SOCIO-ECONOMIC AND ENVIRONMENTAL VULNERABILITY TO HEAT-RELATED PHENOMENA IN DOBROGEA. ROMANIA

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ABSTRACT

The effects of extreme climate phenomena (mainly heat-related) on agricultural crops, infrastructure and human health have become increasingly severe, varying between regions in response to the differences in the socio-economic and environmental features. In Romania, heat-related phenomena (i.e. drought) are affecting extended areas in the southern and south-eastern parts where the study area (Dobrogea) lies. The paper aims to develop a multi-criteria vulnerability assessment. Over 20 indicators were selected and processed in order to assess the vulnerability to heat-related phenomena using the statistical data available at local administrative units (LAU). The indicators were grouped into the three key components of vulnerability (potential exposure, sensitivity and adaptive capacity) and on two dimensions (socio-economic and environmental), resulting two indexes: Socio-Economic Vulnerability (SEV) and Environmental Vulnerability (EV). Finally, an integrated Heat Vulnerability index (HV) (using Hull score, average 50 and standard deviation 14) was computed.

Keywords: *Socio-Economic Vulnerability index (SEV); Environmental Vulnerability index (EV); Heat Vulnerability index (HV), Dobrogea*

INTRODUCTION

During the last decades almost every region has witnessed an increase in the occurrence and intensity of the effects of extreme climate phenomena (mostly heat-related) on society and economy. The local responses to the adverse effects of heat-related phenomena significantly vary in relation to the differences in the socio-economic and environmental characteristics. Because of the high damage potential of heat-related phenomena, i.e. droughts (e.g. economic losses, ecological damages, and negative implications on life quality through the injury of human health), the socio-economic and environmental vulnerability assessment raised the interest for development of indices [1]. According to [2], the quantification of vulnerability can be made at local scale but it should be based on a global scale conceptual approach. Thus, in this paper, the components of the vulnerability were addressed in the light of international conceptual and methodological framework of vulnerability assessment; vulnerability is a function of exposure, sensitivity and adaptive capacity

[3]. In Romania, heat-related phenomena (mainly drought) are affecting wide areas in the southern and south-eastern parts where the study area (Dobrogea) lies. The current study aims to assess the socio-economic and environmental vulnerability to heat-related phenomena (i.e. drought) in Dobrogea having as main research steps: ***i)*** to characterise each local administrative unit (LAU) in terms of susceptibility to the negative effects of drought; ***ii)*** to determine the vulnerability level based on statistical indicators and secondary indexes; ***iii)*** to integrate these indexes into a single final index of heat-related vulnerability.

STUDY AREA

Dobrogea is located in south-eastern part of Romania (Fig. 1), being almost entirely surrounded by the Danube River (in the west and north) and by the Black Sea (in the east).

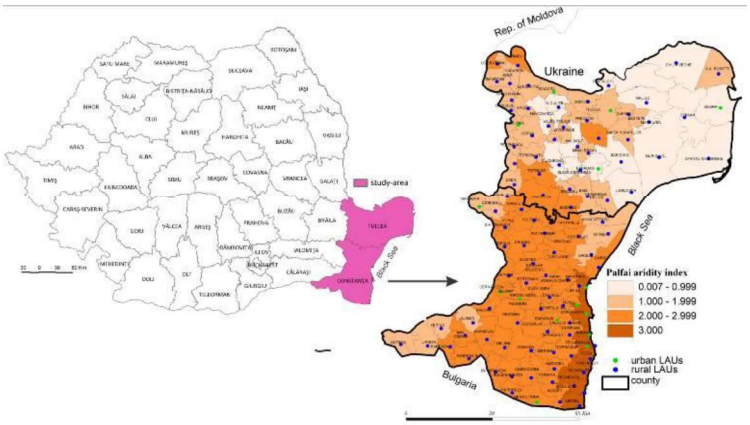


Fig. 1. The location of the study area in Romania

The area is made up by 2 counties (Tulcea and Constanța), counting a total area of 15,570 km^2 and a population of about 999,000 inhabitants. The study-area fully feels the climatic influences of water surfaces, especially in coastal strip, but in has a semi-arid continental temperate climate [4].

Dobrogea is an unique region in terms of natural (the oldest land of the country from a geological point of view Casimcea Plateau and the newest – Danube Delta), historic (since Antiquity it bears the positive and negative effects of the geo-strategic position between the Black Sea, Danube River and its delta), cultural (an ethnic, confessional and linguistic mosaic) and economic (e.g. the largest Romanian seaport - Constanța, river and sea harbours - Galați, Tulcea, extended, fertile and productive arable land, renewable energy resources – solar and wind). All these landmarks influence each component of vulnerability of both socio-economic and environmental dimensions.

METHODOLOGY

In order to select and apply the best set of socio-economic indicators to heat-related phenomena, this study also took into account the analysed climate hazard

(i.e. drought) in relation to the characteristics of the underlying biophysical conditions. In order to highlight the areas exposed to heat-related phenomena in Dobrogea, the authors used Palfai aridity index, which considers an initial complex of factors (air temperature and precipitation) corrected by the number of extremely hot days, the number of days with precipitation amounts $\leq$ 0.5 mm and the groundwater contribution. In this way, it highlights the drought phenomena in its complexity.

Theoretically, as agreed by the scientific community [5], [6], [7], the socio-economic and environmental vulnerability is influenced, among other factors, mainly by population density, age, gender, race and ethnicity, income, the quality of inhabited environment, occupancy, rural-urban relations, education, water resources and their accessibility, medical services and health status, land use/cover, climate conditions, vegetation etc. Thus, in order to build-up a successful method, all these factors should be reflected in their main internal features by statistical indicators. Their selection is a very important step for compute the secondary and final indexes of vulnerability. The conceptual and empirical frameworks, the drought vulnerability indicators, the persistent gaps in drought vulnerability assessment are only few relevant issues debated by academics [8], [9], and by the worldwide and European bodies focused on climatic changes (e.g. European Drought Observatory, Intergovernmental Panel on Climate Change - [10], [2], [11]. The assessment of drought vulnerability in Dobrogea is based on this broad scientific background. Some of the indicators were considered as the most relevant for the socio-economic and environmental dimensions of vulnerability (i.e. dependency on agricultural land for livelihood, irrigated land, water resources, water quality, access to clean water), as they have already been evaluated by [2], [11], [9].

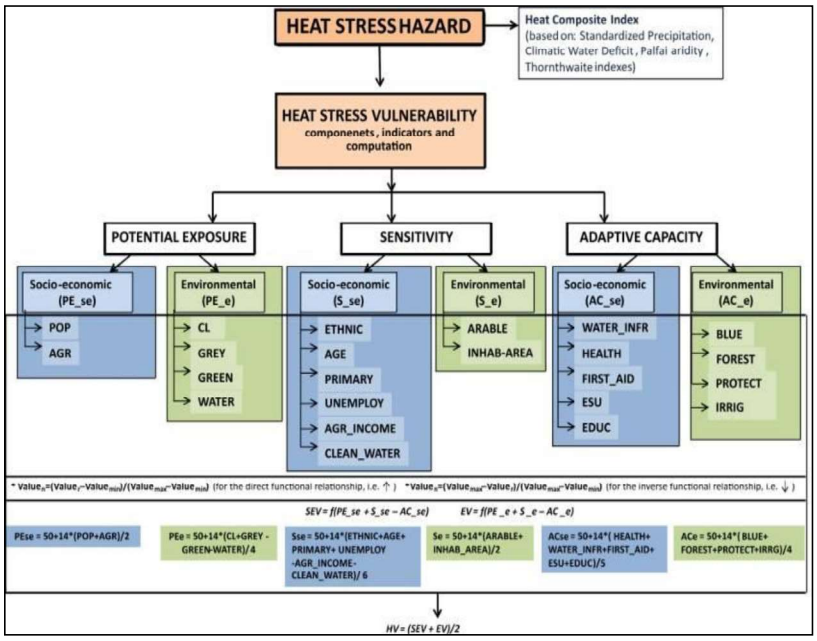


Fig. 3. Vulnerability assessment framework to heat-related phenomena (based on & adapted after: [2], [7], [9], [11], [12], [13]. Note: please see Table 1. for abbreviations, descriptions and data sources

In addition, other indicators were included (e.g. aged and very young persons, unemployment, areas protected for biodiversity conservation) based only on their availability and significance at local territorial level. Fig. 3 shows the main steps of the heat stress vulnerability approach.

Table 1. Selected indicators – details useful for their importance in methodological approach

Indicators/Abbreviation	**Description *(i)*, data sources *(ii)* and measurement units *(iii)***
1.Permanent resident population=**POP**	***(i)*** number of persons with Romanian citizenship and permanent residence at LAU level; ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** number of persons.
2.Agricultural area=**AGR**	***(i)*** all agricultural lands (arable, pastures, meadows, vineyards and vine nurseries, orchards and fruit tree nurseries) from the farm registers; ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** ha.
3. Climate conditions=**CL**	***(i)*** Palfai aridity index ***(ii)*** National Meteorological Administration ***(iii)*** units.
4. Impervious surfaces (grey areas)=**GREY**	***(i)*** land covered by built-up areas and infrastructure-related uses (e.g. roads, parking lots) at LAU level; ***(ii)*** Urban Atlas Copernicus Land Service dataset (2012); ***(iii)*** %.
5.Green areas=**GREEN**	***(i)*** land covered by "green fingerprint" in different shares, regardless of their structure or functionality (e.g. green urban areas, pastures, forests), as well as green

	infrastructure (e.g. isolated trees, tree lines) at LAU level ***(ii)*** Urban Atlas Copernicus Land Service dataset (2012), Street Tree Layer (STL); ***(iii)*** %.
6.Water resources=**WATER**	***(i)*** surface water bodies (e.g. rivers, lakes, ponds) and groundwater productivity; ***(ii)*** Urban Atlas Copernicus Land Service dataset (2018), International Hydrogeological Map of Europe, scale 1:1500000 (2008); ***(iii)*** %.
7.Vulnerable age groups=**AGE**	***(i)*** persons aged 65 and above and the children (0 to 10 years old); ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** %.
8.Ethnic Diversity Index=**ETHNIC**	***(i)*** Ethnic Diversity Index (EDI) is based on the share of the minorities of total population ***(ii)*** NIS, Census 2011; ***(iii)*** %
9. Dependency on primary sector for livelihood=**PRIMARY**	***(i)*** population employed in agriculture, forestry and fishing of the total population; ***(ii)*** NIS, Census 2011; ***(iii)*** %.
10. Unemployment rate=**UNEMPLOY**	***(i)*** unemployed population of the total labour resources aged 18-62 years ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** %.
11. Agricultural income=**INCOME_AGR**	***(i)*** households income as money from agriculture multiplied by the number of employed population in agriculture/LAU level; ***(ii)*** computed by authors based on NIS-Romanian Statistical Yearbook 2017 and TEMPOnline time series, using a methodology developed by [14]; ***(iii)*** Lei/month/LAU.
12. Access to clean water=**CLEAN_WATER**	***(i)*** houses connected to the drinking water supply network ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** km of water supply network/1,000 inhabitants.
13. Cultivated environment (arable land)=**ARABLE**	***(i)*** arable land from farm registers; ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** ha.
14. Inhabited environment=**INHAB_AREA**	***(i)*** total floor areas of habitable rooms, measured by interior dimensions/1,000inh.; ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** m^2.
15. Connectivity to drinking water infrastructure=**WATER_INFR**	***(i)*** length of drinking water infrastructure/LAU ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** km.
16. Health care services provided by high-level medical infrastructure=**HEALTH**	***(i)*** health care infrastructure as the number of hospital beds in each LAU ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** no. of hospital beds/1,000 inhabitants.
17. Pharmacies=**FIRST_AID**	***(i)*** pharmacies considered as fist aid points/LAU; ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** no. of pharmacies/1,000 inhabitants.
18. Early warning and intervention services=**ESU**	***(i)*** Inspectorates for Emergency Situations; ***(ii)*** https://www.igsu.ro/; ***(iii)*** number of Emergency Situations Units/1,000 inhabitants.
19. Education level=**EDUC**	***(i)*** literates; (ii) NIS, 2011 Population Census returns; ***(iii)*** % of literates/total over 10 year-old population

20. Heat management & adaptation in agriculture=**IRRIG**	***(i)*** measures to cope with heat stress in agriculture (i.e. irrigation); ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** ha irrigation network.
21. Blue areas=**BLUE**	***(i)*** land covered by static or dynamic surface water bodies (e.g. rivers, lakes, ponds) ***(ii)*** Urban Atlas Copernicus Land Service dataset (2018); ***(iii)*** %.
22. Forest areas=**FOREST**	***(i)*** land covered by forest areas ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** %.
23. Protected areas=**PROTECT**	***(i)*** land covered by protected areas (natural reserves, Natura 2000) ***(ii)*** NIS, TEMPOnline time series; ***(iii)*** ha.

The statistical data used in the current study, available at 121 LAU level - the lowest level administrative-territorial units -, was provided by the TEMPO-Online time series published by the National Institute of Statistics.

The set of indicators was introduced in a graph matrix to establish the degree of determination or subordination of each statistical indicator on a dichotomous query [15]. Each indicator, which had the highest value of the general level of determination, has been maintained as is shown in Tab. 1, with its influence on vulnerability (Tab. 2). All indicators are equally weighted in the final index. The values of SEV, EV and HV show the levels/degrees of exposure, sensitivity and adaptive capacity to heat-related phenomena, as reflected by all figures and Table 3.

Table 2. Selected indicators and their influence on socio-economic and environmental vulnerability to heat-related phenomena

Abbreviation	Influence of indicators on heat vulnerability	Final expression of influence
1. POP	If ↑ POP, then VULN ↑	+
2. AGR	If ↑ AGR, then VULN ↑	+
3. CL	If ↑ CL, then VULN ↑	+
4. GREY	If ↑ GREY, then VULN ↑	+
5. GREEN	If ↑ GREEN, then VULN ↓	-
6. WATER	If ↑ WATER, then VULN ↓	-
7. AGE	If ↑ AGE, then VULN ↑	+
8. ETHNIC	If ↑ ETHNIC, then VULN ↑	+
9. PRIMARY	If ↑ PRIMARY, then VULN ↑	+
10. UNEMPLOY	If ↑ UNEMPLOY, then VULN ↑	+
11. INCOME_AGR	If ↑ INCOME_AGR, then VULN ↓	-
12. CLEAN_WATER	If ↑ CLEAN_WATER, then VULN ↓	-
13. ARABLE	If ↑ ARABLE, then VULN ↑	+
14. INHAB_AREA	If ↑ INHAB_AREA, then VULN ↑	+
15. WATER_INFR	If ↑ WATER_INFR, then VULN ↓	-
16. HEALTH	If ↑ HEALTH, then VULN ↓	-
17. FIRST_AID	If ↑ FIRST_AID, then VULN ↓	-
18. ESU	If ↑ ESU, then VULN ↓	-
19. EDUC	If ↑ EDUC, then VULN ↓	-
20. IRRIG	If ↑ IRRIG, then VULN ↓	-
21. BLUE	If ↑ BLUE, then VULN ↓	-
22. FOREST	If ↑ FOREST, then VULN ↓	-
23. PROTECT	If ↑ PROTECT, then VULN ↓	-

RESULTS AND DISCUSSIONS

The ***socio-economic potential exposure*** (***PE_se***) index depends on POP and AGR. The first indicator recorded a territorial concentration in three distinct areas: ***i)*** the two regional county-seats (i.e. Constanța and Tulcea); ***ii)*** along the A2 Highway that crosses from west to east the study-area and ***iii)*** in the southern coastal areas. The PE_se index shows a relative homogenous low level, exceptions being the two county-seats and the Delta area, with average and very high levels (Fig. 4).

The ***environmental potential exposure*** (***PE_e***) is shaped by four indicators: of which CL and GREY increase its level, while GREEN and WATER decrease it.

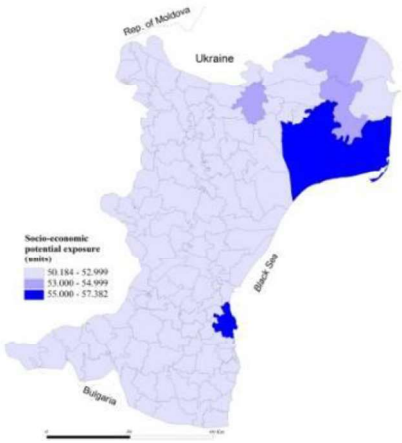


Fig. 4. The socio-economic potential exposure

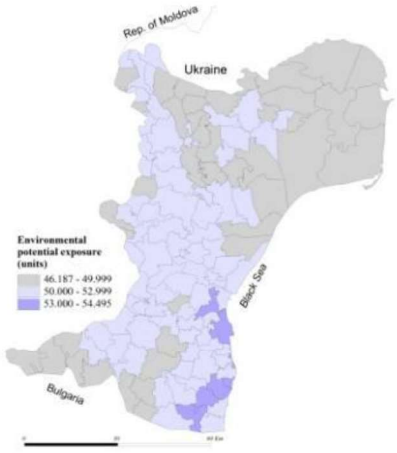


Fig. 5. The environmental potential exposure

Fig. 5 shows the predominance of very low (north-eastern and extreme south-western parts) and low (north, centre and south) PE_e levels. The largest impervious surfaces coupled with the highest Palfai index values explain the average PE_e index in the southern coastal area.

In the study-area, the ***socio-economic sensitivity*** (***S_se***) has a very homogenous territorial distribution with the predominance of the low level of this index (Fig. 6). The fact is explained by a mix of two situations: ***i)*** the indicators which increase the S_se (e.g. ETHNIC, AGE) have values close to the regional average and a balanced territorial distribution; ***ii)*** other indicators which increase (e.g. EMPLOY_AGR) or decrease (e.g. CLEAN_WATER) the S_se have an homogenous territorial distribution of their high values, an opposite situation to ***i)*** but with the same effect on the spatial distribution of the S_se index, in terms of a balanced one. Average S_se values are recorded in 12 LAUs territorially concentrated mainly in the northern half of the study area, while very high S_se values are registered in one LAU, in extreme south-west of Constanța County (Fig. 6).

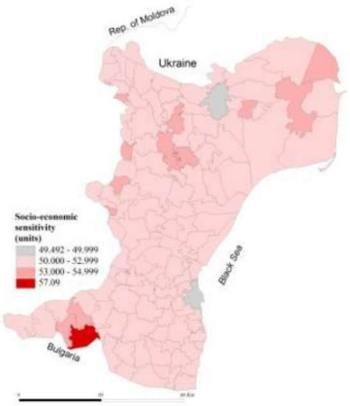


Fig. 6. The socio-economic sensitivity

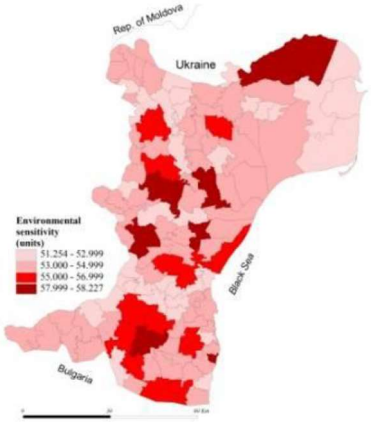


Fig. 7. The environmental sensitivity

The ***environmental sensitivity*** (***S_e***) appears to register a territorial variation in relation to the two indicators it relies on, i.e. ARABLE and INHAB. ARABLE is largely spread in study area, especially in the central and southern parts, while INHAB registers the highest values in north and on coastal sector (Fig. 7).

The ***socio-economic adaptive capacity*** (***AC_se***) is shaped by five indicators (Fig. 3) and their high level is linked with the highest values of WATER_INFR, HEALTH, FIRST_AID and EDUC; these values are specific to Constanța county-seat and to its surrounding area. Also, one deltaic LAU falls into the high AC_se level, due to the highest ESU values. Extended areas register low and very low AC_se levels, especially those located in the northern and extreme southern parts. These LAUs are devoid of several vital services, e.g. drinking water infrastructure, education, health care services, first aid units and early warning and intervention services (Fig. 8).

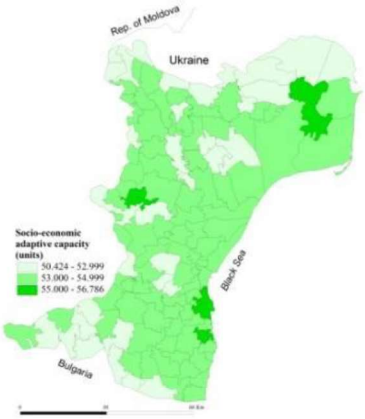


Fig. 8. The socio-economic adaptive capacity

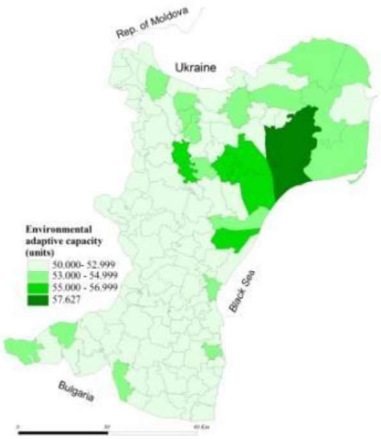


Fig. 9. The environmental adaptive capacity

In terms of the ***environmental adaptive capacity*** (***AC_e***), the study-area is divided in two areas: ***i)*** an extended one comprising the central, north-western and southern parts, which registers the lowest AC_e levels; ***ii)*** a smaller one, in north-eastern part, recording average (in 11 LAUs from the Danube

Delta and North Dobrogea Plateau, with high value of FOREST and PROTECT), high (in 5 LAUs with very high values of indicators considered) and very high (in one deltaic settlement, with very large protected and "blue" areas) AC_e levels (Fig. 9).

According to the ***heat socio-economic vulnerability*** (***SEV***) index, Dobrogea is dominated by the very low and low levels in northern and western parts. Three LAUs (in Tulcea County) register average SEV level and one LAU very high level (extreme south-west of Constanța County). This situation is driven by the different PE_se levels: a high level in Constanța county-seat and in few deltaic localities, the territorially dominant average of S_se and AC_se, with high degrees only in Constanța county-seat and in one deltaic settlement (Fig. 10).

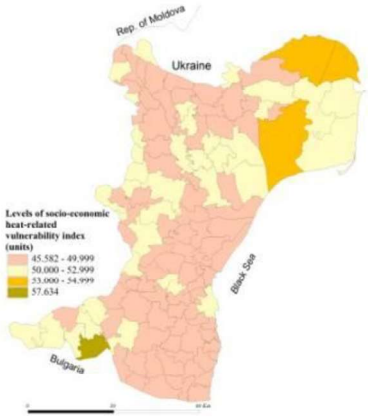


Fig. 10. Heat socio-economic vulnerability

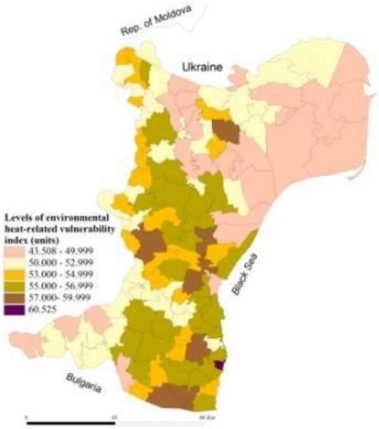
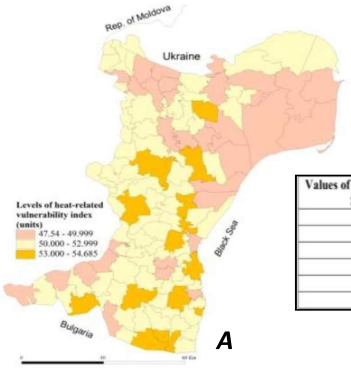


Fig. 11. Heat environmental vulnerability

The ***heat environmental vulnerability*** (***EV***) index varies between very low and high, with a predominance of very low and low in the north-eastern part. The central and south-eastern parts are dominant by high EV because of a very low AC_e, high and very high S_e and a general low and average PE_e (Fig. 11)

In Dobrogea, the prevalence of very low and low levels registered by the final ***heat vulnerability*** (***HV***) index (88% of total LAUs analysed) is presented in Fig. 12. The LAUs with HV average level are mainly located in Constanța County) being linked with the high and very high EV levels which are caused by the highest S_e level and the very low AC_e level.



Values of PE, S and AC to heat stress and of SEV, EV and HV indexes	Levels/degrees of PE, S and AC to heat stress and of SEV, EV and HV indexes
Minimum – 49.99	Very low
50.00 – 52.99	Low
53.00 – 54.99	Average
55.00 – 56.99	High
57.00 – 59.99	Very high
60.00 - maximum	Extremely high

B

Fig. 12. Heat vulnerability (HV) index (A); SEV, EV and HV values and the levels of PE, S and AC to heat stress

The lowest HV level recorded by a large area in Dobrogea is due to the low and very low SEV levels in several sub-areas overlapped by the same EV levels (e.g. in extreme south-western, northern and partially central parts of the study-area).

CONCLUSIONS

In Dobrogea, the climate features are combining with two different socio-economic and environmental situations: ***i)*** in the urban areas and along the southern coastal sector, they are overlapped high population densities, continuous built-up areas, traffic-induced pollution, lack/reduced vegetation cover etc.; ***ii)*** in the large rural areas, they are linked with high and very high levels of socio-economic and environmental sensitivities and with a very low or the lack of adaptive capacity. These differences between urban and rural areas indicate the need for future researches to be carried out at finer scales (e.g. "HV urban and rural hotspots") in order to complete the existing picture of the socio-economic vulnerability in a complex and varied region as Dobrogea is in terms of climatte, social and economic features. Within this context, the current research would be fruitful for academics (to replicate and/or to improve the methodology for future studies), but also for local decision-makers and planners, thus further contributing to the local climate change-related mitigation and adaptation strategies.

ACKNOWLEDGEMENTS

The current study was equally performed within two research projects **(1)** GAR-UM-2019-XI-5.4-2 "Sets of statistical indicators for assessing the socio-economic vulnerabilities to extreme climate events in Romania. A territorial multi-scales development, adaptation and valorization (VULSERO)" financed by the Romanian Academy ("PATRIMONIU" Foundation) and **(2)** Pollution Identification, Mapping, and Ecosystem Observation with AI-powered water quality USV, ERANET- MarTERA-PIMEO-AI-1.

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