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Towards a Sustainable Agriculture Development Based on the Field Vulnerability Evaluation in Miandoab Region, Iran

Hacia un desarrollo agrícola sostenible basado en la evaluación de vulnerabilidad de campo en la región de Miandoab, Irán

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ABSTRACT

Exploring the agro-ecological limits is necessary in sustainable agriculture development. Soil contamination and erosion are two main indices in land vulnerability evaluation. Raizal and Pantanal models within MicroLEIS DSS, the Ero&Con package, were established in identification of vulnerable areas due to erosion and contamination risks, respectively. This study was performed in Miandoab region under different land-use scenarios with approximately 5269 ha extension in the North-West of Iran (west Azarbaijan). The extracted morphological and analytical data from 62 soil profiles representative of the study area were used as basic information. A total of 17 land unites were then classified according to the Geopedologic approach. The benchmark soil profiles were categorized as Typic Torripsamments, Typic Haploxerepts, Typic Haplocambids and Typic Haplargids. The results taken by using the aforementioned models were presented as an attainable mode whereas the management practices were not mentioned. The application of Raizal model revealed that the water erosion has less impact than wind erosion on vulnerability classes whereas climate change will result extremely high vulnerable area in the future. In terms of soil contamination risks resulted by Pantanal model, phosphorous risks were classified in V2 (23%) and V4 (77%). Also, heavy metal and nitrogen as well as pesticide contamination vulnerability risks were classified as V3 and V4. Since there was no different in classes when cultivating maize and wheat, the attainable vulnerability classes are equal with the actual ones. Overall, this research demonstrates that application of models increase our understanding about the behavior of soil and landscape interactions.

Keywords: Contamination, erosion, sustainable agriculture, vulnerability evaluation, Raizal and Pantanal models.

RESUMEN

Explorar los límites agroecológicos es necesario en el desarrollo de una agricultura sostenible. La contaminación y la erosión del suelo son dos índices principales en la evaluación de la vulnerabilidad de la tierra. Se establecieron los modelos Raizal y Pantanal dentro de MicroLEIS DSS, el paquete Ero&Con, en la identificación de áreas vulnerables por riesgos de erosión y contaminación, respectivamente. Este estudio se realizó en la región de Miandoab bajo diferentes escenarios de uso de la tierra con una extensión de aproximadamente 5269 ha en el noroeste de Irán (oeste de Azarbaiyán). Los datos morfológicos y analíticos extraídos de 62 perfiles de suelo representativos del área de estudio se utilizaron como información básica. Luego se clasificaron un total de 17 unidades de tierra de acuerdo con el enfoque Geopedológico. Los perfiles de suelo de referencia se clasificaron como Typic Torripsamments, Typic Haploxerepts, Typic Haplocambids y Typic Haplargids. Los resultados obtenidos mediante el uso de los modelos antes mencionados se presentaron como un modo alcanzable mientras que las prácticas de gestión no se mencionaron. La aplicación del modelo Raizal reveló que la erosión hídrica tiene menos impacto que la erosión eólica en las clases de vulnerabilidad, mientras que el cambio climático resultará en un área extremadamente vulnerable en el futuro. En cuanto a los riesgos de contaminación del suelo resultantes del modelo Pantanal, los riesgos de fósforo fueron clasificados en V2 (23%) y V4 (77%). Además, los riesgos de vulnerabilidad a la contaminación por metales pesados y nitrógeno, así como por pesticidas, se clasificaron como V3 y V4. Dado que no hubo diferencias en las clases al cultivar maíz y trigo, las clases de vulnerabilidad alcanzables son iguales a las reales. En general, esta investigación demuestra que la aplicación de modelos aumenta nuestra comprensión sobre el comportamiento de las interacciones del suelo y el paisaje.

Palabras clave: Contaminación, erosión, agricultura sostenible, evaluación de vulnerabilidad, modelos Raizal y Pantanal.

1. INTRODUCCION

Sustainable agriculture development can be achieved by exploring the agro-ecological limits of sustainability in terms of land quality as well as field vulnerability evaluation (De la Rosa et al., 2004). In this case, use of the land does not progressively degrade its productive capacity for any defined purpose. Since land degradation and desertification occurring in particular climate zones i.e., arid and semi-arid regions (Xiaoping, 2011), it was assessed as one of the leading environmental issues facing in Miandoab region, North-West of Iran. Therefore, agricultural management in Iran needs special attention to reach sustainable conditions because during the past six decades, agriculture has been identified as the main sector in Iran's economy. It is obvious that overusing from the land causes serious challenges i.e., soil erosion, fall in groundwater levels, salinity, and pollution by use of chemical fertilizers (Emadodin et al., 2012).

The literatures demonstrated that the possibilities for exploitation of land evaluation models in decision-making by developing the model application software or generalization phase are enormous (Antoine, 1994). Fortunately, the MicroLEIS DSS was developed by De la Rosa et al. (1993) using soil type information in decision making for evaluating the sustainable use and management of agricultural land. It is based on the multifunctional evaluation of biophysical soil quality, using basically input data collected in standard soil inventories, and with particular reference to the peculiarities of the Mediterranean region. However, it was recently used in Iran both for land suitability evaluation (Niknam et al., 2018; Pakpour Rabati et al., 2012; Shahbazi et al., 2008) and for land vulnerability evaluation (Shahbazi et al., 2009) with in success. This DSS has proved to be an appropriate methodology that is readily comprehensible to policy makers and farmers. With special reference to the semi-arid regions, soil erosion caused by water and wind as well as contamination caused by four agro-contaminant types i.e., phosphorus, nitrogen, heavy metals and pesticides which can be evaluated using Raizal and Pantanal models within the

Ero&Con package of MicroLEIS DSS (De la Rosa et al., 2004). Both aforementioned models work as a qualitative empirical modelling tool that uses high-quality, in-depth, knowledge to solve complex and advanced problems typically requiring experts which called a knowledge-based model or expert system.

One of the advantages of model application in land resources management is the possibility of converting input data based on defined hypothesis i.e., climate change or site-, soil- and management-related attributes. This paper aims to show the possibilities of using agro-ecological field vulnerability evaluation models as decision support systems to point out the vulnerable areas caused by water and wind erosion as well as some major contaminants. The final step was to create thematic geo-referenced maps with integrating the model results and Geographic Information System (GIS). It facilitates to predict land degradation risks, along their response to climate change and cultivation of maize as well as wheat using Raizal and Pantanal models within the MicroLEIS DSS program.

2. MATERIALS AND METHODS

2.1. Initial Data

The initial requirements for model application are climate, site, soil and management data which were warehoused in software i.e., CDBm, SDBm+ and MDBm, respectively. This study was conducted in Miandoab region with different kinds of physiographical units of plain, alluvial plain, plateau and hill side in West Azarbaijan Province of Iran. The selected site is 5269 ha, which is delimited by longitude 51°00′ - 51°48′ E and latitude 41°33′ - 41°36′ N. The main aspect for the entire study area was distinguished as flat followed by northwest, west and northeast directions. The elevation was not varied across the study area. Furthermore, the minimum, maximum and mean temperatures for the last 10 consecutive years were recorded 12.8ºC, 19.9ºC and 5.7ºC, respectively. The study area comprises 17 land units and was represented in Fig. 1. The samples were taken from each genetic horizon, subsequently transferred to the laboratory for analyses.

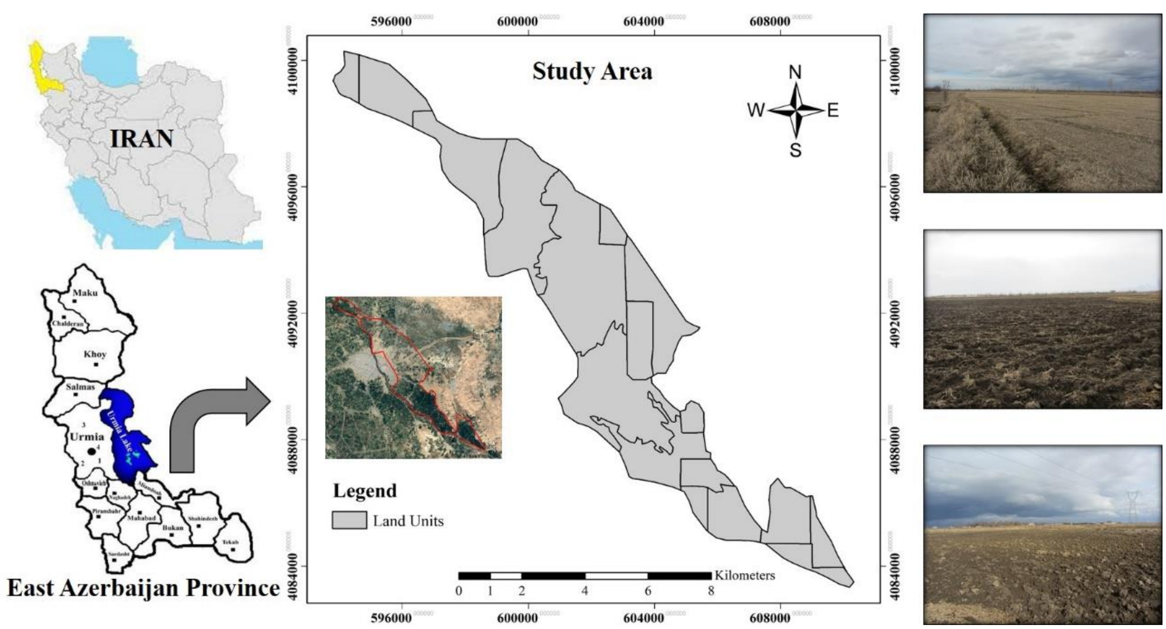

Fig.1 Study area associated with land units

2.2. Soil Analysis

The soils were analysed according to the Raizal and Pantanal models requirements. The superficial stoniness was determined in addition to particle size distribution (soil texture) using the hydrometer method (Gee and Or, 2002) with clay defined as particles< 0.002 mm, silt (0.002–0.05 mm), and sand (0.05–2 mm). Soil Organic carbon (OC) was measured by wet oxidation with chromic acid and back titration with ferrous ammonium sulphate according to the Nelson and Sommers (1996). Soil saturation extracts were prepared according to the method of Rhoades (1996) and sodium saturation was then measured. Electrical conductivity (EC_e) by an EC-meter and reaction (pH_e) by a pH-meter were measured using the conventional methods. Finally, cation exchange capacity (CEC) was measured using the method of Chapman (1965).

2.3. Model Application

2.3.1. Raizal and Pantanal Models Requirements

Land and management characteristics for handling the Raizal model within the MicroLEIS DSS area site-, soil-, climate-, crop- and cultivation-related attributes (De la Rosa et al., 2004). Landform (21 classes), slope gradient (%), and groundwater table depth (m) are the three components of site-related characteristics. Soil-related characteristics were defined as above in soil analysis. Climate-related characteristics are mean monthly precipitation (mm) and temperature (ºC), maximum precipitation as well as latitude. Crop- and cultivation-related characteristics were defined as land-use type, leaf duration, growing season length, leaf situation, specific leaf area, plant height, sowing date and many practices interrelated to tillage operation. For this purpose, the created Raizal and Pantanal models were used for identification of vulnerability areas with soil erosion problems and rationalization of specific soil input applications e.g., N and P fertilizers, urban wastes, and pesticides, respectively. These models were initially formulated and calibrated by using expert knowledge (experience) of specialists and land users, and collected literature (knowledge). Then the models were recalibrated and validated by point-to-point application using data (information) of 62 representative sites of the Andalucia province, Spain, and of 42 sites of the European Union (De la Rosa et al. 1996).

2.3.2. Raizal model attributes

This model was originated by decision trees to develop the attainable and actual water and wind erosion risk vulnerabilities. The soil erosion vulnerability is defined as classes V1 to V10 (De la Rosa et al. 1993). Class V1 (None), these field units are not vulnerable to water or wind erosion. For these fields, management erosivity is not considered to be a controlling factor and almost any farming system can be implemented. When the class numbers increased from one to 10, indicating that there is a high degradation risk and demonstrates an extremely high vulnerability to water or wind erosion. It is obvious that such fields having these marginal conditions will not be useful for crops and must be reclaimed. Since this model can estimate the actual and attainable erosion risks, it has been used for prediction of total sediment transport by the rivers in Italy (Farroni et al., 2002). It was also used in Iran for land use planning and a field vulnerability evaluation impacted by climate change (Shahbazi et al., 2009). De la Roas et al. (2005) reported that when using Raizal model, an opportunity was created to manage land resources e.g., improving the soil quality and controlling erosion by soil conservation techniques such as construction of terraces. With attention to water and wind erosion meaning, and attempts have been made for modelling the equation based on classical mechanistic physics, and on a statistical or stochastic framework. Since for observation of actual vulnerability classes, management plays an important role and there was no attention to that, the attainable vulnerability risk was only discussed in this research work.

2.3.4. Pantanal model Attributes

The pathways constructed to develop the Pantanal model demonstrated that Four agro-contaminant types e.g., i) phosphorus (P); ii) nitrogen (N); iii) heavy metals (H); and iv) pesticides (X) have been considered

(De la Rosa et al. 2004). Since phosphates are a possible source to be transported by runoff, moreover, the amount of phosphate adsorbed by soil depends greatly on pH, particle size distribution, and organic matter, it is very important to be considered. Phosphorus, once only a nutrient, has become a contaminant on a global scale because of its overusing by the farmers with intensive agriculture (Panagos et al., 2022). In terms of nitrate, nitrogen is an important element that gives plants the energy to grow. It is indispensable to all life, but it can be very damaging in excess. Therefore, nitrate is the major nitrogen-derived pollutant and, because of its high mobility, the main source of groundwater contamination (Gao et al., 2012). In relation to pesticide both hydrophilic and hydrophobic behavior in soil, two major processes, sorption and degradation, are considered. The use of pesticides in developing countries and their impact on health and the right to food is abrupt even at agricultural area. Therefore, ensuring the safe use of pesticides is a real challenge for regulating authorities **(**Storck et al., 2017). Understanding the attainable risk due to pesticides consumption may help to have a better decision. A possible reason is that OMC strongly affects adsorption and bio-degradation of many pesticides, although other soil properties such as particle size distribution and CEC are also considered to be decision criteria. Similar to pesticides, it is necessary to have a full information about the heavy metal concentrations and vulnerabilities occurred by those metals.

2.4. Integrating the Model Results with GIS

The next step was to provide maps based on the models outputs. Since the soil science is at the heart of numerous industries and it's clear that managing soil sustainability offers many benefits, therefore, the role of GIS in soil science is more to come. Oshunsanya and Aliku (2016) reported that it plays a significant role in agronomy at several levels due to the fact that it can be used to study the key soil properties of individual fields to arrive at specific requirements for excessive practices. It is also used to derive relevant information from the land suitability and estimated erosion rates as well as to integrate the findings with land cover/use and accessibility information (Liengsakul et al., 1993). Application of GIS in various disciplines of soil science e.g., soil loss and erosion (Jahun et al., 2015), soil biological properties (Shahbazi et al., 2013), field vulnerability evaluation (Shahbazi et al., 2009), digital soil mapping (McBratney et al., 2003), soil contamination (Alvyar et al., 2022) and land resources management (Obi Reddy, 2018).

3. RESULTS AND DISCUSSION

3.1. Soil Data

The major used soil variables as a summary of statistical description were presented in in Table 1. These data were obtained from 72 soil profiles and the data of 17 benchmark profiles were applied according to Raizal and Pantanal models requirements. According to the Keys to Soil Taxonomy (USDA, 2014), three orders i.e., Entisols, Inceptisols and Aridisols were identified across the study area. Cambic and Argillic were recognized as the two main diagnostic horizons. Figure 2 represents the soil family map for the entire study area.

Table 1. Statistical descriptive of studied soil properties across the study area

	Sand (%)	Silt (%)	Clay (%)	pH	EC dS/m	CCE (%)	OC (%)	CEC meq/100g	SAR	ESP
Min	1	0	0	7.39	0.23	2.5	0.04	2	0.34	0.51
Max	99	72	60	9.25	8.37	16.5	3.82	49	53.22	44.39
Mean	40.47	37.19	22.08	8.06	1.77	9.5	0.54	23.38	7.6	8.81
SD	25.95	18.16	13.63	0.38	1.8	3.25	0.65	9.47	10.67	10.23
CV (%)	64	49	62	5	102	34	121	40	140	116

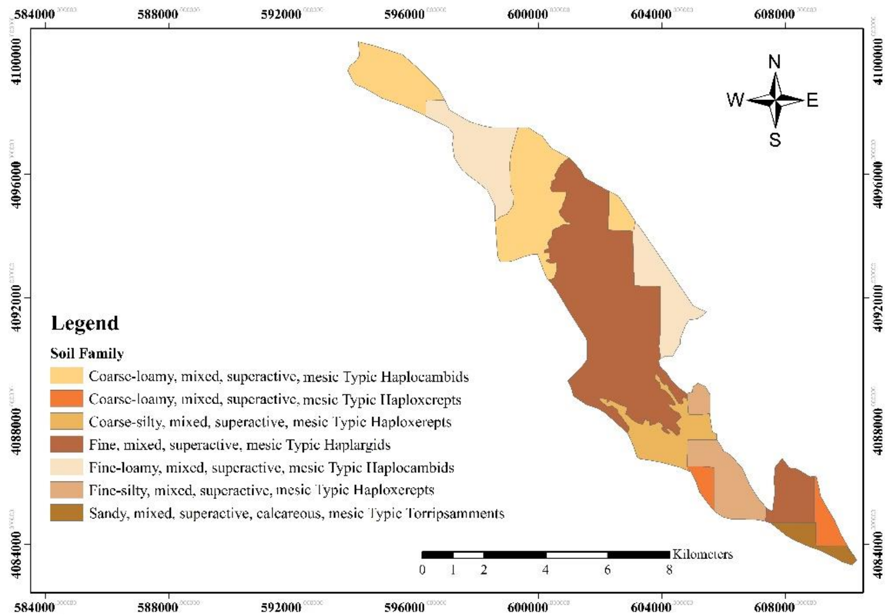

Fig. 2- The map of soil family for the entire study area

3.2. Erosion Risk Assessment

According to Raizal model results, the impact of water erosion is less than that of wind erosion in terms of the susceptibility of land to vulnerability. For water erosion, 42% of study area was classified as V1 representing none level of risk and a further 58% at a very low and medium levels (Class V2). Also, for wind erosion, 56% and 44% of entire study area were categorized as very high (V9) and extremely high vulnerable areas (V10), respectively. Therefore, it is necessary to follow management recommends i.e., using windbreaks and contour farming. Moreover, paying attention to the suitable crop rotation is required. For further visualization, the spatial distribution of model outputs was illustrated in Figure 3.

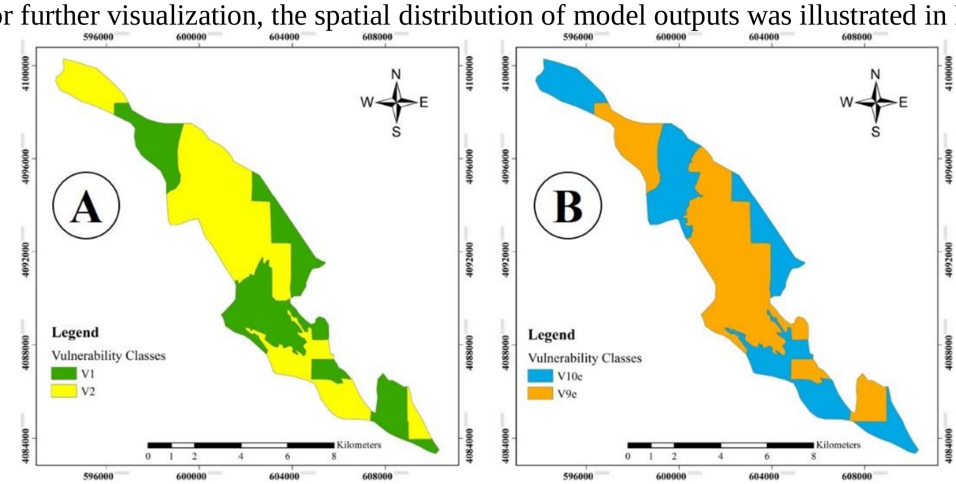

Fig. 3- Applying model spatially resulted by Raizal. A) Water erosion and B) wind erosion

The created thematic maps showed that the vulnerable areas in terms of wind and water erosion risk were somewhat similar. Therefore, management practices are needed in the central part of the site. Regarding the integrating of soil family map with Raizal model revealed that Aridisols is the most susceptible order among the present soils within the area.

3.3. Soil Pollution Risk Assessment

The next step was to assess the specific pollution raised by phosphorus, nitrogen, heavy metals and pesticides using Pantanal model. The results of applied aforementioned model using benchmark soil profiles data are summarized in Table 2.

Table 2. Summary of vulnerability classes (area extension in %) caused by agro-contaminant types across the study area based on utilization type.

Agro-contaminant type		V1	V2	V3	V4
P (Wheat & Corn)			23		77
N (Wheat & Corn)				23	77
H (Wheat & Corn)				98	2
X	Wheat			40.5	59.5
	Corn			44.6	55.4

The overall result showed that there were no different vulnerability classes among the utilization types in terms of P, N and H while it was found a minor variation regarding pesticide. Moreover, three classes of V2 (low risk), V3 (moderate risk) and V4 (high risk) caused by agro-contaminants were identified for the entire study area which the low risk class was only observed for P application. Since more than three quarters of the study area is susceptible for P and N, the consumption of fertilizers must be done with caution. Overuse of P as a dominant fertilizer has led to be stored in soil and cause water pollution (De la Rosa et al., 1996). Zalidis et al. (2002) reported that soil saturation with nitrogen has led to nitrate leaching into shallow groundwater. Ahmed et al. (2017) informed about an unawareness causing serious threats to environment and human health due to excessive use of N fertilizers. Additionally, application of livestock manure and organic waste as handy manures for the farmers caused accumulation of heavy metals in soil. Vukobratović et al. (2014) revealed that although composted manures play an important role in maintaining soil fertility, but they can be a significant source of heavy metals. Therefore, manure derived by various livestock comprising different concentrations of heavy metals must be monitored during composting. According to the results, more than 98% of the study are has a moderate vulnerability class (V3) relates to heavy metals as a significant concern in this region, claimed that there was no different source of heavy metals as well as manure applications over the study area. The most significant risk of extensive pesticide use is the leaching and drainage of pesticides into surface and groundwater (De la Rosa and Sobral, 2008). Pesticide contamination risk in wheat fields demonstrating a total of 60% and 55% of the study area show a high and moderate risk, respectively. A somewhat similar trend was also observed for corn fields. Finally, we obtained evidence that an expert system approach within the Ero & Con package is a useful tool to classify vulnerable areas according to soil functions (De la Rosa et al., 2004). Overlapping the above mentioned results with land units using GIS were shown in Figure 4.

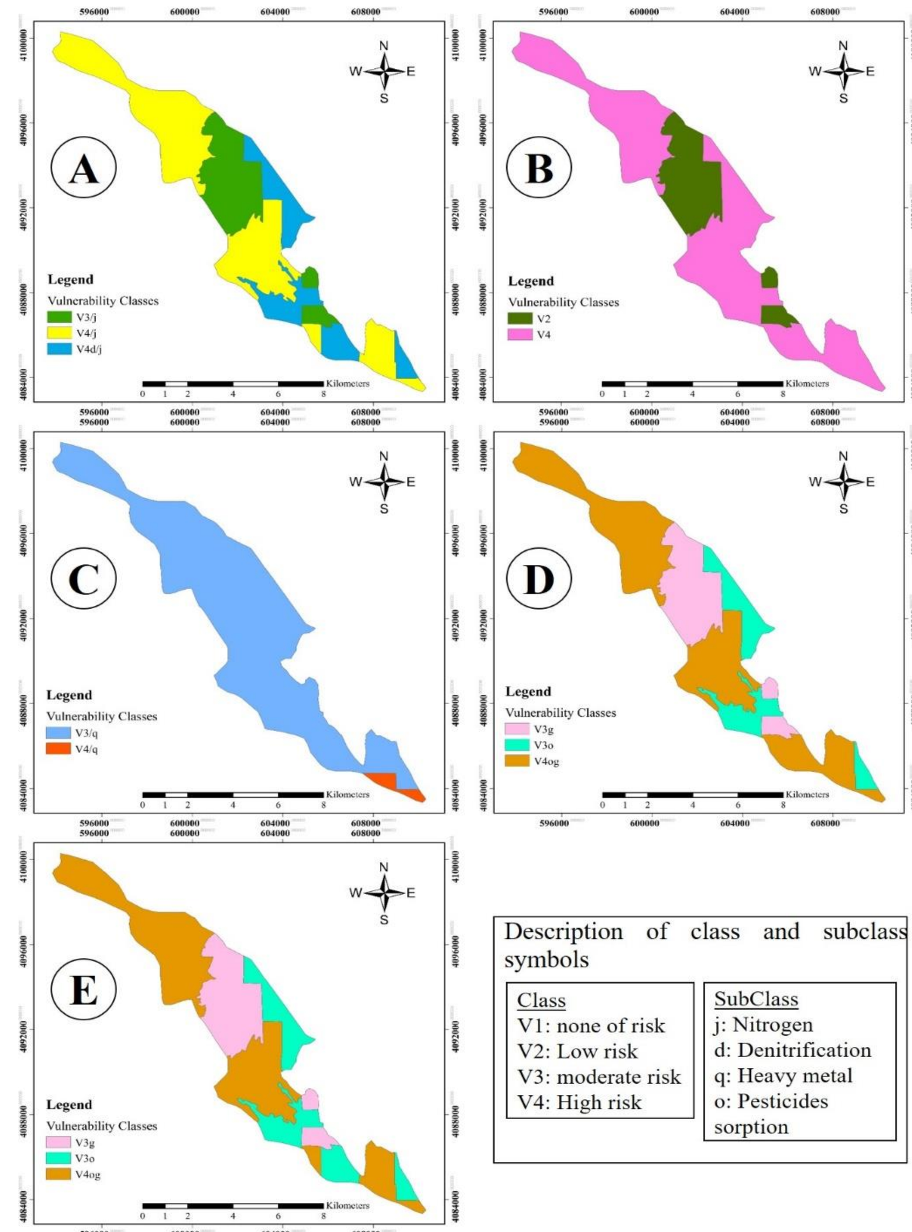

Fig. 4. Applying model spatially resulted by Pantanal. A, B and C represent the vulnerability classes of N, P and H, respectively; D and E represent the vulnerability classes in terms of X for wheat and corn, respectively.

4. CONCLUSION

Since sustainable agriculture development can be achieved using simultaneously land suitability and vulnerability evaluation, it was concluded that Raizal and Pantanal models within the MicroLEIS DSS were successfully conducted in prediction of erosion and specific contamination in Miandoab region. The actual risk was not addressed in this article due to the taken results were as an attainable mode.

Integrating the model results with GIS demonstrated that it eases the interpretation of occurred challenges in the area based on the present soil families as well as geographical location. One important finding of this research is that the study are is more susceptible for wind erosion than water erosion. Furthermore, Aridisols is the most susceptible order compared with Entisols and Inceptisols across the study area. In terms of specific pollution, it was found that there was a minor variation regarding pesticide while there were no different vulnerability classes among the utilization types in terms of P, N and H for the entire study area.

Assessing the vulnerability of the study area with respect to optimum moisture for working and selection of suitable machinery type, it is advised to evaluate using the Engineering and Technology (Eng & Tec) package too.

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