INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 11, No. 6, p. 1-8, 2017

RESEARCH PAPER OPEN ACCESS

Use of GIS to study the effect of air pollutants on the vegetation cover

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Key words: Air pollutants, Vegetation cover, GIS, Power plant, NDVI

http://dx.doi.org/10.12692/ijb/11.6.1-8 Article published on December 12, 2017

Abstract

The present study was performed to inspect the effect of pollutant gases on the vegetation cover around Safaniya Power Plant using GIS (Geographic Information System) and remote sensing technologies. The concentrations of various gases such as CO_2, CH_4, ethane and nitrogen were determined at ground level around Safaniya Power Plant. These pollutant gases were estimated around distance of 1500 meters from the power plant stack. The changes in vegetation cover were monitored during the period of 1990 and 2016 using satellite images of Landsat-7 and Landsat-8. The Landsat-8 image acquired in 2016was used to estimate normalized difference vegetation index (NDVI). The data indicated that the vegetation cover in the study area is highly degraded specially at south and southwest of Safaniya Power Plant. A high correlation between the distance from the stack and the normalized difference vegetation index (NDVI) values (r^2= 0.597) was observed. In general, the vegetation cover is highly degraded around Safaniya Power Plant due to release of pollutant gases. Thus, it is revealed that there is required a great efforts for environmental protection and conservation of the habitat of the area.

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Introduction

In current scenario of industrialization, air pollution is a one of the serious problems of the world and deteriorates the ecological equilibrium (Britton *et al.,* 2017; Song *et al.*, 2017). Air pollution is the fluctuation in the atmospheric constituent resulting from the human activities (Tripathi and Gautam, 2007; Janhall, 2015). The release of pollutants in the air may have a negative influence on the plant either directly (toxicity), or indirectly (by changing soil pH). Plants have different mechanism to take up these pollutant from air such as,1) deposition of particulates and aerosols over leaf surfaces, 2) absorption by the leaves, and 3) fallout of air particulates on the leeward side of the plantation (Rawat and Banerjee, 1996; Gheorghe and Ion. 2011).

Consequently, due to deposition of pollutants, the concentration of chlorophyll in the vegetation leaves is reduced (Seyyednjad *et al.,* 2011) and effect the overall growth of the plants. Air pollutants associated with crop yield losses and vegetation injury, are triggering to serious concerns (Joshia and Swami, 2007). Many forms of air pollution are anthropogenic and lead to production of NOx, CO_2, CO, SO_2 and particulates. This problem has been increased over the years (Joshi *et al.,* 2009)and causing the serious environmental stress(air pollution) which is considered as the most limiting factor in plant productivity (Woo *et al.,* 2007). It has been found in the literature that about 90% of all air emissions are gaseous in nature which may include carbon dioxide, methane, ethane and nitrogen etc. (Godish, 1997; Jacobson, 2006).

Safaniya oil field is known as one of the greatest offshore field in all over the world. It is located 200 km north of Dhahran in the Arabian Gulf of Saudi Arabia (Fig. 1).

The oil field is producing 1.2 m barrels of oil per day and, is owned and operated by Saudi Aramco Company. This huge industry could have serious impact on environment. According to a study, Safaniya power plant is sources various air pollutants which have been found to affect the area up to 1.5 km around the plant (Al-Seroury, 2012). Also, this increase in air pollution could have a negative effect on vegetation cover in the area. However, no study is performed to observe the effect of air pollutants of Safaniya power plant on vegetation cover in the area. To control the environmental degradation, the studies on impact of pollutant on vegetation cover support the decision maker to put suitable solutions.

The modern techniques such as remote sensing and GIS can be applied to provide geospatial distribution of pollutants over the time and location, and digital records and maps are acquired as output (Agrawal *et al.,* 2003; Hurlock and Stutz, 2004).GIS is a modern and innovative technology that has made it possible to map and monitor rapidly changing phenomena on the surface or land area (Sohrabiniaa and Khorshiddoust, 2007).

The key objective of the present study is to evaluate the impact of air pollution on the vegetation cover around Safaniya Power Plant, Saudi Arabia through remote sensing and GIS. The Gaussian Plume Model was applied for the approximation of the concentration of air pollutants around power plant. The Normalized Difference Vegetation Index was calculated using concentration of various pollutant gases to analyze the patterns of vegetative growth on a landscape.

Materials and methods

Study area

The area of investigation was located 200 km north of Dhahran in the Arabian Gulf of KSA. The location of the Safaniya Power Plant and can be located in Fig. 1. The area of 1500 m was investigated around the stack of the power plant.

Remote sensing work

The Landsat-7 and Landsat-8 images of path 165 and row 41 (Landsat-7 acquired in 1990, 2000 andLandsat-8 in 2016) cover the investigated area were used in this study (Fig. 2). To reduce the undesired variations such as noise and to enhance

some desired features, pre-processing activities were performed. The software ENVI4.7 was used to apply the operations of radiometric correction, normalization, geometric correction, masking, image registration, image enhancement and imagery geometric rectification (ITT, 2009; El Baroudy and Moghanm, 2014). Further, the image enhancement such as stretching, slicing, stretch and gray-level threshold) were tested to increase the visual interpretability through increasing apparent division between the features on the image. By using digital data of remote sensing and process of supervised classification, the map of the land cover classes was developed (Thomas *et al.,* 1987; Campbell, 1996).

Fig. 1. Location of the investigated area. The red mark showed the study area around Safaniya power plant.

The image classification is mainly used to categorize all pixels of image in land cover classes (Lillesand and Kiefer, 1994). The maximum likelihood classifier evaluates the covariance and variance of spectral response patterns category on quantitative basis. This can be done when classifying an unknown pixel to consider this as one of the most accurate classifier. The supervised classification was applied using digital maps of topography of the study area and checkpoints at ground. Further, the accuracy assessment was performed by using 30 points from field data. For the purpose of to improve the accuracy of land cover, mapping of the image, ancillary data and the result of visual interpretation were integrated with the classification result using GIS. The layers of vegetation cover were converted to victor format and transported to GIS system for mapping vegetation in 1990, 2000 and 2016.

Normalized difference vegetation index (NDVI)

The NDVI is used to indicate quantity of actively photosynthesizing biomass to show the patterns of vegetative growth on a landscape (Burgan *et al.,*1996). By using the following relation (Eq. 1), NDVI can be calculated;

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \quad (1)$$

where, NIR stands for near infrared band and RED represents the red band. The above equation generates scoring value between–1 to 1. The negative values (-1 to 0) designated for the non-vegetative areas or non-reflective surfaces, whereas, the positive values (0 to +1)represent the vegetated or reflective surfaces (Burgan and Hartford, 1993).

GIS operation

The Gaussian Plume Model (GPM) is applied to estimate the concentration of pollutants at ground level as well as at elevated sources by considering the plume rise, and climatic conditions (IAEA, 1996). GPM model calculate the concentration of CO_2, CH_4,

ethane and nitrogen at 30 sites at different distances in range of 1–1550 m around the stack. Further, the outputs in the form of pollutants concentrations at 30 sites was used in GIS for development of layers of spatial distribution of air pollutants concentration using the spatial analyst functions of software Arc-GIS 9.2 with a buffer zone of 1450 m around the Safaniya Power Plant. The matching of the layer of air pollutants buffer zone with map of area was performed to study observe the impact of air pollutants on the vegetation cover degradation(Graeme and Bonham, 1996).

Results and discussion

Air pollutants and normalized difference vegetation index (NDVI)

The ground level concentrations of the dominant pollutants such as CO_2, CH_4, C_2H_6, and N at different distances around the stack of Safaniya power plant is described in Table 1.

Table 1. Ground level concentrations of the air pollutant at anc NDVI values calculated for various distances from the stack.

Distance from stack (m)	Concentration of pollutants (µ gram/ m²)				NDVI
	CO_2	CH_4	N	C_2H_6	0.02000
51	0.001	0.003	0.00	0.001	0.02009
101	526.13	1850.06	13.99	385.28	0.02165
151	5178.62	18209.10	137.79	3792.28	-0.01823
201	9491.40	33375.31	252.54	6950.50	-0.02697
251	10973.17	38585.75	291.97	8035.6	-0.02442
301	10781.10	37910.29	286.86	7894.92	-0.02067
351	9930.32	34918.75	264.21	7271.93	-0.01334
401	8910.85	31333.90	237.10	6525.37	-0.01246
451	7921.10	27853.41	210.76	5800.55	-0.01239
501	7029.34	24717.77	187.03	5147.55	-0.01762
551	6250.41	21978.77	166.31	4577.14	-0.02153
601	5578.44	19615.87	148.43	4085.06	-0.01841
651	5000.89	17585.00	133.06	3662.16	-0.02579
701	4504.15	15838.28	119.84	3298.37	0.02100
751	4075.63	14331.45	108.44	2984.56	0.01947
801	3704.44	13026.19	98.57	2712.74	0.01819
851	3318.39	11890.23	89.97	2476.17	0.02758
901	3098.87	10896.80	82.45	2269.29	0.03000
951	2850.59	10023.77	75.85	2087.50	0.03289
1001	2631.38	9252.92	70.01	1926.95	0.03648
1051	2436.93	8569.17	64.84	1784.55	0.03806
1101	2263.71	7960.04	60.23	1657.70	0.03955
1151	2108.75	7415.14	56.20	1544.22	0.05401
1201	1969.58	6925.78	52.41	1442.31	0.05805
1251	1844.14	6484.68	49.10	1350.45	0.06107
1301	1730.67	6085.68	46.10	1267.36	0.06989
1351	1627.70	5723.58	43.31	1191.95	0.07212
1401	1533.95	5393.94	40.81	1123.30	0.14113
1451	1448.36	5092.97	38.54	1060.62	0.18017
1501	0.00	0.00	0.00	0.00	0.02000

The data showed theranges of these gases concentration as: nitrogen levels varied between 13.99 to 291.97 µg/m², $CO_2$526.13 to 10973.17µg/m², methane 1850.06 to 38585.75µg/m², and ethane lies between 385.28- 8035.6µg/m². It was observed that the all pollutants showed the minimum concentration at distance below 101 meter from the stack. The spatial distribution of CO_2, CH_4, C_2H_6 and nitrogen concentration around the stack indicated that all pollutants have the same trend around the stack. The maximum values observed at 251 meter from the stack, later, a gradual decrease in concentration showed the minimum level at 1500 meter far from the stack.

This data revealed that the area around 250 meters from the stack could be more susceptible to vegetation loss due present of high pollutant

concentration. The main reason of degradation of vegetation is release of gaseous pollutants Safaniya power plant. Twumasi and Merem (2006) also indicated the severe environmental degradation in the Niger Delta due to inception of oil and gas activities causing uninterrupted gas flaring.

NDVI was estimated from the Landsat image of 2016 around Safaniya power plant with a buffering zone of 1500 m. Values of NDVI in 30 sites were determined using spatial analyst of Arc-GIS 9.2. The data indicate the high correlation between NDVI and the distance from stack (r^2= 0.597). It is noticed that the NDVI values were initially increased to 150 m distance, then decreased within the distance range of 250 to 800 m and further again increased up to 1450 m distance from the stack (Fig. 3). The decrease in NVDI in area lies between 250 to 800 revealed that, this is the highly polluted zone that affects the vegetation cover around this area.

Table 2. Overall change in vegetation cover area between 1990 and 2016.

Year	Area (km²)	Area (acre)	Area (%)
1990	187.82	46955.20	100.00
2000	142.37	35592.80	75.80
2016	103.03	25756.70	54.85

This change in NDVI value indicated the loss of vegetation biomass due decrease in photosynthetic activity (Burgan *et al.,* 1996). The molecules of pollutant gases can be deposited over the plants when they pass close to a surface. Moreover, some plants have large surface area which increase the probability of deposition of pollutants and gases (Janhall, 2015).

Changes in vegetation cover

Vegetation cover of the years 1990, 2000 and 2016 was mapped using remote sensing and GIS.

The results indicate that the vegetated area was decreased from 46955 acre in 1990 to 35592 acre in 2000 and to 25756 acre in 2016 with an average of 927 acre (1.96 %) per year.

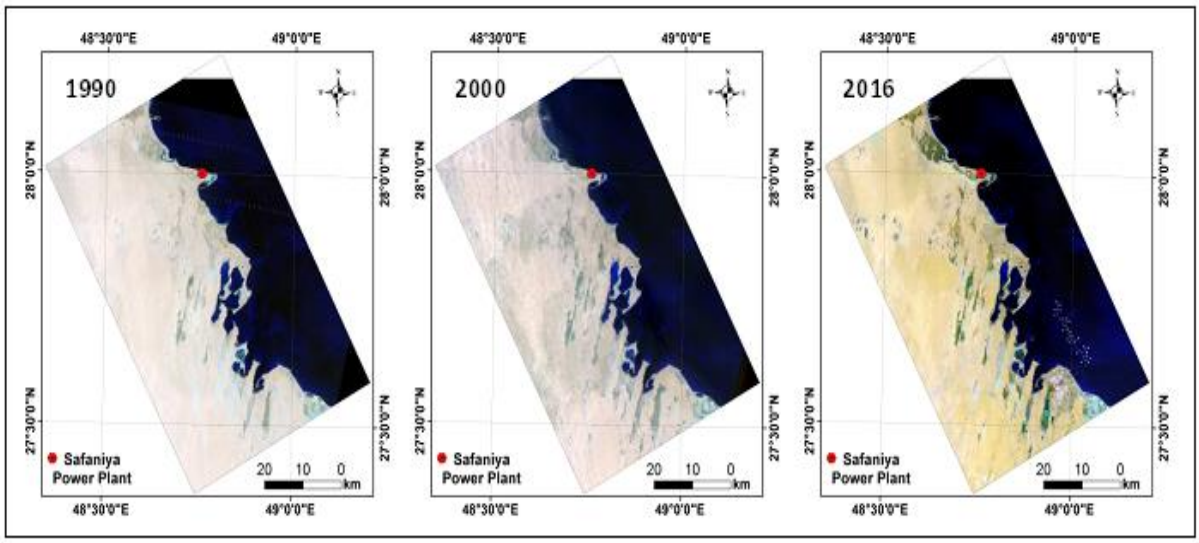

Fig. 2. Satellite images of the investigated area acquired in 1990, 2000 and 2016.

The average of decrement in the vegetation area between 1990 and 2000 was 1136.24 acre (i.e. 2.5 %) per year, while decreased to 756.62 acre (1.61%) per year was observed during 2000 and 2016 period. Fig. 4 represents the distribution of vegetated area in 1990 (Fig. 4a), 2000 (Fig. 4b) and 2016 (Fig. 4c), respectively. The data indicate a severe degradation of vegetation especially to the south and south west of Safaniya Power Plant. The area closed to the Power Plant almost has no vegetation in 2016.

It is also noticed that the decrement of vegetation cover between 1990 and 2000 was concentrated to the south west of the Safaniya Power Plant due to the wind action. During the period of 2000 and 2016 the decrement of vegetation cover was expanded to include large areas to the south of the Power Plant.

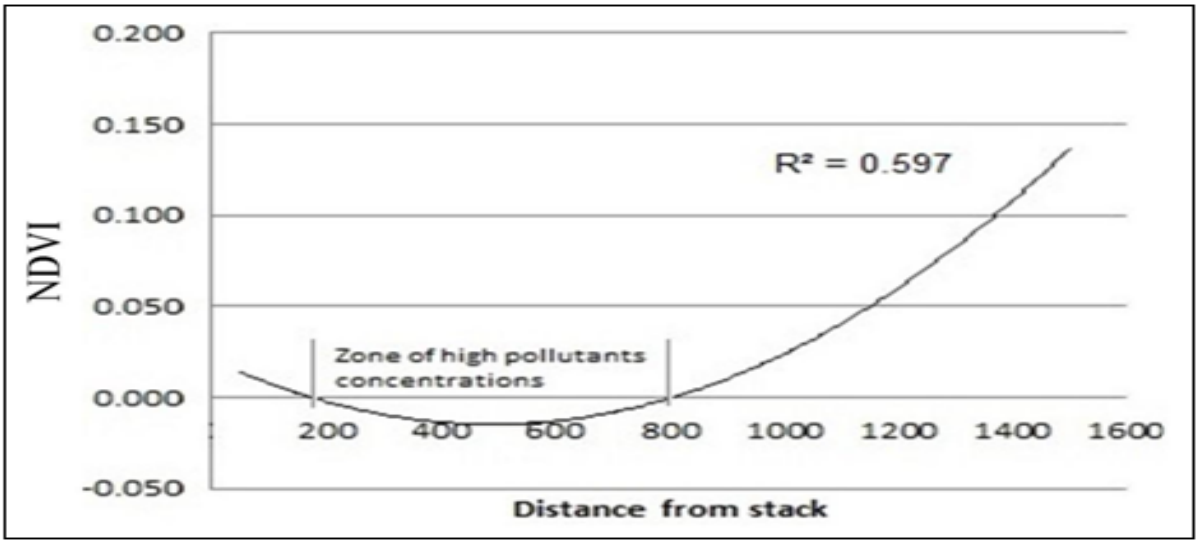

Fig. 3. Correlation between NDVI and the distance from stack.

The rate of degradation of vegetation cover and the spatial distribution of degraded areas could be explained on view of the distribution of air pollutants around Safaniya Power Plant. The types of gases (CH_4, CO_2, ethane and N) estimated in the present study have been reported to effect the vegetation negatively through different ways. For instance, nitrogen and nitrogen based pollutants present in the atmosphere can affect the vegetation either directly through being deposition on the plants surface, water and soil or indirectly via chemical reaction in the air (WHO, 2000) Similarly, the high CO_2 concentration in atmosphere likely to cause a profound effect on the plant growth, chemistry and physiology (Ziska, 2008), thus ultimately degrade the overall vegetation.

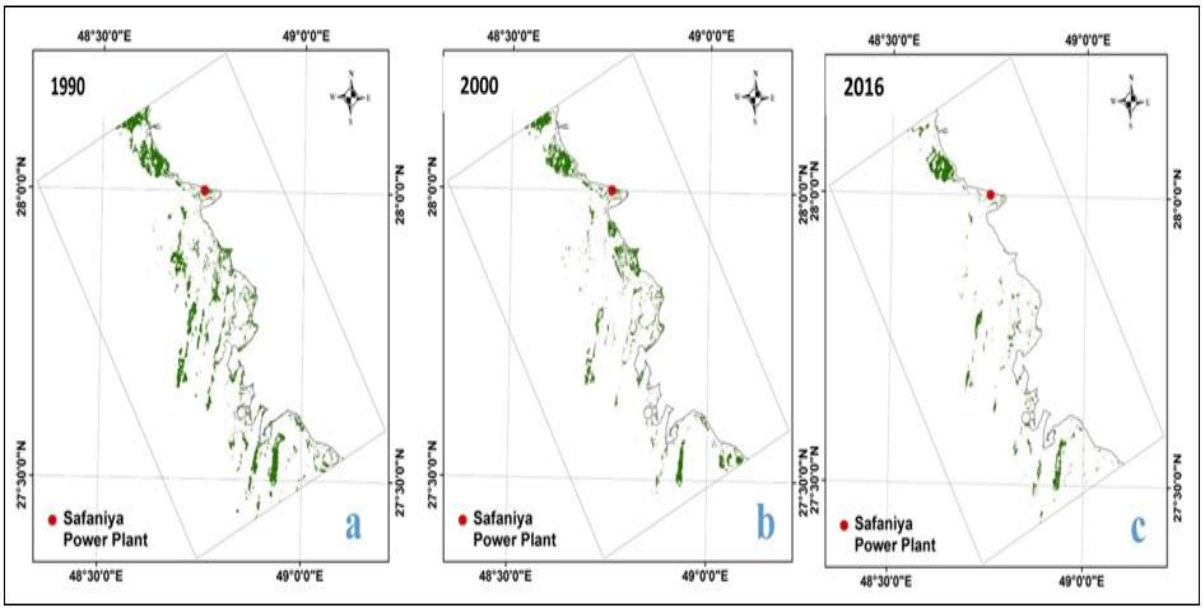

Fig. 4. Vegetation covers around Safaniya Power Plant in 1990(a), 2000(b) and 2016(c). The green color indicates the vegetation cover of the area.

The overall changes in vegetative cover between the 1990 and 2016is illustrated in Table 2. From 1990 to 2000 vegetation cover was decreased by 24.2 % with the total area of about 45.4 km². Furthermore, the area is still continuously degrading due to loss of extensive release of air pollutant gases from the power plant where loss of vegetation has been increased up to 45 % in 2016 from 1990.

Conclusion

Remote sensing and Geographic Information System (GIS) were employed in this work to study the impact of air pollutants on vegetation cover around Safaniya Power Plant. It is found that the vegetation cover in investigated area is highly degraded between 1990 and 2016. The main pollutants released from power plant include carbon dioxide, methane, ethane and nitrogen and causing severe impact on the vegetation cover around power plant as the vegetation cover is decreased by rate of 1.96% per year. With buffer zone of 1500 m diameter, the area located to the south and south west of the power plant is almost degraded. High correlation (r^2= 0.597) was found between the distance from the power plant and NDVI values, where the increase the distance the increase the NDVI values. Thus, from our present study it is revealed that, there is a need to a great efforts and priority to develop future planning for conservation and environmental protection of the area.

Acknowledgment

The author appreciate the support of Department of Physics, King Abdulaziz University, Jeddah, Saudi Arabia for completion of this study.

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