algorithms. The ground data is for the 30 stations of the two mentioned provinces, thus all analysis related to computing and image processing is done on the pixel location of the 30 stations in the image.

As mentioned before, the aim of this study is detection of dust pixels using corrected TIIDI. In the study area there are three types of classes namely cloud, dust and sky without clouds and dust. As a result, the radiative behavior of these three classes in thermal infrared bands of MODIS should be checked. Hence, in the first step appropriate training data must be collected for all three classes and then diagram of three classes' radiation in thermal bands is obtained and analyzed. According to the results of previous researches for sky without cloud and dust, BT<sub>D</sub> (BT<sub>31</sub>-BT<sub>32</sub>) is negative. This means the slope line of band 31 to band 32 must be negative but it

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is positive like cloud due to the complexity of study area. This means a pixel  $1 \times 1 \text{ km}$  in the study area does not contains only one class but it also contains more than one class such as building, vegetation, desert lands and wasteland. Because the spectral changes in surface emissivity will also cause change in the behavior of the index.

If  $BTD_{BT31-BT32}$  is positive for sky without cloud and dust, then it cannot be concluded that  $iTIIDI$  is positive. In this case, the dust and the sky without cloud and dust will have not a similar behavior. Dust based on the horizontal visibility is separated into four groups (See the introduction section). As previously mentioned, dust intensity is defined based on four categories. Because one of the challenges in dust detection is lower intensity of dust event and horizontal visibility of more than one kilometer and also inability to detect them on true color MODIS images. According to what was said,  $iTIIDI$  index must be improved for this study area. Figure 1 indicates that slope line of band 29 to band 32 for both dust and sky without cloud and dust is same and for both cases it is positive. As a result, in the formula (2)  $BTD_{BT32-BT29}$  it can be replaced by  $BTD_{BT31-BT32}$ .

$$iTIIDI = (BTD_{BT32-BT29}) \times \exp(BTD_{BT29-BT31}/a) \times (BTD_{BT20-BT31}) \quad (2)$$

$$BTD_{BT32-BT29} > 0, BTD_{BT29-BT31} < 0, BTD_{BT20-BT31} > 0 \rightarrow iTIIDI > 0 \quad \text{Dust}$$

$$BTD_{BT32-BT29} > 0, BTD_{BT29-BT31} < 0, BTD_{BT20-BT31} > 0 \rightarrow iTIIDI > 0 \quad \text{Sky without dust and cloud}$$

$$BTD_{BT32-BT29} < 0, BTD_{BT29-BT31} > 0, BTD_{BT20-BT31} > 0 \rightarrow iTIIDI < 0 \quad \text{Cloud}$$

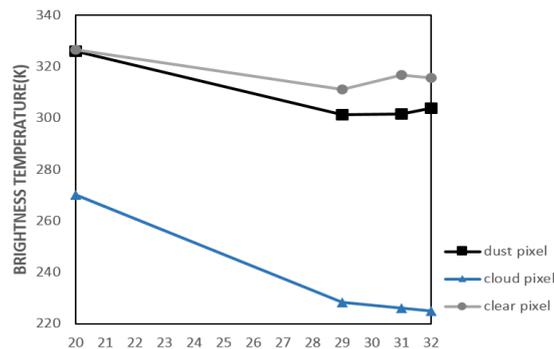


Fig. 1. reflectance behavior diagram of cloud, dust and sky without dust and cloud pixels in thermal infrared bands of MODIS

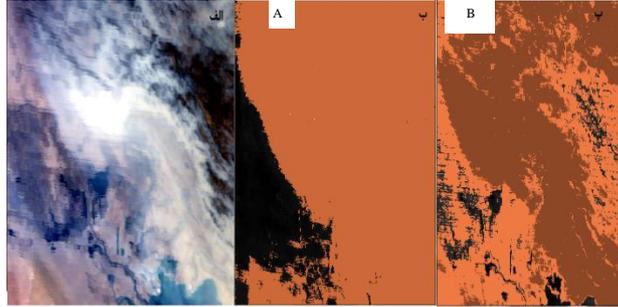
Our studies on the  $iTIIDI$  for cloudy days, days of dust and the days when the sky is free of clouds and dust reveals that this index have smaller value (10-25) for sky without cloud and dust but in during dust event the values will be increased (more than 25). Also,  $iTIIDI$  index have negative values for cloud pixels. Therefore, first, by choosing zero threshold on  $iTIIDI$  cloud pixels it is possible to eliminate those with values more than 25. From pixels known as dust pixels, if corrected index value is between 25 to 50 it shows weaker dust otherwise, if  $iTIIDI$  is more than 50 it specifies the dust with more intensity.

## Results and Discussion

To assess the accuracy of the proposed indices and its success rate in dust detection, the indices on 6 July, 2009 (15 Tir, 1388) is calculated, when a severe dust storm occurred over the region. In this image taken at 10:35 AM of local time, meteorological data shows the minimum and maximum horizontal visibility of 200 m and 6000 m in the study area, respectively. Based on beginning categories (See the introduction section), in this day severe dust storm is occurred. In the figure 4, the results of enforcement  $iTIIDI$  index is shown on the image and is compared with the true color MODIS image for same day. There is good agreement between image (a) and image (b). In addition, improved index can be able to detect dust as well as the severity of dust. On the other hand, the accuracy of the developed method is evaluated using the ground observation data. Meteorological data from 30 synoptic stations located in the provinces of the study area are listed in Table 1. The information includes horizontal visibility and meteorological codes. According to meteorological organization standards,

during dust event and reduction in the horizontal visibility, this parameter reaches less than 10 km and meteorological codes determine the value 05 or 06 or 07. The overall accuracy of the corrected index of iTIIDI is about 65% for detection of dust pixel and the accuracy of 64 percent is achieved by using the TIIDI index.

Figure 2 shows result of index implementation (iTIIDI) on the image. It is also compared with RGB image on the same day (6 July, 2009).



**Fig. 2. Comparison of (A) MODIS RGB image taken on 6 July, 2009 (B) and TIIDI index by Yang and (C) Improved index (iTIIDI) for dust detection for same day**

### Conclusion

Because of the land cover presented in the west and southwest Iran there are combined different classes such as Vegetation, Bare land or Sandy land, and Mountainous areas. A review of the indices proposed at a global level is inevitable. In this review, in one hand, the former index is improved and on the other hand its threshold is customized. Therefore, Thermal Infrared Integrated Dust Index (TIIDI) has been developed for dust detection and the improved index is presented. Although the accuracy achieved in this study is not more than 65 percent, the results obtained demonstrate the simplicity and accessibility of the method. An extensive coverage of MODIS data and its products would all increase the speed of the algorithm in dust detection. By comparing the two indices, the results show that the improved method not only is able to detect severe dust storms but it is also able to detect less intense dust storms from the severe ones.

**Keywords:** dust detection, improved TIIDI index, synoptic data.

## Estimation of the Damage Caused by Dust Phenomenon on Public Health in Iran, Case Study: Provinces of Khuzestan, Kermanshah and Kurdistan

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### Expanded Abstract

#### Introduction

Developing countries and newly industrialized countries are faced with the twin challenges of protecting the environment and also strengthening their economies. Over the past few decades, the intensified process of urbanization and industrialization undertaken by these countries, coupled with rapid population growth, has resulted in degradation of the environmental quality. Particularly, the emission of harmful pollutants such as particulate matter has contributed considerably to a rapid drop in the air quality in the cities.

Recent studies on the effects of chronic exposure to air pollution have identified PM10 as the pollutant most responsible for the life-shortening effect of dirty air. The major concerns for human health include effects on breathing and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defense systems against foreign materials, damage to lung tissue, carcinogenesis and premature death. Particulate exposure might increase susceptibility to bacterial or viral respiratory infections and lead to an increased incidence of pneumonia in vulnerable members of the population. It might also aggravate the severity of underlying chronic lung disease and cause more frequent or severe exacerbation of airway disease or more rapid loss of lung function. Besides its adverse impacts on human health, particulate matter can also result in visibility degradation.

#### Materials and Methods

This paper attempts to provide more insights in the epidemiological and valuation relationships of particulate air pollution. Similar study is rarely conducted in Iran. If cost of particulate air pollution were substantial, it would highlight the importance of not ignoring the environment in pursuing economic progresses. Given the available epidemiological data, PM10 may be regarded as an important and useful indicator for the health risk of air pollution. We use PM10 as the main indicator for air pollution and its impact on health as the proxy for estimation of the economic cost of particulate air pollution. One of finding from many recent scientific health studies in the air pollution epidemiological literature is that increase in ambient concentrations of particulate matter under 10 mg (PM10) is associated with increase in the risk of premature mortality.

Once the links between emissions to human health effect have been established, the next stage requires assignment of economic (monetary) values to the predicted health effects. In the case of health effects, the monetarization approach should determine values according to individual stated preferences (willingness to pay). It has been argued that if people's preferences are a valid basis upon which to make judgments concerning changes in human well being, then it follows that changes in human mortality and morbidity should also be valued according to what individuals are willing to pay or willing to accept as compensation to forgo the changes in health status. The value of a statistical life (VOSL) is the value of a small change in the risks associated with an unnamed member of a large group dying. COI measures the total cost of illness that is imposed on the society. These costs include value of the lost productivity (loss in earnings) due to illness, medical costs such as hospital care, home health care, and medicine, as well as services of the doctors and nurses, and other related out-of-pocket expenditures.

We adopt the DRFs developed by Ostro (1994) and Rowe, (1995). The estimated health impact can be calculated by the following relationship:

$$dH_{ij} = a_{ij} \times POP_i \times dA_i$$

where,  $dH_{ij}$  is the change in population's risk of health impact  $i$  due to pollutant  $j$ ;  $a_{ij}$  is slope from the dose response curve for health impact  $i$  due to pollutant  $j$ ;  $POP_i$ , population at risk of health effect  $i$  and  $dA_j$  is the change in ambient concentration of air pollutant  $j$ .

DRFs is related to the information on changes in ambient air quality for different pollutants to different health outcomes. The principle is that changes in ambient air pollution levels for certain pollutants can be statistically related to observed changes in morbidity and mortality in a population. Since there are great variations in the coefficients estimated by the various studies, three alternative assumptions about health effects are presented with the central estimate being given the most weight. The high (low) end estimates are calculated by increase in (decreasing) the coefficient by one estimated standard deviation. For the estimation of percentage change in mortality, Ostro (1994) suggests use of 0.062, 0.096 and 0.13 as the lower, central and upper coefficient, respectively.

Following the DRF in following formula, the number of cases of premature mortality due to PM10 can then be expressed as:

$$\Delta \text{Mortality} = b \times PM_{10} \times 0.01 \times \text{Crude Mortality Rate} \times \text{POP}$$

where  $b$  is the mortality coefficient (0.062, 0.096 and 0.13 for lower, central and higher estimate, respectively) and POP is the population exposed to risk.

A similar approach is also used to estimate the effects of changes in air quality on air pollution-related illnesses. The increase in number of morbidity in terms of respiratory health admission (RHA), emergency room visits (ERV), restricted activity days (RAD), lower respiratory illness in children (LRI), asthma attacks, respiratory symptoms and chronic bronchitis can be estimated using the following formula:

$$\Delta \text{Morbidity} = C_i \times \text{POP} \times \Delta PM_{10}$$

where  $c_i$  is the morbidity coefficients for each discrete measure of morbidity effect and POP is the population exposed to risk.

In the recent years, environmental economists and policy makers have taken a lot of effort to estimate the value of change in the quality of the environment, and especially in reducing air pollution and its effect on the reduction of mortality in developing countries. One of these efforts is to estimate V.S.L. through income elasticity method. This elasticity, which Bowled and Beghin estimate to range from 1.52 to 2.269, can be expressed as part of the following formula:

$$VOSL_A = VOSL_B \times \left(\frac{Y_A}{Y_B}\right)^e$$

where  $VOSL_A$  and  $VOSL_B$  are the value of statistical life in two countries, and  $Y$  denotes the per capital income in each nation. The  $e$  term is the income elasticity of WTP. To provide a check on the validity of our previous V.S.L. estimates, we used this Bowland- Beghin along with our Iranian V.S.L. numbers, to infer the value of  $a$  for Iran. Assuming a US value of statistical life of \$5 million, PPP-adjusted per capital incomes to estimate the V.S.L. through this method, we used the simple concept of income elasticity in microeconomics. Using this method, it is possible to use the V.S.L. of other countries to determine the V.S.L. for Iran. When the V.S.L. of another country is used to estimate the V.S.L. of Iran, the effect of income should be considered in the estimation and the V.S.L. should be adjusted on that basis. In order to achieve more precision and care in this study, the researchers used three income elasticity values of 1, 1.5, and 2. If WTPA is kept constant, the elasticity of 1 will show a higher elasticity compared to 1.5. Similarly, the income elasticity of 1.5 demonstrates a higher elasticity compared to income elasticity of 2 for Iran. Therefore, the income elasticity of 1 is Upper Limit, the income elasticity of 2 is Lower Limit and the income elasticity of 1.5 is mid Limit.

In order to estimate the direct medical costs, sufficient values of general hospitals were selected. Then, all the files pertaining to the illnesses caused by air pollution were extracted. The required information were extracted from the files and registered in the prepared forms. This information included the number of the patient's file, age, sex, the costs of hoteling, cost of drugs, cost of physician, cost of surgery, cost of physiotherapy, cost of consumed materials, duration of hospitalization, type of insurance, job and the total expenditure. At the end, the mean of the total direct costs of each illness in every group of hospitals was estimated.

## Results and Discussion

A recent dust phenomenon cover in the South West and the West has adverse effects on human health. The most important effect is on mortality and diseases such as chronic bronchitis, asthma, and infections, and respiratory in children mild. The aim of this study was to estimate the number of premature mortality and morbidity and economic costs of the effects of particulate matter (pm10) in Khuzestan, Kermanshah and Kurdistan in 2010. These are calculated using the dose response, the value of statistical life and cost of illness methods. The paper adopts a three-step procedure to estimate the cost of particulate air pollution. Firstly, the ambient concentration of the pollutant, PM10, is determined. The second step involves the use of one increasingly accepted

methodology-the damage function approach using dose- response relationships- to estimate the health impacts of PM10 pollution. The health impacts considered here are the increase in mortality or morbidity. The last step then assigns economic (monetary) values to the increase in mortality and morbidity. The results show that about 2783, 752 and 370 of mortality (central estimate) in the province of Khuzestan, Kermanshah and Kurdistan PM10 in 2010 and also about 12 361 hospital admissions, 244,157 visits to emergency, 44534793 restricted activity days (days when the  $N=$  days, some but not all activities are normal-width), 446008 lower respiratory infections in children, 59751598 asthma attacks, and 63,047 chronic bronchitis, in the selected provinces can be attribute to air pollution. The total cost of mortality associated with particulate pollution PM10 is calculated using the statistical value of life method in the province of Khuzestan, Kermanshah and Kurdistan about 3506580000, 947520000 and 466200000 dollars, respectively. This is 0.8, 0.2 and 0.1 percent of Iran GDP, respectively. Using the money blood, this is estimated about 100,000, 20,715 and 10,332 dollars, respectively. Direct medical costs of disease, asthma, chronic bronchitis and lower respiratory infections in children associated with particulate pollution PM10 is calculated in selected provinces in 2010, 35 645, 37 and 266 billion dollars (central estimate) and the average opportunity cost per patient (during hospital stay) is calculated about 85775 dollars.

According to increase in the importance of air pollution of dust particles and adverse effects on human health and the need to estimate the health damage caused by this phenomenon, it is essential to identify the importance and necessity of this phenomenon. It must be admitted that this requires detailed knowledge and resources to the release of particulate matter. One of the major problems in this area is prevention and finding the causes changes in air pollution and also predicted pollution-reducing factors.

**Keywords:** air pollution, cost of illness, dose-response function, health effects, value of statistical life.

## City for Urban Development Land Use

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### Expanded Abstract

#### Introduction

In order to achieve sustainable development, it is necessary to obtain and adopt planning procedures based on Multi Criteria Evaluation of natural environment. Since biophysical (natural) environment has limited ecological capabilities for human use, ecological capability assessment, as a fundamental for environmental studies and with the aim of preventing existing crises, yields proper bases for environmental planning. The analysis of land capability and sufficiency for urban development is one of the main categories with which urban planners are dealing.

In administrative divisions of Iran, Yasuj city is center of Kohgiluyeh and Boyerahmad. It is located in the eastern part of the province and in the Zagros Mountains in cold weather conditions. The area is limited from the north to Esfahan Province, from south and east to the Fars Province and from the west and south west to the cities of Gachsaran and Dehdasht. Yasuj population were up to 931, 4524, 29,991, 69,133, 100,544, and 108,505 people in the years 1966, 1976, 1986, 1996, 2006, and 2011, respectively. Undoubtedly among all cities of Kohgiluyeh and Boyerahmad, Yasuj is the only city with increase in concentrations of various services. It is due to the special characteristics such as the political and administrative center of the province, the establishment of institutions and government agencies, and enjoyment of the services and facilities more than other cities and towns and villages. Yet, it has a high population growth. Therefore, the optimal plan based on scientific principles and standards of ecological estimation of land for urban development can be minimized or even prevented in the future prospects of future problems.

#### Materials and Methods

The study area of this research is 127.6 square kilometers at 1:100,000 scale. After detecting the ecological resources of the area (scale 1: 100000) the obtained data were entered into ArcGIS application. Since implementation and applicability of urban land use require to have synchronized evaluation of numerous criteria or variables, the study employed spatial multi criteria evaluation method (SMCEM). Therefore, the initial attempts are focused on preparation and standardization of the criteria. Fuzzy expert system and linear functions were used for the purpose of the study. To analyze land suitability for development of the expected application, Weighted Linear Combination (WLC) method was used and then by combining the layers of information and analysis on fuzzy evaluation software it was possible to prepare the ecologically relevant maps. Sustainable and unsustainable resources were identified in a research scale. The criteria and variables were also identified for suitability evaluation of Yasuj City for implementation urban land use development. The required data were obtained through twenty-one layers as criteria maps for spatial evaluation of the implementation urban land use development.

#### Analytic Hierarchy Process (AHP)

In this research, each criterion or sub criterion was weighted using pairwise comparison method to select the preferred criteria. The preference value table of the Saaty is used. To ease the calculation of the weights in purpose of preference degrees and hierarchies, the Expert Choice software was used. The operations of AHP, the weights are evaluated with acceptable CR. The CR ratio is less than 0.1 can just be accepted. Remarkably, in this study, the number of CR is 0.06, respectively. This represents the acceptable result. Weights were calculated by the method of integrated layers with WLC.

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### Weighted Linear Combination (WLC)

Weighted Linear Combination (WLC) technique was applied to select the best option (site), according to criteria evaluation method. The site which obtained the highest score is identified as the most suitable site or class. In this method, the value of each criterion is calculated by the following equation:

$$A_i = \sum_j W_j X_{ij}$$

where  $X_{ij}$  is the value of  $i$  alternative towards  $j$  criterion. This is a standardized weight as aggregation of all weights is equal to one ( $\sum W_j = 1$ ). The calculated weights showed the relative importance of each criterion and preferred alternative is selected by defining maximum value of  $A_i$  ( $i = 1, 2, 3, \dots, n$ ). This is to apply the weighted linear combination (WLC) method.

Finally, Standard raster layers of all factors were multiplied by all the three physicochemical, biological and socio - economic weights derived from AHP.

$$\text{Result: } W_1 S_1 + W_2 S_2 + \dots + W_i S_i$$

$$W_i = \text{Weight Layer} \quad S_i = \text{Layer standard}$$

Then, layers of standardized weight criteria were evaluated for Multi-criteria evaluation analysis by GIS. This was to achieve the overall assessment rating based on the proposed mathematical model and order Fuzzy Overlay.

Urban Land Use =  $([\text{Slop 01}] \times 0.263) + ([\text{Land Use 01}] \times 0.162) + ([\text{Quantity Water 01}] \times 0.150) + ([\text{Soil Type 01}] \times 0.089) + ([\text{hypso 01}] \times 0.072) + ([\text{Surface Water 01}] \times 0.05) + ([\text{Vegetation Density 01}] \times 0.05) + ([\text{aspect 01}] \times 0.041) + ([\text{Bed rock 01}] \times 0.031) + ([\text{Wind power 01}] \times 0.021) + ([\text{Vegetation type 01}] \times 0.016) + ([\text{Fault 01}] \times 0.014) + ([\text{Depth 01}] \times 0.013) + ([\text{Geo 01}] \times 0.011) + ([\text{Forest 01}] \times 0.008) + ([\text{Rain 01}] \times 0.005) + ([\text{Agriculture 01}] \times 0.005) + ([\text{temperature 01}] \times 0.003) + ([\text{River 01}] \times 0.003) + ([\text{Airport 01}] \times 0.001) + ([\text{Indst complex 01}] \times 0.001)$

### Results and Discussion

Final classification map of the evaluation of ecological capability on Yasuj City for urban land use development in this study shows that a total of 12736 hectare about 3541 acres in the study area has high potential and 5153 acres has good potential, 1678 hectares of medium power and 1,898 acres low power and 466 acres of the study area is very weak for the purpose. Table 1 shows ecological potential classes of Yasuj City for the urban land use plan.

Table 1. ecological potential classes of Yasuj City

Area (square kilometers)	Area (hectare)	potential classes
35414807.14	3541	high
51528911.01	5153	Good
16782526.77	1678	Medium
18976520.63	1898	Low
4660145.622	466	very weak
127362911.2	12736	Total

### Conclusion

The results of the study indicated that Yasuj City from east and south and south west are limited to natural constraints such as Zagros Mountains of high slope land and dense oak forests. By conducting WLC model, the suitable directions are found. The suitable areas obtained by map are in conformity with the present realities based on field evidences. Limiting factors such as the Zagros heights, high slope, oak mass forests, fault, agricultural lands, and rivers prevent urban development. The final map shows regions suitable for physical urban development of the city. The results and findings of this research can be applied by urban planners and managers.

**Keywords:** evaluation of ecological capability, geographical information system, spatial multi criteria evaluation method, urban development, Yasuj City.

## Urban Green Infrastructure Assessment for Their Regeneration in Tehran Landscape

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### Introduction

The term “Green infrastructure” describes the abundance and distribution of natural features providing ecological services necessary for community wellbeing especially in urban areas where these services are limited. Green infrastructure is increasingly mixed by landscape conservation and metropolitan planning because it is an effective way to surrogate ecological network functions where landscapes are highly impacted by anthropogenic changes.

In this study structural characteristic of open and green patch network called green infrastructure was central in deciding urban management strategies because of their life support services. Finally, applicable strategies have been presented for a gradual regeneration according to the intensity and extent of degradation in these patches and other natural elements faced in each urban district. Decision making regarding selection of each strategy and priorities are estimated in correlation to the current condition of green infrastructure as well as the speed of alteration they are experiencing in Tehran (with very rapid change or alteration).

### Materials and Methods

City of Tehran, with 730 km<sup>2</sup> area is located in the southern slope of Alborz Mountains and Northern margins of central desert of Iran, and has 22 urban districts. Tehran urban landscape structure, viability and environment have incredible speed of fluctuations in time and in space. This pace of change forced us to focus on conservative policies and protection of natural conditions, in order to prevent landscape structure destruction before any other objective (for rehabilitation).

The method used in this study is based on structure - function interdependency and basic concepts of landscape ecology such as patch features are considered to evaluate the degree of fragmentation and connectivity of green infrastructure network at the landscape scale with its alteration speed.

In order to present optimized ecological services and effective function at the scale of urban landscape, these infrastructures are required to have sufficient presence, high stability with appropriate composition and configuration regarding their spatial distribution. Therefore, landscape metrics were used to evaluate these features of green infrastructure quantitatively. Selected metrics regarding evaluation of composition and configuration of landscape elements related to our research goal were selected to be PD, MPS, MNND and CAP. Their quantities were then used at landscape and patch type levels as finding for discussions and conclusion.

### Results and Discussion

Landsat satellite image was used for derivation of land cover information and then landscape metrics were estimated based on time series of land cover maps (Fig. 1 and 2). Structural analysis of the current conditions of greenspace: Districts in the north of Tehran specially district one and three had better conditions in terms of many parameters (like presence of green patches, their stability and distribution) rather than the other ones. In turn, central districts specially districts 10 and 17 and also those located from center to east and west had inappropriate conditions in terms of most metrics. The presence of green patches in these districts was very low, and the patches were fine grain with low stability.

Structural analysis of the current conditions of open space: In terms of open space of Tehran, it can be noted

that in the districts located on the west edge like districts 19 and 22 and specially 22, the condition of the patches was better than others. The result showed highly presence and stability of large open patches in these areas. Nevertheless, the conditions of open patches distributions in these districts were low and the north districts had better distribution of open patches. In turn, conditions of open patches in central districts especially 10, 17 and also 8 in northeast were inappropriate and presence of open patches of fine with low stability and relatively inappropriate distribution were observed.

**Total analysis of changes in Tehran green space (2003-2013):** In green space of Tehran, during the studied period, the process of all metrics changes except CAP was similar in all districts such that MNND and MPS have decreased and PD has increased in all the districts. Therefore, it can be stated that decrease of the patch size and their fine size has decreased their stabilities in all districts. Despite of MNND decrease in all districts which shows a relatively high connectivity among green patches, this change cannot be considered as a positive one as regarding to PD and MPS changes, it can be stated that green patches have been fragmented. CAP of green patches had been increased in 12 districts and decreased in 6 districts. This trend was constant in four districts.

**Total analysis of changes in open space of Tehran (2003 -2013):** During the studied time, in terms of open space metrics, CAP has decreased in all districts except districts 7, 12 and 14. PD had been increased in most districts and constant in some ones. MPS and MNND had been decreased in all districts. Regarding to the process of open patches changes, it can be noted that open patches have had a destructive process (decrease presence and stability of open patches) in most districts. The trend of PD and MNND changes also showed the fragmentation of open patches in Tehran.

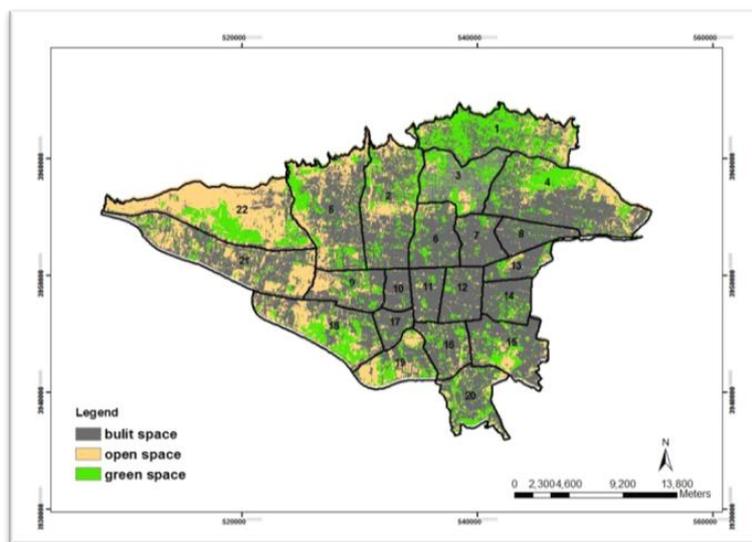


Fig. 1. Classified image of study area in 2003

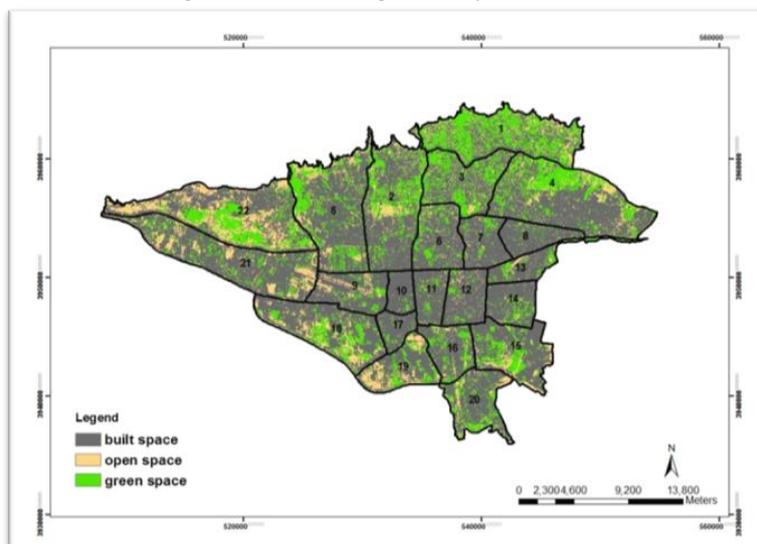


Fig. 2. Classified image of study area in 2013

### Planning Strategies:

- Protective strategy: where the existing landscape supports sustainable process and patterns, a protective strategy should be employed (even along with defensive strategy in some cases suffering a regressive tendency). This strategy can be recommended for greenspace protection in the districts located in north, west and southwestern parts of Tehran and for open space protection, northern and northwestern districts are also prioritized.
- Rehabilitation strategy: where the existing landscape is disturbed and fragmented, such as those districts of northern and southwestern Tehran. These should have rehabilitation of natural elements as priority task.
- Development (offensive) strategy: this is to be recommended for those urban districts with a low presence of green and open patch as well as with low connectedness. The districts located in south, east and central parts of Tehran are required to develop greenspace.
- Defensive strategy: this was most needed in the districts where these contain valuable natural elements (such as north and west of Tehran) that provide desire function. Utilization strategy can be employed for these districts but defensive attitudes are needed to sustain the present situation.

### Conclusion

Findings show that the main problem of green infrastructural network in Tehran may be its uneven distribution, with low connectivity and almost non-existing in the central city matrix. This along with the much reduced natural matrix connectivity has created an unsustainable urban texture with very low livability and polluted atmosphere.

It can be noted that in terms of green space, expansion of the area has been the only plan with no consideration regarding advantageous use of all natural spaces of Tehran at micro up to macro scale planning. Hence, a better configuration of natural patches with connectedness to each other (specially to 9 river valleys and the row of hills crossing them in perpendicular) should be also part of a comprehensive green structural renovation and development strategy for the future of Tehran.

In order to overcome landscape structural degradation, a strategic perspective is needed to be based on pattern-process principles and to be implemented based on landscape linking concepts. This planning may well follow the strategic perspectives found by this research. The strategy is also based on several years of research by others along with frequent revisions. Added value of all these efforts is presented here by our final completion looking for a comprehensive synthesis.

**Keywords:** land cover change, landscape ecology, landscape metrics, urban green infrastructure.

## Design of Elder Sanatorium Based on Healing Landscape, Case Study: Baraki Sanatorium of Borujerd

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### Introduction

Elderly is a period of human life cycle when men need especial health and spiritual care in the aging. Elder sanatorium is one of care providers introduced for aging people nursery and accommodation. Elder sanatoriums are symbols of aging people isolation in Iran. It is reflect of society tendency to ostracize this class of society. Loneliness, boredom, frustration and helpless are imposed to sanatorium residents. Some of conditions are created due to unsuitable environmental characteristics. Elder sanatoriums could be improved by application of environmental design principles and solutions. Environmental design is able to enhance the sanatoriums location and reduce improper circumstances. Healing landscape approach is the main strategy for environmental design in such sites. Healing landscape applied different elements and natural features to enrich the landscape in such manner that can contribute to improvement of physical and mental health. Natural views, pleasure aroma, song and sound of nature, fresh air, colorizing landscape by natural plants are some of natural elements and features that could be effective in reduction of stress and enhance people health. The article tried to design an elder sanatorium based on healing approach. It tried to prepare a comfort and favorable place which aging people experience a quality of life inside the sanatorium.

Healing approach discussed here from three view stands of point:

- Providing nature landscape or naturalism strategy;
- Horticultural therapy;
- Aromatherapy.

Natural landscape views have positive impact on improving the patient's physical and psychological diseases. Positive effects are realized through four statuses: 1- avoiding daily stress and anxiety, 2- Natural landscape is favor of men, 3- perception of naturalness and feeling freedom, 4- participatory actions in nature and concentration on favor of natural features by any person.

Horticultural therapy is set of patients' participation in gardening and related activities in order to help acceleration of patient healing process. It accelerate healing process through: 1. Adoptability of such activities with patient ability, 2. They could do this in different places from normal therapeutic spaces , 3- Normally patients are interested in undertaking such kind of activities.

Aromatherapy is a third aspect of healing landscape. It is a branch of herbal medicine. The art of aromatherapy is use of herbal perfume, oils and pharmaceutical essences through massage and inhalation for the treatment of diseases. Use of natural fragrant flower in healing landscape is an especial dimension of aromatherapy. It is common method in depress treatment.

### Materials and Methods

#### Study area

This study has been done in the Brakati Sanatorium. The Brakati Sanatorium is one of elder care center in the Borujerd. Borujerd is center of Borujerd County in Lorestan province in west part of Iran. Borujerd City had population about 245737 people in 2012. The elder population is about 13123 people. The Brakati Sanatorium located in Shaikh Miri Village nearby the city. The sanitarium area is about 1500 square meters including two main parts: about 30 percent of the area is allocated to buildings and remained areas are open spaces.

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### Method

The article is composed of two parts: First part includes selected approaches, and the second is related to the study area. Two main approaches are selected to create a healing landscape. The first approach is naturalism and the second is horticultural approach. Concentration of the first approach is on creation of natural landscape in order to generate relationship between elders and nature (Table 1).

**Table 1. Naturalism approach solutions for healing landscape**

Solution	Effect on health
Diversity and heterogeneity	Increase in concentration power Increase in elders right of selection
Planting colored flowers	Increase in concentration power and heart rate
Planting herbs with medical benefits	Use of treatment characteristics
Create natural sounds	Reduction in noise pollution and relaxation and reduction of stress
Water effects in different forms	Positive impact on heart rate Decrease in anger, fear, and heartbeat possibility

Second approach emphasize on physical activities in form light garden actions to increase and improve physical power of elders. Gardening aspects are important in healing landscape design for elders. Different solutions is applied in healing landscape design (Table 2)

**Table 2. Design solutions based on horticulture approach in healing landscape**

Landscape design solution	Effects on health
Use of private croft	Increase in physical movement, Physiotherapy and socializing
Use high gardens	Increase in physical movement of disable people Creation of sense of usefulness for elders and disable people
Use of fruit plant	This creates sense of usefulness after work
Use of fragrant plant	factory stimulation, relaxation and reduction of stress
Create natural sounds	Positive impacts on heart rate, sedation
Colored Flowers	Increase in concentration power
Non-use of poisonous plants	Risk of poisoning

Design comprises the indoor and outdoor spaces. Based on these three approaches, the first for study of area, field survey has been done. Then, an interview is performed with residents and personnel of the sanatorium in order to identify the facility of changes in area and primary assessment of the elders. Then, the area was analyzed based on filed survey, assessment and also aerial photos. Indoor and outdoor spatial relationship is identified and reorganized. Challenges and problems of status quo are revealed and simultaneously facilities and capabilities are identified. Healing landscape solutions are categorized into two main groups: 1. Naturalism approach, 2. Horticultural approach. Finally, design concept is prepared and finalized based on site analysis. Final design is tried to complete interaction of elements and spaces in order to realize healing landscape for elders.

### Results and Discussion

In the first step, problems of space organization were identified. Elder room was located in isolation arrangement with limited view on walls. The existing plants are restricted to *rosa*, *Turf grass*, *moros alba* and *Salix babilonica* that planted uniform. The interviews showed that the planted area has not any attraction for residents and they have no relationship with open spaces and its landscape. While the relationship between people and landscape is an important part of such spaces and it has vital role in diseases treatment and elder people health.

In the first step rooms' reconfiguration should be done. The organization of sanatorium is corrected and new configuration of rooms and spaces are presented. The new arrangement prepares a view to open space. More ever, environment entered into the rooms can add some natural elements and features like natural flower vases in interior spaces.

### Landscape Design

All design solutions are presented for better quality of life and enhancement of living conditions based on healing landscape concept. Development strategies are used from geometric forms. All steps between spaces are omitted. It will facilitate elder movements in all corners of sites. The height differentiation is about 60

centimeters along the site. The calculated slope is about 1% to strengthen the space relationship and people movements. All other movement barriers are removed and path and pedestrians are floored by flexible Rubber Flooring. Water fountain and streams are added to the site to enhance the sense of naturalness. Some experimental gardens are also designed nearby the residential rooms to increase easy access.

A variety of plants and trees are also introduced to the site. Combination of cherries, red maple and eucalyptus are emphasized. Planting shrubs composition of lavender, Rosa and elder are rarified in irregular forms to make the landscape closer to the natural. The floor is covered by Lawn and spearm in edge. Some significant plant species have been preserved in the area.

### **Conclusion**

The high percent of Iranian population will be in aging in the near future. These parts of population need suitable elder sanatoriums. Thus, a healing landscape concept is a necessary approach to make such spaces as appropriate place. Barekati Sanatorium is designed based on this concept and emphasize on two naturalism and horticulture strategies and solutions. Naturalness is brought into the site and interior spaces for enrichment of living elder places and enhancement of elders' health. The study of elder behavior could help design more accurate and effective spaces.

**Keywords:** Borujerd, elder sanatorium, environmental design, healing landscape.

## Remediation of Petroleum Contaminated Soils in Urban Areas Using Thermal Desorption

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### Expanded Abstract

#### Introduction

Growing use of hydrocarbon constituents in various industries have generated significant quantities of hazardous wastes which lead to environmental pollution. In the recent years, strong global demands for fossil fuels and industrial chemicals have resulted in release of some of these compounds into soil, water and air. Hydrocarbon-contaminated soils are among the important environmental issues which could be present around refineries, fuel stations, pipelines and storage tanks. Selection of an effective solution to purify the contaminated sites depends on several factors depending on soil conditions and pollutant concentrations. Thus, this process of cleanup requires one or more treatment techniques for purification of such sites. In general, contaminated sites remediation methods can be classified as in situ or ex situ types. Several technologies, such as chemical oxidation, biostimulation and bioaugmentation, or electrokinetic oxidation can be used for the treatment of these specific polluted sites. Therefore, many different technologies have been developed for remediation of the contaminated soils: biological treatment, soil washing with surfactants, air stripping, thermal desorption, incineration, and etc. Among the various processes, thermal desorption is a very attractive one because it can promptly treat the contaminated soils with high efficiency, regardless of their chemical species. They are the most popular and versatile due to their removal efficiency, cost, and required time. According to their treatment temperatures, treatments can be classified as low-temperature (100–350°C) and high-temperature (350–600°C) thermal desorption, involving the physical separation of contaminants from the soil, and thermal destruction (600–1000°C), involving the chemical modification of contaminants.

In this study, soil samples were collected from Baghershahr contaminated area in south part of Tehran, adjacent to Tehran oil refinery. The soil in the area is polluted with different hazardous hydrocarbons due to the leaching of the refinery. LTTD remediation method was evaluated for decontamination of the soil of this area. To assess the temperature and residence time on removal efficiency of gasoline from the contaminated soil, LTTD was conducted on temperature of 90, 110, and 150°C and residence time of 10, 20 and 25 minutes.

#### Materials and Methods

Soil sampling was carried out at the vicinity of Tehran oil refinery area. Samples were collected from 10-30 cm depths of the ground surface and placed in glass jars. After transferring the samples to the laboratory, tests were performed to determine the moisture content and geotechnical properties of the samples such as soil texture, Atterberg's limits, soil classification and the amount of organic matter. The EPA and ASTM methods were applied to test the samples.

Due to low concentrations of hydrocarbons in the soil, the samples were spiked with gasoline at two concentrations of 4000 and 10000 ppm. The spiking of the samples was carried out to acquire more clear results regarding the performance of LTTD experiments. Low temperature thermal desorption experiments were performed in a reaction glass. Moreover, two thermometers were used to measure temperatures inside the chamber and the exhaust gas. A condenser was also connected to reaction glass to get liquidity the generated vapors during the test.

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In order to investigate the effects of temperature and residence times on the removals of contaminants, the experiments were performed at different temperatures of 90, 110, 150°C and at three residence times of 10, 20 and 25 minutes. A gas chromatography with Flame Ionization Detector (GC-FID) instrument was used for analyzing the gasoline concentration.

## Results and Discussion

### Moisture content

The solids processing capacity of a thermal desorption system is inversely proportional to the moisture content of the feed material. The presence of moisture in the excavated soils to be treated in the LTTD unit will determine the residence time required and heating requirements for effective removal of contaminants. In order to do desorption of petroleum constituents to occur, most of the soil moisture must be evaporated in the desorber. This process may require significant additional thermal input to the desorber and excessive residence time for the soil in the desorber. In many LTTD studies conducted on the petroleum contaminated soils, the optimum ranges of moisture contents were between 10% and 20% (W/W). In this study, however, the moisture content of the soil was measured to be 15%.

The effects of operating parameters were investigated for the thermal treatment of petroleum contaminated soils in a desorber. Batch operation result shows that achieving the significant efficiency depends on temperature and residence time.

### Removal efficiency

The minimum removal efficiency achieved for the soils with the 10000 ppm contaminants was 70.1% at the residence time of 10 minutes and temperature of 90 ° C. Nevertheless, regarding the 10000 ppm samples, the maximum removal efficiency of 87% was achieved for the samples at residence time of 25 minutes and temperature of 150°C. Likewise, for 4000 ppm gasoline concentration soil samples, Maximum and minimum removal efficiencies were 80% and 94.45%, respectively. The overall results indicate that LTTD method is an appropriate remediation method for hydrocarbon contaminated sites.

### Temperature

In this study, temperature effect on the low temperature thermal desorption was evaluated. Treatment temperature is a key parameter affecting the degree of treatment of organic components. The required treatment temperature depends upon the specific types of petroleum contamination in the soil. The recommended treatment temperatures for various petroleum products and the operating temperature are in the range of boiling point of the chemicals. The actual temperature achieved by an LTTD system is a function of the moisture content and heat capacity of the soil, soil particle size, and the heat transfer and mixing characteristics of the thermal desorber. The results indicate that more significant removal efficiencies of removing gasoline from contaminated soil samples will be achieved as the temperature increased. For instance, as temperature increased from 110 to 150 °C in 4000 ppm gasoline contaminated sample and resident time of 25 minutes, the removal efficiencies are also increased from 90.3% to 93.4%.

### Residence time

To demonstrate the effects of residence time on removal of gasoil from soil, experiments were conducted in 10, 20, and 25 residence times. This is a key parameter affecting the degree to which decontamination is achievable. Residence time depends upon the design and operation of the system, characteristics of the contaminants and the soil, and the degree of treatment required. Moreover, the removals of contaminants from the samples are increased by increasing heating residence times. The maximum LTTD removal efficiency of 94.5% occurred in a time period between 20 to 25 minutes (i.e. 23 minutes) for the samples with 4000 ppm concentration. This is considered as optimum time for this concentration. Nevertheless, greater residence time is essential for decontamination of contaminated soil with concentration of 10000 ppm of gasoline.

### Conclusion

For sites with petroleum contaminated soils, the primary concern is to reduce the residual concentration of the organic constituents to or below regulatory levels. This criterion applies to both the soil surrounding the excavation and the soil excavated and thermally treated. The results of this study indicate that LTTD remediation method is capable of gasoline contaminated soil removal with efficiency of greater than 90%.

The results of LTTD tests also indicated that the increase in temperature from 90 to 110 and 150 °C can also increase the gasoline removal efficiencies. Furthermore, as residence time of process is increased, the removal efficiencies of gasoline from soil are also increased. For instance, removal efficiency increased from 71% to 82.5% for 4000 ppm contaminated samples as the residence times increased from 10 minutes to 25 minutes. The

data obtained from the low temperature thermal desorption experiments indicate that the higher removal efficiencies of volatile gasoline hydrocarbons in soils with concentrations of 10000 ppm will be achieved at residence times and temperature above 25 minutes and 150 °C.

**Keywords:** gasoline leakage, Low Temperature Thermal Desorption (LTTD), petroleum hydrocarbon, soil pollution.

## Evaluation of Soil Potential of Urmia Landfill as Cadmium (Cd) Absorbent Liner in Construction of Engineering-Health Landfill

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### Introduction

One concern in the disposal of municipal solid waste (MSW) by landfill is production of leachate. Acidic water is capable of dissolving elements from the waste; and, as a result, the leachate can become quite contaminated. As one of the heavy metals present in leachate, cadmium poses a great concern in terms of environmental contamination since it is toxic to nearly all living organisms and cannot be used in any biological functions. Clay liners are used to contain contaminants such as heavy metals present in leachate from landfill sites containing MSW. In this study, the chemical and physical characteristics of soils of Urmia City landfill site in Nazloo region were examined to evaluate their cadmium sorption potential.

### Materials and Methods

Surface soil samples (0-30 cm) were collected from around Urmia landfill soils. Soil physical and chemical properties were determined using standard methods. The pH was determined using a 1:2.5 soil to 0.01 M CaCl<sub>2</sub> suspension and a glass electrode. Electrical conductivity was determined in saturated extracts of the soils. Particle size distribution was measured by the hydrometer method. Total soil carbonates expressed as calcium carbonate equivalent (CCE) were determined by a rapid titration method. Organic carbon was determined by wet digestion. Cation exchange capacity (CEC) of the soils was determined by the 1 M NaOAc (pH 8.2) methods. Sorption isotherms were obtained using the batch equilibrium method. Soils of 1 g were separately equilibrated in the tubes containing 20 ml of different concentrations of Cd: 2.5-40 mg l<sup>-1</sup> by dissolving Cd (NO<sub>3</sub>)<sub>2</sub> in 0.01M CaCl<sub>2</sub> as background electrolyte solution. The samples were equilibrated on an end-over-end shaker for 24 h, followed by centrifugation; filtration and Cd concentrations were determined using Shimadzu 6300 atomic absorption spectrophotometer. The Langmuir and Freundlich one-surface sorption equations were applied to describe the reaction of Cd with soil. The desorption experiment was carried out by adding additional 0.01M CaCl<sub>2</sub> solution as a background solution to the soil remaining in the centrifuge tubes and maintaining the total amount of the solution exactly at 20 ml. Then, the desorbed solutions were centrifuged, decanted and analyzed. The Langmuir and Freundlich models, applicable to heavy metals sorption processes, were used to determine the sorption capacity of different soils. The equations used were:

$$Q = \frac{(C_0 - C_e) \times V_{sol}}{M_s} \quad (1)$$

where C<sub>0</sub>= the initial concentration of Cd<sup>+2</sup>(mg/l), V<sub>sol</sub>= the volume of the solution (L) and M<sub>s</sub>= the soil mass (g). The Freundlich and Langmuir isotherm equations are adopted as expressed by Eq. (2 & 3).

$$Q = K_f C_e^{\frac{1}{n}} \quad (2)$$

$$Q = \frac{bKC_e}{1 + KC_e} \quad (3)$$

where, K<sub>f</sub> (Sorption capacity or distribution coefficient) and n (Intensity Sorption) are the Freundlich sorption parameters and K (Bonding Energy) and b (Maximum Sorption) are Langmuir parameters adjusted to fit Eq. (2 & 3) to the experimental data.

## Results and Discussion

### Chemical and mechanical characteristics of soil samples

Soil properties are given in table 1. There is a direct relationship between content of clay and CEC in soils. Also the  $\text{CaCO}_3$  observed in soil number 1 has a noticeable difference in comparison with other soils (2 & 3). Calcium carbonate is one of the important factors in sorption of heavy metals. It can directly influence sorption of these metals, so increase in amount of  $\text{CaCO}_3$  lead to enhancement sorption of Cd.

**Table 1. Some of chemical properties of the soil samples**

Sample	Sand %	Silt	Clay	OM	CCE	pH 0.01M $\text{CaCl}_2$	EC $\text{dSm}^{-1}$	CEC $\text{cmolckg}^{-1}$	Soil texture
1	1.12	55	43.9	0.26	16.7	7.17	5.6	29	Silty Clay
2	69.2	11.3	19.2	0.68	3.64	7.53	0.67	18	Sandy loam
3	50.8	20	29.2	1.17	4.68	6.56	1.11	19	Sandy Clay Loam

The materials most commonly used for compacted clay liner construction are natural cohesive soils. The soil may be used in fine liner, total pore volume and porosity turns more and more surface area to adsorb. The term compacted clay liner (CCL) is used for all mineral liners which predominantly consist of fine grained soils like clays, silty clays and clayey silts. Soils with more than 20 percent of clay are used for construction of engineering-sanitary landfill liner (Table 2).

**Table 2. Mechanical properties of the soil samples**

Sample Code	1	2	3
Liquid limit ( $W_L$ )	30.9	22.5	25.3
Plastic limit ( $W_p$ )	15.8	14	14.5
Plastic Index (PI)	15.1	8.5	10.8
Specific density ( $G_s$ )	2.73	3.01	2.89
Maximum dry density ( $\gamma_{d_{max}}$ ) ( $\text{Kg/m}^3$ )	1882	1841	17.91
Optimum moisture content ( $\omega_{opt}$ ) (%)	14.2	17	16

Based on the results of the test, the samples 1 and 3 have about Aterbrg plasticity index over 10. According to Environment Agency standards, plasticity index of the clay liner should be between 10 and 65 units. Standard Proctor test results on soil samples showed that soil 1 has significant difference with in soil 2 and 3 in the maximum dry density and moisture content. The difference is evident in the density plots. Assessed in terms of compaction to soil moisture content, soil 1 has the highest density at optimum moisture content to less than soils 2 and 3. This means that in soil 1, to achieve the maximum density of water, it is to build more affordable liner.

### Cadmium adsorption characteristics

Adsorption isotherm diagram is shown in Figure 1. The results indicated that the adsorption curve of soil 1, due to the high adsorption capacity, appears to be linear. This suggests that adsorption sites of soil 1, with a maximum concentration of cadmium (40 mg/L of soil solution using a ratio of 1:20) in the adsorption isotherm tests are as half full and not completely occurring. It also indicated that with increase in the cadmium concentration, adsorption in the sites will also be blank. While adsorption sites of 2 and 3 soils are immediately filled, and precipitation of cadmium were also absorbed on surface particles. To evaluate the intensity and the amount of absorbed cadmium concentration in soil adsorption data of 2 and 3, Sigma Plot v12 software were fitted using the Langmuir and Freundlich nonlinear equations. Freundlich and Langmuir adsorption equation parameters are shown in Table 3.

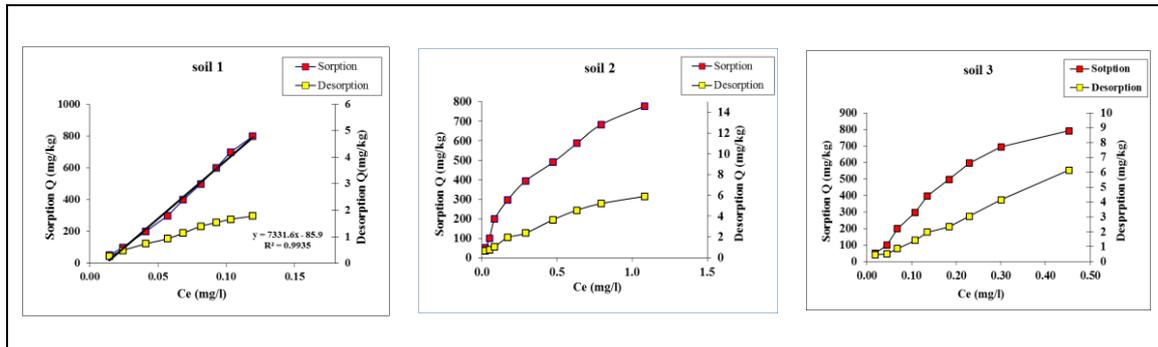


Fig. 1. Adsorption isotherms of soils

Table 3. Freundlich and Langmuir adsorption parameters

Samples	Langmuir adsorption parameters				Freundlich adsorption parameters			
	K	b	SE	R <sup>2</sup>	K <sub>f</sub>	n	SE	R <sup>2</sup>
1								
					a	b	SE	R <sup>2</sup>
					85.9	7331	12.5	0.994
2	1.90	1121	25.76	0.992	764.2	1.73	25.15	0.993
3	2.30	1623	31.5	0.988	1501.4	1.43	51.40	0.969

The regression coefficient equations, Freundlich model, and Langmuir adsorption data indicated good fit disruption; But Freundlich compared with Langmuir model was more uniform. Slope steep and linear soil 1 indicates a high degree of absorption and the absorption maximum, the maximum amount of soil 2 and 3, and also the concentrations of these results. Desorption of cadmium levels in soils 2 and 3 is almost 3 times the amount of desorption in soil 1. This process of absorbing and filtering pollutants by soil particles is considered as a strong point. Therefore, soil 1 has been increased in the amount of sorption, and on the other hand, reduced in the amount of cadmium desorption. Consequently, due to the high potential for soil 1, the absorption and desorption of cadmium decreases as the soil was suitable for use in the construction of clay liners.

**Conclusion**

The main objective of this study was to evaluate and select a suitable soil for the construction of clay liners. To this end, the parameters of cadmium absorption on sorption surface of soils in Urmia landfill, and their relationship with the engineering properties of soils were studied. Maximum absorption of cadmium in soil 1, due to high clay content, pH, CEC, CaCO<sub>3</sub>, and great places absorption surface than other soils were higher. Furthermore, desorption of cadmium in soil 1, compared to the other soils, show that the minimum amount is an important factor in evaluation of the facility. Also, based on the mechanical properties of the soil, being fine aggregate, dry the high density, low moisture optimization, and plasticity index above 10 percent, the soil 1 is the better option to use a liner.

**Keywords:** clay minerals, isotherms of cadmium, landfill, surface adsorption.

## Evaluation of Bioavailability, Mobility and Speciation of Heavy Metals in Dredged Sediments of Anzali Wetland

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### Expanded Abstract

#### Introduction

A large volume of sediments are dredged from water bodies such as ports, waterways and wetlands to be deposited on land. Sediments are typically polluted by contaminants such as heavy metals. Metals in the sediments are in soluble, carbonate bound, Fe-Mn oxide, sulfide/organic matter bound and residual fractions. The metal solubility and mobility are mainly controlled by organic matter content, clay minerals, pH and redox potential. In exposure to air, the metals are released from loosely bound fractions and become available. One impact of dredging and on-land deposition of the sediments is metal release enhancing their bioavailability and mobility. After the sediments are deposited, plants start to grow; thus, metals can be up-taken by the plants and become further available to the food chain. In case of human contact, there is a potential for direct accessibility of the metals. Besides, long term leachability of the metals can contaminate surface and ground water. According to former investigations, the mobility, availability and toxicity of the metals cannot be assessed based on their total contents, and those are usually controlled by their chemical forms. The metal speciation can be determined by sequential extraction procedures and various single extraction methods can be used to evaluate their bioavailability and mobility. Other authors have studied metal leachability, bioavailability, bioaccessibility and speciation using various methods.

#### Study area

The Anzali International wetland was registered in the Ramsar Convention in 1975. It covers an area of 193 km<sup>2</sup>, located at the southwest coast of the Caspian Sea, in Guilan, Iran. Due to the excessive discharge of different contaminants such as heavy metals, most of which are carried by rivers into the wetland. Thus, bed sediments have become a sink for the metals. The Pasikhan River is one of the most polluted rivers leading into the south east zone of Anzali Wetland. A sediment trap is placed on the entry of the river. The sediments are being dredged and deposited in places adjacent to the trap; exposing to air, heavy metals might be released from soluble and bioavailable phases.

#### Material and Methods

Sampling was carried out after dredged sediments were deposited in the area for four months. pH of sediments, the solid density, grain-size distributions, moisture content, Atterberg limits, mineralogical composition, major elements and total metal contents were determined. A sequential extraction procedure was applied for metal speciation. The detailed scheme for 1 g sample is as follows:

Table 1. Sequential extraction procedure

Step	Fraction	Reagent	Experimental conditions
F1	Exchangeable	10 ml of 1 molL <sup>-1</sup> MgCl <sub>2</sub>	Room temp, 1h, shaking
F2	Carbonate	10 ml of 1 molL <sup>-1</sup> NaOAc	Room temp, 5h, shaking
F3	Fe-Mn oxide	20 ml of 0.04 molL <sup>-1</sup> NH <sub>2</sub> OH·HCl in 25% (v/v) HOAc	96 °C, 6h agitation
F4	Organic matter	3 ml HNO <sub>3</sub> 0.02 molL <sup>-1</sup> + 5 ml 30% w/v, H <sub>2</sub> O <sub>2</sub> 3 ml of 30% w/v, H <sub>2</sub> O <sub>2</sub> 5 ml NH <sub>4</sub> Ac 3.2 molL <sup>-1</sup> in 20% (v/v) HOAc	85 °C, 2h agitation 85 °C, 3h agitation Room temp, diluted, 30mins shaking
F5	Residual	Digestion	Method 3050B

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The phytoavailability, bioaccessibility and mobility of the metals were assessed using CaCl<sub>2</sub> and EDTA, SBET and TCLP, respectively. Due to frequent precipitations in the area, SPLP test was conducted to simulate the amount of metals which can be washed and re-entered into the wetland.

**Table 2. Leaching tests applied to assess dredged sediment samples**

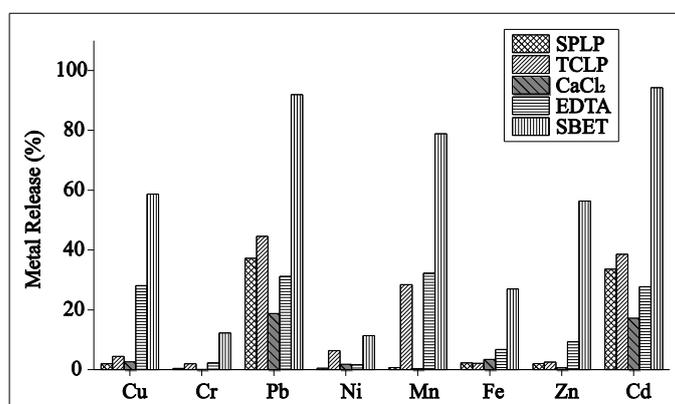
Test	Reagent	Contact time
CaCl <sub>2</sub>	0.01 molL <sup>-1</sup> CaCl <sub>2</sub> , L/S= 10:1	3h, room temp
EDTA	0.05 molL <sup>-1</sup> EDTA, L/S= 10:1	1h, room temp
SBET	0.4 molL <sup>-1</sup> Glycine, L/S= 100:1	1h, 37 °C
TCLP	AcOH, L/S= 20:1	18h
SPLP	H <sub>2</sub> SO <sub>4</sub> /HNO <sub>3</sub> (60:40), L/S= 20:1	18h

To determine the release risk of the metals, modified risk assessment code (mRAC) based on metal fractionations was applied. To evaluate the metal bioavailability and bioaccessibility, a new bioavailability/bioaccessibility index (BRAI) is used based on EDTA and SBET results.

## Results and Discussion

Sediments were classified as ML. Quartz was the dominant mineral observed in the XRD analysis which accorded with XRF. Concentrations of most metals exceeded those of earth's crust, global average, Shijan zone of wetland and the Caspian Sea. Thus, these fine-grained sediments contained a high amount of metals. The sequential extraction showed that the highest percentages of metal associations with exchangeable, carbonate bound, Fe-Mn oxide, organic matter and residual fractions were related to Pb and Cd, Mn, Zn, Cu and Cr, respectively. Using the sum of metal extractions in exchangeable and carbonate fractions, the mRAC value was equal to 44.09 indicating high potential adverse impact.

The actual bioavailability of the metals evaluated by CaCl<sub>2</sub> was low due to low concentrations of extracted metals (Fig. 1), and the concentrations of Pb and Cd mainly associated with exchangeable fraction, were higher than those of other metals. EDTA extracts the potential bioavailable fraction of metals. Compared to other studied metals, high amounts of Cu, Mn, Pb and Cd were extracted by EDTA (Fig. 1); Cu and Mn were mainly associated with organic matter and carbonate bound fractions, respectively. Based on the results obtained from EDTA extraction, the calculated BRAI value of 2.4 showed medium risk of bioavailability. The concentrations of metals extracted by SBET method were high (Fig. 1). The highest concentrations were reported for Pb and Cd, almost all fractions of which were extracted. Based on SBET results, the calculated BRAI value was equal to 7.14 indicating very high risk of bioaccessibility. The release of Pb, Cd and Mn by TCLP method was higher than release of other metals (Fig. 1). Pb, Cd and Cr concentrations were below the USEPA regulatory limits indicating that sediments were not toxic and beneficial use of them is viable. The contents of Pb and Cd in the SPLP leachate were high compared to other metals with low concentrations (Fig. 1). Metal concentrations in SPLP leachate were commonly lower than drinking water standards.



**Fig. 1. Metal extraction by bioavailability/bioaccessibility and mobility tests**

In all extractions, the highest metal contents were reported for Pb and Cd and the lowest for Cr. The bioavailability of metals was in the decreasing order of Cd ~ Pb > Cu > Mn > Zn > Fe > Ni > Cr. Metal extractability of the methods was in the order of SBET > TCLP > EDTA > SPLP > CaCl<sub>2</sub> for Pb, Ni, Cd and SBET > EDTA > TCLP > SPLP > CaCl<sub>2</sub> for the rest. The potential bioavailability of the metals was higher than

their actual bioavailability while the bioaccessibility of them was the highest. The concentrations of the metals extracted by SBET were higher than those of TCLP. This was due to acidic pH and higher temperature in SBET. Although TCLP and SPLP methods are very similar, metal concentrations in TCLP were higher than SPLP. TCLP represents metal leaching under landfill conditions while SPLP can simulate their release owing to precipitation which is an easier condition.

### **Conclusion**

In this study, bioavailability, mobility and speciation of heavy metals in dredged sediments of Anzali Wetland are assessed. The metal speciation and the mRAC index showed high potential adverse impacts. BRAI index using bioavailability and bioaccessibility test results represented medium and very high risks. Metal concentrations in TCLP test were lower than USEPA limits and in SPLP test were occasionally higher than standards. Results of this study also showed that the metals in sediments of Anzali Wetland can be up-taken by plants. Moreover, the metals can leach to the underlying soil and contaminate ground water. They can also be washed due to the precipitation and re-enter into the wetland. On the other hand, sediments are not toxic and can be used for beneficial purposes. It can be concluded that unless properly managed, to deposit sediments can cause adverse effects on the environment and terrestrial organisms of Anzali Wetland.

**Keywords:** Anzali Wetland, bioavailability, dredged sediments, heavy metals, mobility.

## Treatment and Regeneration of PCBs in Transformer Oil by a Chemical Process (Case Study: Tehran Besat Power Plant)

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### Expanded Abstract

#### Introduction

PCBs belong to a broad family of man-made organic chemicals known as chlorinated hydrocarbons. They have a range of toxicity and vary in consistency from thin, light-colored liquids to yellow or black waxy solids. Due to their non-flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer, and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; in pigments, dyes, and carbonless copy paper; and many other industrial applications. PCB (or PCBs) is a category, or family, of chemical compounds formed by the addition of Chlorine (Cl<sub>2</sub>) to Biphenyl (C<sub>12</sub>H<sub>10</sub>), which is a dual-ring structure comprising two 6-carbon Benzene rings linked by a single carbon-carbon bond.

Polychlorinated biphenyl, commonly referred to as PCB, was in widespread use as a dielectric fluid due to its special physical and chemical properties. Since then, PCBs have developed a notorious reputation due to their potential for environmental contamination and for their potential to react to form other, highly toxic substances. Under incomplete combustion, PCBs can form products such as furans and dioxins. Due to the stability of PCB and its potential for environmental accumulation and harm, many different processes can and have been used to destroy PCBs, but each has its limitations and potential risks. High temperature incineration has been widely used, but has the inherent risk that if inadequate temperatures are attained at the point of destruction of the PCB, dioxins and furans can be formed.

Another dechlorination process is the gas-phase reduction, in which the main difference is the chemical used as reducing reagents. The molten salt process has been used on a small scale since 1950. In the process, a bed of alkaline molten salt, usually sodium carbonate oxidizes organic materials. Any chlorine, sulfur, phosphorous, or ash products in the feed are converted to inorganic salts and retained in the salt bed. This process cannot treat soils and other materials with a high content of inert material. With bench and pilot scale systems, PCBs was destroyed in molten sodium carbonate/sodium chloride with efficiencies of 99.99 percent. Destruction efficiency with chlordane was apparently not determined. Indeed, the use of performance measures, "destruction efficiency" and DRE, in describing the performance of this technology suggests that one may have been used inaccurately. i.e., destruction efficiency can be determined only if all process residues are analyzed for the presence of undestroyed chemicals of concern.

#### Materials and Methods

Chemical dehalogenation (or dechlorination) is a chemical process used to remove halogens (usually chlorine) from a chemical contaminant by hydrogen or a reducing radical containing hydrogen donor.

In the case of based catalyzed dechlorination, the process key is the hydrogen donor with an oxidation potential low enough to produce nucleophilic hydrogen in the presence of base Na<sup>+</sup>. On the other hand, for the Eco-Logic process gaseous hydrogen at high temperature is the reducing reagent to destroy chlorinated organic compounds. Chemical dehalogenation technologies are applicable to halogenated aromatic compounds, including PCBs, PCDDs, PCDFs.

Treated transformer oil was segregated from the contents (Fig. 1.).

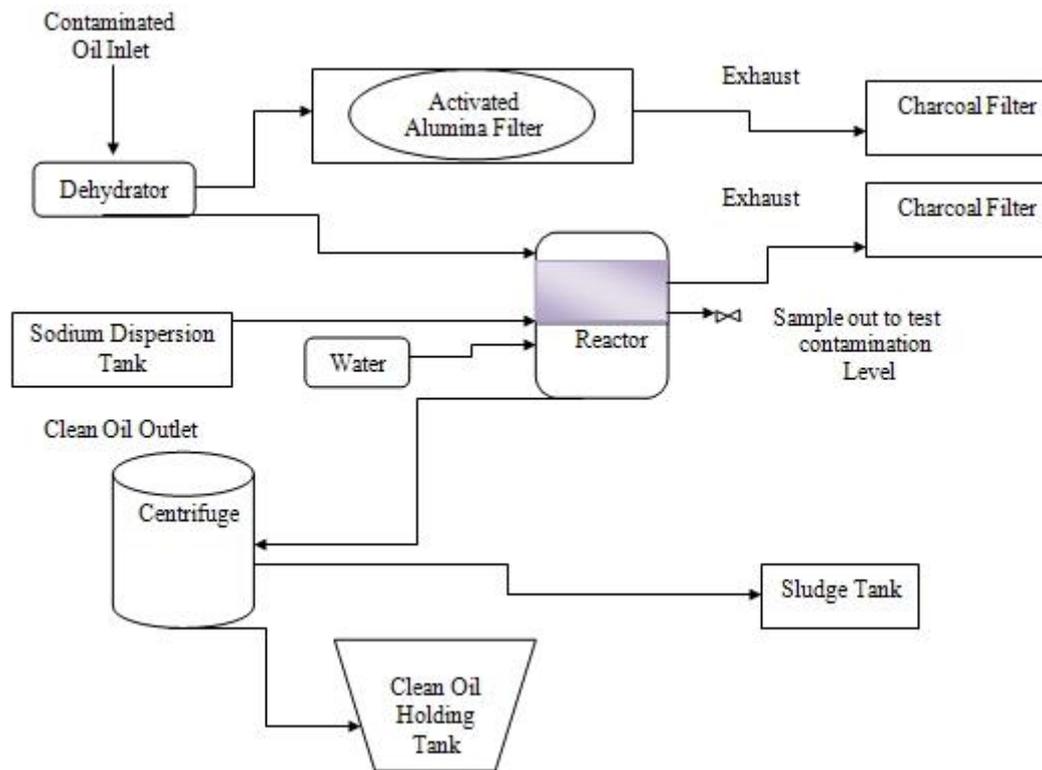


Fig. 1. PCB Destruction Flow Chart

### Results and Discussion

In this study a practical and efficient disposal dechlorination process has been reported for Tehran Besat Power Plant, PCBs less than 10000 ppm. The transformer oil containing commercial PCB mixtures (Aroclor 1242, 1254 and 1260) was treated by chemical process. 74000 lit (666000Kg) of PCBs oil (less than 7000 ppm) from Tehran Besat Power Plant sent to site plan. Content of 4 transformer oil samples is reported in Figure 2.

Results of PCB content of transformer oil sample are presented. The diluted is cleaned with solvent and then analyzed by a capillary Gas Chromatograph with an electron capture detector for the detection of PCBs. The results are reported as mg of PCB per liter of oil (ppm). The samples containing less than 2 mg/l PCB will be reported as <2 mg/l. The results of the study confirmed that the treatment and regeneration efficiency of PCBs was 99.99% and/or less than 2 ppm. Results of physical, chemical and electrical properties of PCBs oil after chemical treatment and regeneration are reported as quality oil with IEC60296 standard.

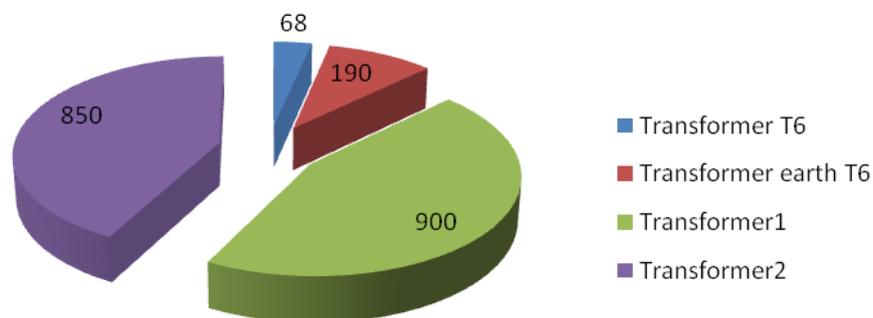


Fig. 2. Tehran Besat Power Plant PCBs waste less than 7000 ppm

**Conclusions**

The destruction and removal efficiency of PCBs was 99.99% and/ or less than 2 ppm. After destruction, the reactor content was drained. The treated transformer oil was segregated from the contents by filtering, washing, dehydrating under vacuum. Such segregation steps described standard treatment of treated transformer oil before reuse. Treated transformer oil passed IEC60296 (oil quality standard). We have developed a safe, inexpensive and efficient chemical dechlorinating process for the disposal of Besat Plant PCBs directly in transformer oil. Disposal/decontamination of slightly PCB contaminated transformer oils could be established in Iran quite rapidly if decisions and resources were secured. A destruction and removal of PCBs in Transformer Oil by a Chemical Process is one of the commercial technologies. Considerable PCB issue in Iran and firm steps need to be taken in order to avoid releases in the environment from inappropriate waste management or spillage.

**Keywords:** Besat Power Plant, chemical process, polychlorinated biphenyls, regeneration, stockholm convention.

## Upgrading of the Fenton and Electrochemical Combined Reactor (Fered-Fenton) for Optimum Waste-Activated Sludge Stabilization and Energy Consumption

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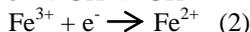
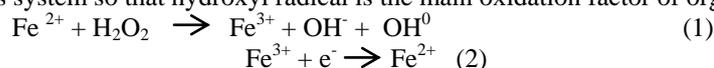
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### Expanded Abstract

#### Introduction

Activated sludge process is one of the most common methods used in wastewater treatment plants. Regarding the large volume of sludge obtained from such biological wastewater treatment processes and considerable costs of its treatment and disposal, extensive research has been and is being done on novel effective methods of sludge stabilization. In previous investigations research group introduced Fered-Fenton reactor as a novel efficient system for waste-activated sludge stabilization. Reactions (1) and (2) are the most important and effective reactions occurring in this system so that hydroxyl radical is the main oxidation factor of organics to be produced.



In this study reengineering, optimizing and upgrading of the reactor in stabilizing waste-activated sludge obtained from urban wastewater treatment (case study: waste-activated sludge in Shahid Mahallati Treatment Plant) is focused on by investigating effective functional parameters including electrodes material, inflow organic concentrations, interelectrode distance, number of Fenton's reagent injection, sodium sulfate concentrations (the factor of electrical conductivity generation in the medium), and the ratio of electrodes surface to system volume. Besides, due to the important role of electrical energy consumption in electrochemical issues and the efforts to minimize it, analysis and estimation of electrical energy consumption in the system and its comparison to sludge aerobic digestion is discussed.

#### Materials and Methods

Pilot studies were conducted in 2014. Excess sludge samples were provided from return activated sludge site of Shahid Mahallati wastewater treatment plant. Pilot reactor was a Plexiglas cylinder of 0.9 liter, embedding two anodes and two cathodes. Electrodes material was selected of iron, stainless steel and graphite. Electrodes dimensions, setting depth in sludge and contact surface of each electrode with sludge are 140×60×1, 100 and 100×60 mm, respectively. Interelectrode distance is varied. Stirring in reactor was done by using an electrical engine (Zheng, zs-ri, 6(V) DC, 366 rpm). Using magnetic stirrer was relinquished because of its negative effect on iron ion and its catalytic function in Fenton process. To adjust reactor amperage, digital power supply (Mps, DC-3003D, 0-3 (A), 0-30 (V)) was used. Chemicals including ferrous sulfate and hydrogen peroxide (fenton's reagent), sulfuric acid and sodium hydroxide (to adjust pH), sodium sulfate (to generate electrical conductivity), and filter papers (No. 42) were provided from Merck and Whatman company, respectively.

Primarily, sludge pH was adjusted by sulfuric acid and sodium hydroxide. Then, an initial sample of 50 cc was taken to measure initial VSS. Ferrous sulfate and hydrogen peroxide were injected to the reactor. Electrodes were set in the reactor after connecting to the power supply and current intensity was then adjusted. After 240 minutes, a secondary sample was taken from reactor depth of 80 mm and voltage was measured during the experiment. All the experiments were conducted according to standard method and each set of experiments were repeated three times to control errors.

## Results and Discussion

Regarding the conducted experiments and investigations, the following results has been obtained:

- As concentrations of inflow organics increases, reactor efficiency rises gently; thus, only a four-percent rise is obtained in the range of 3500-5000 mg/lit.

- Due to the highest reactor efficiency, being environmentally friendly, leaving no residual in medium and thus causing no medium contamination, availability, reasonable operation cost, not being corroded. Therefore, appropriate for long use, graphite is selected as the best electrode material among electrodes of stainless steel, iron and graphite.

- Interelectrode distance was experimented in the range of 0.5-2.25 cm. The effect of interelectrode distance on reactor efficiency is a downward quadratic equation which the highest reactor efficiency is obtained at 1.5 cm.

- The number of Fenton's reagent injection has been experimented up to 6 stages. As the number of injection stages increases, reactor efficiency rises thus the highest efficiency was obtained at stage 5; however, more increase in injection stages does not increase VSS removal efficiency and reactor efficiency remains constant.

- Generating electrical conductivity, adding a slight amount of sodium sulfate positively affects reactor efficiency rise and this trend continues up to 0.111 mole/lit, however more addition conduces to noticeable reduction in efficiency.

- The ratio of electrodes surface to system volume was investigated in the range of 0-266 cm<sup>2</sup>/lit. As electrodes surface increases in the range of 0-66 cm<sup>2</sup>/lit, system efficiency steeply rises from 22% to 79% (57% rise in system efficiency). However, in the range of 66-100 cm<sup>2</sup>/lit a much more gentle slope is noticed (7% rise in system efficiency) and eventually in the range of 100-200 cm<sup>2</sup>/lit system efficiency rises only 2 percent. Increase in electrodes surface more than 200 cm<sup>2</sup>/lit has no effect in system efficiency (Fig. 1.).

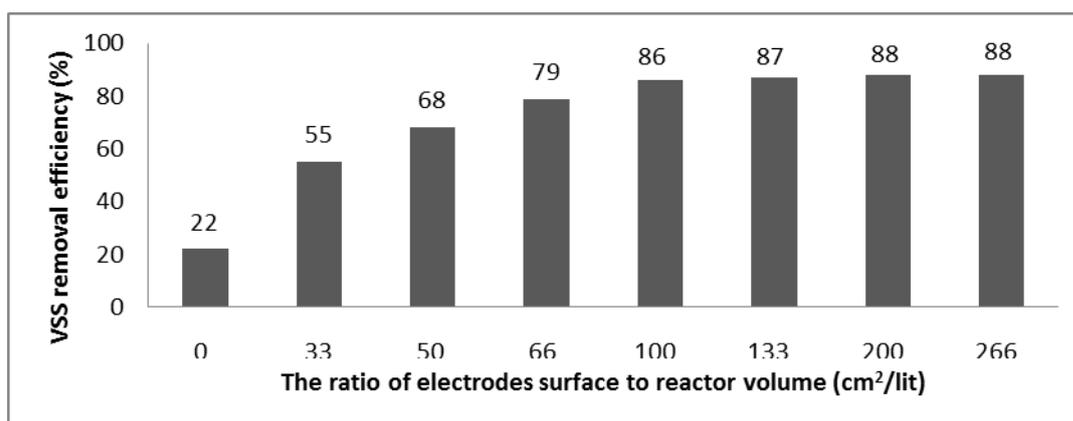


Fig. 1. The relation between VSS removal efficiency and the ratio of electrodes surface to reactor volume

(pH=3, Fe<sup>2+</sup>/H<sub>2</sub>O<sub>2</sub>=0.58, current intensity: 650 mA, retention time: 240 minutes, hydrogen peroxide concentrations: 1568 mg/lit, electrodes material: graphite, interelectrode distance: 1.5 cm, number of Fenton's reagent injection:5, sodium sulfate concentrations: 0.111 mole/lit)

- Voltage slope steeply decreases in the first 90 minutes of experiment; then from 90 to 210 minutes after the run, the slope becomes more gentle and finally in last 30 minutes it becomes stable; however, electrical energy consumption increases during the experiment.

- Increase in concentrations of inflow organics results in increase of power supply voltage but decrease of electrical energy consumption for removal of 1 kg VSS (while total electrical energy consumption increases).

- Electrical energy consumption is directly and linearly related to interelectrode distance.

- As sodium sulfate concentrations increases, electrical energy consumption decreases. Initial addition of sodium sulfate decreases a great deal of electrical energy consumption (consumed electrical energy decreases 1.63 Kwh for removal of 1 kg VSS). Increase in concentrations of sodium sulfate more than a certain amount; however, makes decrease in slope of electrical energy consumption and become very much more gentle (consumed electrical energy decreases 0.36 Kwh for removal of 1 kg VSS).

- Electrical energy consumption is directly and linearly related to the ratio of electrodes surface to reactor volume (Fig. 2.).

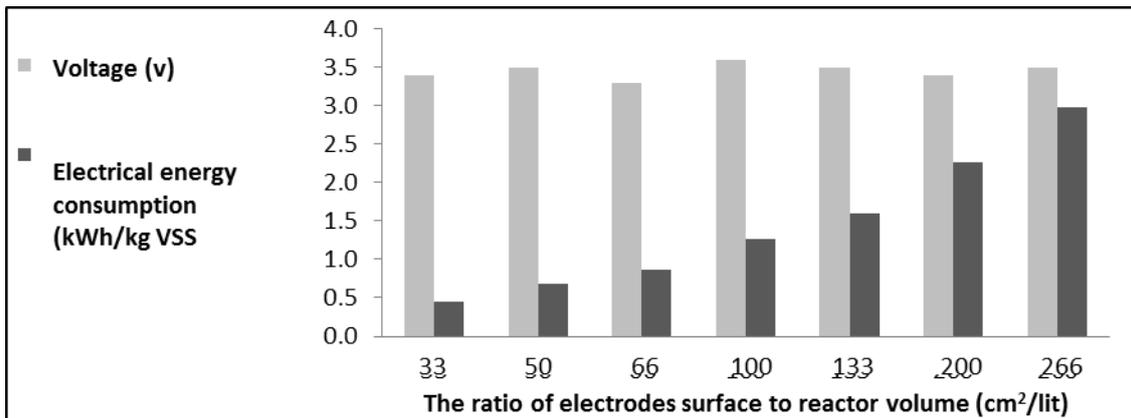


Fig. 2. The relation between voltage and electrical energy consumption and the ratio of electrodes surface to reactor volume

(pH=3,  $\text{Fe}^{2+}/\text{H}_2\text{O}_2=0.58$ , current intensity: 650 mA, retention time: 240 minutes, hydrogen peroxide concentrations: 1568 mg/lit, electrodes material: graphite, interelectrode distance: 1.5 cm, number of Fenton's reagent injection:1, sodium sulfate concentrations: 0.111 mole/lit)

- Since at electrodes surface of 100 and 200 cm<sup>2</sup>/lit, there is no prominent difference in system efficiency (a two-percent system efficiency increase, only) (Fig. 1.). But there are large difference of electrical energy consumption and electrodes surface area (1.7 kWh/(kg VSS removal) difference in electrical energy consumption and 100 cm<sup>2</sup>/lit difference in consumed electrode surface area) (Fig. 2.); it's logical to ignore two percent rise in efficiency to lessen the consumption of electrical energy and electrodes surface area and consequently lower costs. Therefore, electrodes surface of 100 cm<sup>2</sup>/lit is adopted for reactor operation in which condition system efficiency and electrical energy consumption are 86 percent and 1.6 kWh/(kg VSS removal), respectively. This demonstrates that Fered-Fenton process is twice as efficient as sludge aerobic digestion (one of the traditional sludge stabilization processes) while consumes half of its required electrical energy.

### Conclusion

Following previous researches introduced Fered-Fenton reactor as one of the effective novel methods for sludge stabilization, this study has been done to reengineer, optimize and upgrade the reactor. In this study, electrical energy consumption is also analyzed, estimated and compared with sludge aerobic digestion as a traditional sludge stabilization method. These investigations demonstrated that under optimized conditions, 86 % of VSS removal efficiency with electrical energy consumption of about 1.6 kWh/(kg VSS removal) is obtained. This indicates that Fered-Fenton process is twice as efficient as sludge aerobic digestion while consumes half of its required electrical energy. This implies the application of Fered-Fenton system in action and at the same time being highly efficient.

**Keywords:** energy consumption, Fered-Fenton Technology, functional upgrading, waste-activated sludge stabilization.

# Investigation on the Effects of Lead on Aquatic Environments and Its Removal by Electrocoagulation Process

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## Expanded Abstract

### Introduction

Population growth and development of various industries have turned water pollution into one of the most fundamental problems in the world. Researches indicate that, today, underground aquifers, especially in the large and populous cities of the world, are faced with many problems caused by infiltration of industrial wastewater, presence of absorption wells for disposal of human sewage, and infiltration of chemical fertilizers and manure deep into the ground. Rivers, wells, and lakes are contaminated with pollutants produced by man, and their treatment requires a complicated and costly technology. In general, today, most of the rivers, lakes, and surface waters are exposed to contamination by the lead originated from industries, mining operations, and agriculture activities. Presence of lead in drinking water is a serious hazard as it damages human intelligence, accumulates in bones and prevents from hemoglobin synthesis. Knowing that its permissible level in water is 0.01 to 0.05 mg/L, various studies have shown that increased levels of lead weaken the body's immune system and interfere with the activities of many enzymes. Children are more vulnerable to lead pollution and, if exposed to lead, exhibit symptoms such as anemia, digestive problems, or brain inflammation. One of the methods used for removing heavy metals is electrocoagulation which has recently become popular in water and wastewater treatment. In the process of electrocoagulation, metal ions produced from the dissolution of anodes act as a coagulant. Electric field facilitates the movement of small colloidal particles and results in coagulation. Studies on removing fluoride, organic pollutants, dyes, heavy metals, turbidity, suspended solids, COD, and BOD<sub>5</sub> from water and wastewater of pharmaceutical industries, tannery, plating, slaughterhouses, and paper mill have proved the effectiveness of the electrocoagulation process in eliminating the pollutants. This study investigates the removal of lead pollutant using the electrocoagulation method.

### Materials and Methods

Contaminated water containing lead ions with the concentration of 10 mg/L was poured into an electrical coagulation chamber made of plexiglass, and investigated for the removal of the mentioned pollutants. Lead nitrate, sodium hydroxide, and nitric acid (Merck Company, Germany) were used in this study. All the experiments were done at 25 °C. Before and after the electrocoagulation experiment, samples were examined to determine lead (II) based on standard water and wastewater tests manual. Lead concentration was determined using atomic absorption spectrophotometry (AAS) (GBC model). German-made IKA RCT basic magnetic stirrer, a DAZHENG DC POWER SUPPLY PS-305D current transformer, and a Swiss-made 691 pH Meter-Metrohm were used. The electrocoagulation reactor chamber included a tank made of plexiglass with four iron electrodes, in a bipolar arrangement with a cross section of 96 cm<sup>2</sup> and thickness of 0.2 cm, placed at the spacing of 2 cm from each other.

### Results and Discussion

In this study, magnet rotation speed, test time, voltage, and pH were tested to achieve the optimum experimental conditions for the initial lead concentration of 10 mg/L. To find the suitable speed of stirrer, the tests were conducted at 50, 100, 150, and 200 rpm. In these tests, the voltage and test time were 20 V and 20 min, respectively. The results show 100 rpm as a suitable speed, due to the fact that metal cations react with the OH<sup>-</sup> ions, form a metal hydroxide with a high absorption and form bonds with the pollutants. Since ions contact and floc formation are targeted, the higher speeds of stirrer break up the flocs and release the pollutant. It was also

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found that lower speed of stirrer cannot facilitate the required contact rate between anions and cations. Therefore, the removal rate in lower stirrer speed is lower than in suitable stirrer speed.

To reach the optimum time for the reactions, experiments were conducted at durations of 10, 15, 20, and 25 min. In these experiments, the voltage and stirrer speed were 20 V and 100 rpm, respectively. According to the results, 20 min was selected as the optimum time for testing other parameters. Increase in the duration of experiments increased the percentage of pollutants elimination, but reduced the voltage due to the precipitation that happened on the cathode.

High voltages increased the temperature of the system and led to the passivation. On the other hand, low voltages increased the time required to reach the desired elimination rate. Therefore, to determine the suitable voltage, the experiments were conducted at the optimum stirrer speed of 100 rpm and the optimum test time of 20 min (obtained in earlier experiments). The results from these experiments indicated that 20 V was a suitable voltage. Results showed that at higher voltages, the rate of cation production and the extent of the cation hydrolysis reaction are increased and a high percentage of lead pollutant was eliminated.

To attain the suitable pH value, the experiments were done at stirrer speed of 100 rpm, time of 20 min, and voltage of 20 V.

As can be seen in the results in Table 1, the lead removal efficiency increased at higher pH values, because iron hydroxides were rapidly produced at high pH values and these hydroxides eliminated lead particles.

**Table 1. The effect of pH and final Lead amount after electrocoagulation**

Final Lead (mg/L)	Initial Lead (mg/L)	pH
0.09	10	3
0.036	10	5
0.008	10	7
0.01	10	9

Given the standards available for drinking water, pH of about 7 was selected as the optimum pH in this study.

Finally, after specifying the optimal conditions, the amounts of the iron released and the sludge produced by the process were determined to be 0.16 mg/L and 0.174 g, respectively. As can be seen, the amount of released iron falls within the standard limits. Subsequently, in order to further evaluate the process, the energy consumed during the tests was calculated by Eq. (1).

$$E = U.I.t.V^{-1} \quad (1)$$

$E$  represents the consumed energy (kWh/m<sup>3</sup>),  $U$  is used voltage (V),  $I$  is current density (A),  $t$  is test time (h), and  $V$  is volume of the treated fluid (L). In this study, using Eq. (1), the energy consumed during the tests was estimated to be 0.66 kWh/m<sup>3</sup>.

## Conclusion

Presence of lead in drinking water is harmful as it can cause serious problems for human. Therefore, it was attempted to treat the lead-containing water using the new method of electrocoagulation. Results from the experiments showed the appropriateness of electrocoagulation method for the removal of lead from water. In this study, the best pH was 7, because at this pH metal hydroxides were produced in sufficient quantities and also iron co-precipitation with lead occurred. Thus, pH was found to be the parameter which had a direct effect on the reactions taking place in electrocoagulation. Metal cation resulting from electrode corrosion formed a hydroxide with OH<sup>-</sup> ions which had a high absorptive capability and also formed bonds with pollutants. At pH levels ranging from 5 to 7, iron hydroxide was formed and precipitation of lead hydroxide flocs was started. Also, a little amount of consumed energy was observed. In the electrocoagulation process, electric energy initiates the corrosion of electrodes. Since the electrodes used in the tests were made of iron, the aquatic environment was investigated to determine the amount of iron receptors after the tests. The results showed that the amount of iron released to the environment is within the standard limits.

**Keywords:** direct current, electrochemistry, electrocoagulation, heavy metals, lead.