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Thermal Resistance of Clothing in Human Biometeorological Models

Ferenc Ács^{A*}, Zsófia Szalkai^A, Erzsébet Kristóf^A, Annamária Zsákai^B

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Abstract

Three different clothing thermal resistance (r_{cl}) schemes are compared using meteorological and human data collected in Martonvásár. Model 1 is the most complex, it is energy balance based. Model 3 is the simplest, it is the UTCI-clothing model used as submodel in the UTCI (Universal Thermal Climate Index) scheme. It uses air temperature as sole input. Model 2 uses more data than model 3, the data used are the thermal insulation values of the clothing worn. Meteorological data refer to the town Martonvásár. The data were collected in the period August 9, 2016 – May 23, 2018. The main result is that the r_{cl} values obtained by model 1 differ significantly in most of the cases from the results obtained by models 3 or 2. The fact that the results of model 1 rarely match the results of model 3 or model 2 suggests that the energy balance between human body and environment is rarely achieved, merely this is the case in approximately 10 percent of the cases.

Keywords: clothing thermal resistance; energy balance of the human body; clothing ensemble; air temperature; environmental heat deficit; metabolic heat flux density

Introduction

In our day and age, mainly models based on energy balance are used in the human biometeorological investigations (Potchter et al., 2018). It should be emphasized that the human factor can be fully taken into account only in these models. The human factor refers to the activities of people and the clothing they wear. Both factors are decisive in terms of human thermal load and sensation.

Clothing exerts its thermal effect mainly through its thermal insulation. The thermal insulation of clothing (r_{cl}) is mostly an unknown parameter and it varies highly from person to person. It can be both an input and output variable of the energy-balance-based biometeorological models. It is used as an input variable in the vast majority of models, such as in the most commonly used PMV (Predicted Mean

Vote), (Fanger, 1970), PET (Physiologically Equivalent Temperature), (Höppe, 1999), or UTCI (Universal Thermal Climate Index), (Fiala et al., 2012) models. In these models, r_{cl} is either constant (e.g. Höppe, 1999) or can be estimated in a very simple way by parametrization (Havenith et al., 2012; Olesen, 1985). In these cases, the personal variability of r_{cl} is not taken into account at all, although this variability can be very large. There are also models (e.g. Auliciems & de Freitas, 1976; Auliciems & Kalma, 1979; Yan, 2005; Yan & Oliver, 1996), in which r_{cl} is an output variable. In these models, r_{cl} is determined on the basis of energy balance of the clothed human body-environment system. These models are a lot less often used compared to the ones, in which r_{cl} is used as input variable.

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As we mentioned, the thermal effect of the individual differences between human characteristics can only be taken into account in models based on energy balance (de Freitas & Grigorieva, 2015). In these models, a person is characterized by his/her activity-related metabolic heat flux density (M), clothing, and thermal sensation. The last factor is the most complex phenomenon, it can only be estimated by asking people; the pioneering work of Fanger (1970, 1973) should be highlighted in this regard, which determined the development of the entire profession. The methodology for estimating M has also improved a lot, among these works we would highlight Weyand et al. (2010), in which M is parameterized for individuals walking at different speed. Clothing is at least as much a variable and individual factor as the previous two due to its thermal insulation. The thermal insulation of clothing can only be accurately determined by measurement. These measurements are time consuming, expensive and individual measurements have no sense due to high interper-

son variability. Therefore r_{cl} is commonly determined by parameterizations. It is clear that r_{cl} values determined by parameterizations and on the basis of the energy balance of the human body-environment system don't necessarily have to agree. To our knowledge there is no work yet dealing with the comparison of r_{cl} values obtained using different methods.

Based on the aforementioned, the aim of this work is 1) to compare three r_{cl} calculation methods and 2) to test the sensitivity of the energy-balance-based method to variations of wind speed and M . In the following, model 1 is the energy-balance-based method; model 2 is the clothing ensemble model of Olesen (1985), which can be viewed as the most empirical; and model 3 is the wellknown UTCI-clothing model (Havenith et al., 2012). After the presentation of the methods follows a detailed description of the data collected, which is then followed by the presentation and discussion of the results. Eventually, the most important conclusions are drawn at the end.

Clothing thermal resistance models

The basic equations of the models are as follows.

Model 1: Thermal resistance of clothing can be estimated from the energy balance equation of the human body-clothing-environment system (Ács et al., 2021). It can be expressed as follows,

$$r_{cl} = \rho \cdot c_p \cdot \frac{T_s - T_a}{M - \lambda E_{sd} - \lambda E_r - W} - r_{Hr} \cdot \left[\frac{R_{ni}}{M - \lambda E_{sd} - \lambda E_r - W} + 1 \right],$$

where ρ is air density [kgm^{-3}], c_p is specific heat at constant pressure [$\text{Jkg}^{-1} \text{ } ^\circ\text{C}^{-1}$], T_a is air temperature [$^\circ\text{C}$], T_s is skin temperature [$^\circ\text{C}$] (a constant, $34 \text{ } ^\circ\text{C}$), r_{Hr} is the combined resistance for expressing thermal radiative and convective heat exchanges [sm^{-1}], R_{ni} is the isothermal net radiation flux density [Wm^{-2}], M is the metabolic heat flux density [Wm^{-2}], λE_{sd} is the latent heat flux density of dry skin [Wm^{-2}], λE_r is the respiratory latent heat flux density [Wm^{-2}] and W is the mechanical work flux density [Wm^{-2}] referring to each activity, in this case walking. In our model applications, the walking speed is 1.1 ms^{-1} .

The parameterization of environmental and human factors is described in the work of Ács et al. (2019, 2021). The human body is considered as a single node and since T_s is an input variable and r_{cl} is an output

variable, this model is the inverse of the common energy-balance-based models (e.g. Fanger, 1970, 1973).

Model 2: Thermal resistance of clothing can also be estimated on the basis of thermal insulation of the garments (Olesen, 1985) that make up the clothing. The expression is as follows,

$$r_{cl} = \sum_{i=1}^n r_{cl,i},$$

where r_{cl} is the resulting thermal insulation of total clothes worn, $r_{cl,i}$ is the thermal insulation of the i^{th} garment and i is the number of garments. The r_{cl} value obtained this way can be used as input variable in each model, where T_s is an output variable. The model can be called as clothing ensemble model.

Model 3: Thermal resistance of clothing is estimated in the UTCI model as follows,

$$r_{cl} = 1.372 - 0.01866 \cdot T_a - 0.0004849 \cdot T_a^2 - 0.000009333 \cdot T_a^3,$$

where T_a is the air temperature. The model can be referred to as the UTCI-clothing model (Havenith et al., 2012).

Data

Atmospheric and human data are used. They are collected in Martonvásár (geographical latitude 47.31 °N, geographical longitude 18.79 °E), more precisely, during running events at the running track surrounding the soccer field in Martonvásár.

occasions. In other occasions, when there was environmental heat surplus, the energy-balance is not met since the process of sweating (evaporation from the wet skin) is not simulated. In these cases, the value of r_{cl} is negative, which cannot be interpreted physically. In

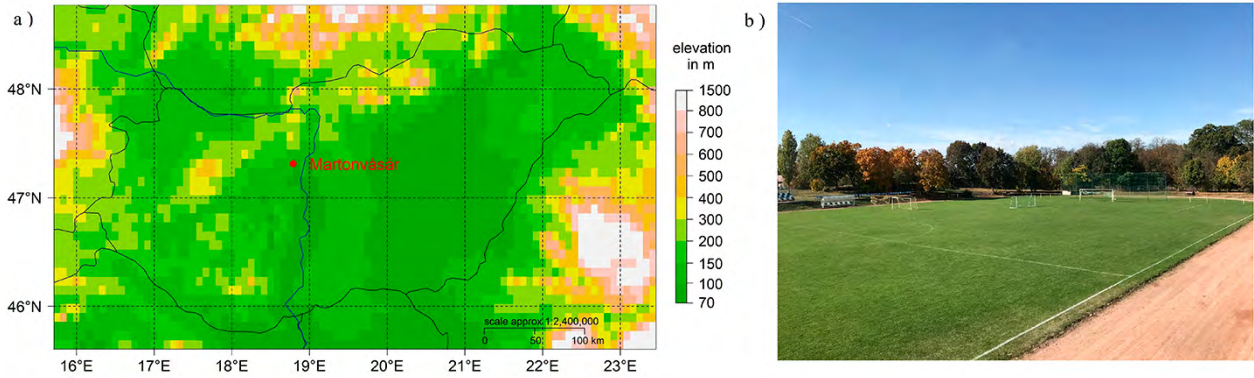


Figure 1. Location of Martonvásár in Hungary and the running track surrounding the soccer field in Martonvásár
Photo by: Ferenc Ács

Atmospheric data

There were in total 112 occasions of running activity (Ács et al., 2019) in the period August 9, 2016 – May 23, 2018. Atmospheric data were collected on each running occasion. Out of these 112 occasions, the energy-balance-based method (method 1) is applicable in 74

the following, we will consider only the applicable cases. Values of air temperature, air humidity, average wind speed, wind gust speed and atmospheric pressure data are taken from the website of Hungarian Meteorological Service (HMS) and refer to Martonvásár. The meteorological station in Martonvásár is one of the stations

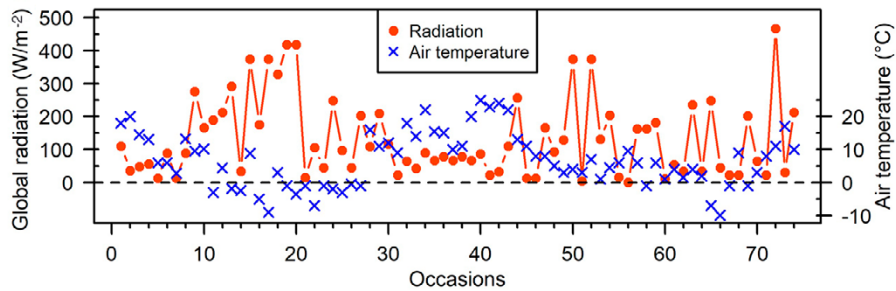


Figure 2. Evolution of air temperature and global radiation values registered during the 74 occasions of running on the Martonvásár athletics track

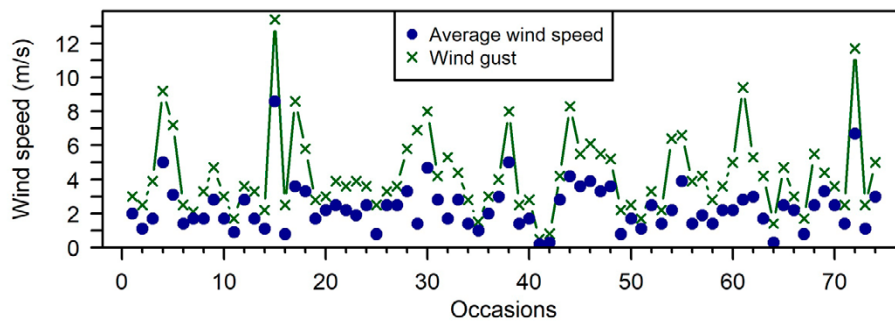


Figure 3. Evolution of average wind speed and wind gust speed values registered during the 74 running occasions on the Martonvásár athletics track

of the Hungarian Meteorological Service from about a thousand stations. The Martonvásár meteorological station - soccer field beeline distance is 100-150 m. Data refer to periods of 10-minutes. The 10-minute period is at the middle of the running activity. The beginning and the end of each running is regularly documented. Relative sunshine duration and cloudiness are visually observed. The referring air temperature and global radiation values as well as wind speed values are presented in Figure 2 and 3, respectively.

Air temperature changed between 10 and 25 °C, whilst global radiation between 0 and 460 Wm⁻². There were cases of lower temperatures coupled with higher values of global radiation (e.g. occasion 17 on January 1, 2017; occasion 19 on January 15, 2017; occasion 20 on January 19, 2017), and conversely, higher temperatures coupled with lower global radiation values (e.g. occasion 40 on April 18, 2017; occasion 41 on April 23, 2017 and occasion 42 on April 26, 2017). Average wind speed changed between 0.5 and 8.5 ms⁻¹, but it fluctuated mostly between 2-3 ms⁻¹. Wind gust speed values were mostly between 3 and 6 ms⁻¹, values exceeded 10 ms⁻¹ only twice. Note that wind gust speed was lower than 1 ms⁻¹ on two occasions.

Human data

There are two types of human data: a) human state variables and the referring basal, walking and total energy flux densities and b) thermal insulation values of garments making up clothing. The anthropometric and energy flux density data of the persons included in the study are presented in Table 1. The heat and energy flux density values shown in Table 1 (the last three columns) were calculated according to Ács et al. (2019) (equations (10)-(14)). Only one person (person 1) undertook the long-term longitudinal experiment – simultaneous and parallel documentation of the weather, activity and the clothing worn. It should be mentioned that such long-term experiments are very rare given the complexity of the work to be performed. The anthropometric data of persons 2 and 3 were used only when the sensitivity of model 1 to changes in metabolic heat flux density was examined (below in chapter: Results, section: Sensitivity of model 1 to metabolic heat flux changes).

Thermal insulation data of the garments making up the clothing of person 1 used during running events are summarized in Table 2.

Table 1. Human characteristics of the persons in the study

Persons	Sex	Age [years]	Body mass [kg]	Body length [cm]	Basal metabolic heat flux density [Wm ⁻²]	Walking energy flux density [Wm ⁻²]	Total energy flux density [Wm ⁻²]
Person 1	male	66	89	190	40.8	94.5	135.3
Person 2	male	53	95	179	42	108	150
Person 3	male	24	120	179	46	124.9	170

Table 2. The thermal insulation value of garments worn and the total thermal insulation value of clothing worn in different seasons based on model 2

GARMENTS	
Summer clothes	
Name	Thermal insulation value (clo)
swim briefs	0.04
shorts	0.06
ankle socks	0.05
sneakers	0.08
	in total 0.23
Autumn clothes	
Name	Thermal insulation value (clo)
swim briefs	0.04
sweatpants	0.25
shirt short sleeve	0.1
thin gray sweater	0.2
thick orange sweater	0.3
green vest	0.13
ankle socks	0.05
sneakers	0.08
thick gloves	0.05
black cap	0.05
	in total 1.25
Winter clothes	
autumn attire complete with 1 pair of socks and 1 pantyhose	in total 1.25 + 0.05 + 0.20 = 1.50

The thermal insulation value is expressed in clo unit, which was introduced by Gagge et al. (1941). 1 clo is 0.155 (m² · °C)/W. Thermal insulation values expressed in clo for different garments are taken from literature (e.g. Parsons, 2014; Innova, 2002). It is worth mentioning that the same clothes were used during the runs, it is only their combination that may have changed from run to run. As mentioned, the weather, the clothing worn and the activity (duration of the run, weight before and after the run) were documented after each running event. Of course, the wearing of clothes had seasonality. Table 2 also provides information on these possible seasonal thermal insulation values on the basis of model 2.

Results

Applying the models we a) compared their behavior and b) examined the sensitivity of model 1 to the changes of wind speed and M . The sensitivity of model 1 to changes in wind speed was investigated by comparing r_{cl} values obtained for average wind speed and wind gust speed. The sensitivity of model 1 to changes in M was examined by comparing the r_{cl} values obtained for the M value of person 1 and the r_{cl} values obtained for the M values of persons 2 and 3. We chose wind speed because it is one of the most rapidly changing factors among the meteorological state variables. In model 1, the person is represented by M , so, the variability between people is expressed via variability of M .

Comparison of the models

The comparison of the models can only be done for person 1, since, as mentioned, there is no documented data for the clothes and weather of person 2 and 3. There are three comparisons: results obtained by model 1 are compared by results obtained by model 2 and 3, and lastly, results obtained by model 2 and 3 are also compared. Each comparison contains 74 points, that is, there are exactly as many points in each scatter chart as there are applicable running events. Comparison of r_{cl} values of person 1 obtained by model 1 and 2 is presented in Figure 4.

We can see that for r_{cl} values smaller than 1 clo, most of the points are below the dashed line, that is, model 2 overestimates model 1. For r_{cl} values greater than 1 clo, the scatter of points is much larger and model 1 can overestimate significantly model 2. It

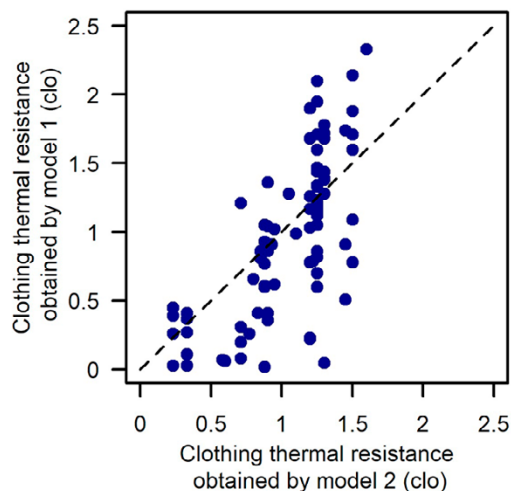


Figure 4. Scatter chart of clothing thermal resistance of person 1 obtained by model 1 (inverse application of the energy-balance-based model) and model 2 (clothing ensemble model)

seems that the agreement of the models increases as heat deficit increases. Comparison of r_{cl} values of person 1 obtained by model 1 and 3 is presented in Figure 5.

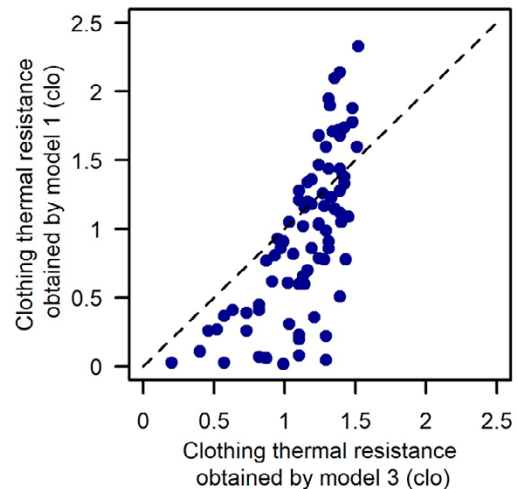


Figure 5. Scatter chart of clothing thermal resistance of person 1 obtained by model 1 (inverse application of the energy-balance-based model) and model 3 (UTCI-clothing model)

Here, the trend observed in Figure 4 is even more pronounced. For r_{cl} values smaller than 1 clo, model 3 overestimates model 1, but for r_{cl} values greater than 1 clo model 1 can significantly overestimate model 3. Note that model 3 cannot produce r_{cl} values greater than 1.7 clo. On the other hand, the r_{cl} values obtained with model 1 became greater than 2 clo in some cases. The biggest differences between the results of model 1 and model 3 are in cases, in which air temperature values are lower (e.g. 4-11 °C) and global radiation values are higher (370-460 Wm^{-2}). These cases can easily be recognized in Figure 2. In these cases, r_{cl} values obtained by model 3 are about 1-1.3 clo, whilst r_{cl} values obtained by model 1 about 0-0.3 clo. The effect of radiation can also be revealed in cases of greater heat deficiency. In these cases, model 1 overestimates (1.7-2.3 clo) model 3 (1.2-1.5 clo), because model 3 is insensitive to the lack of global radiation. Comparison of r_{cl} values of person 1 obtained by model 2 and 3 is presented in Figure 6.

It is noticeable that the results agree much better than previously. In this case, model 3 systematically overestimates model 2. This overestimation is greater in the case of small heat deficits (smaller r_{cl} values), and decreases as heat deficit increases. Based on the results of the scatter charts, differences between the

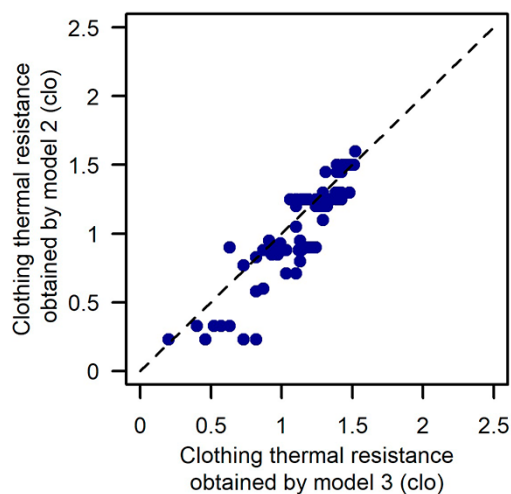


Figure 6. Scatter chart of clothing thermal resistance of person 1 obtained by model 2 (clothing ensemble model) and model 3 (UTCIclothing model)

models are the largest in situations with small heat deficit (r_{cl} less than 0.5 clo).

Sensitivity of model 1 to wind speed changes

Model 1 depends on r_{HP} , therefore it is sensitive to wind speed changes. Wind speed changes are characterized by comparing average wind speed and wind gust speed values (Figure 3). Comparison of r_{cl} values obtained by model 1 using wind gust speed and average wind speed values is presented in Figure 7.

For these wind speed changes, the maximum value of r_{cl} change is around 0.4 clo. r_{cl} deviations of 0.2-0.4 clo can occur both in case of larger (1.5 clo) and smaller (below 0.5 clo) environmental heat deficits. The determining role of wind can even be seen in cases, where $r_{cl} \leq 0.5$ clo.

Sensitivity of model 1 to metabolic heat flux changes

Model 1 depends on M , therefore it is sensitive to changes of M . M values of persons 1, 2, 3 differ about 15-20 Wm^{-2} . The effect of these constant differences on r_{cl} can be seen in Figure 8.

Since M of person 2 and person 3 is greater than the M of person 1, r_{cl} values obtained for persons 2

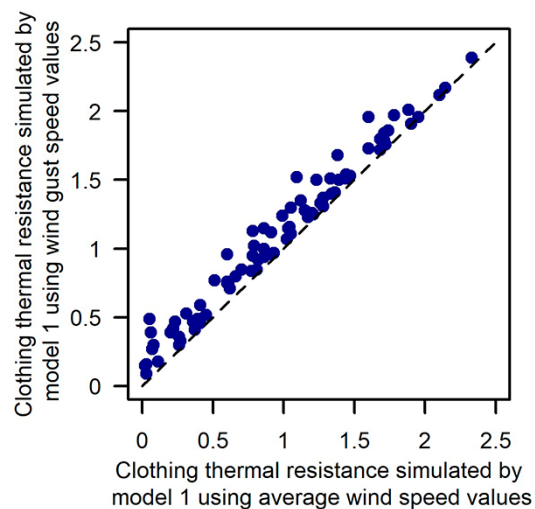


Figure 7. Scatter chart of clothing thermal resistance values obtained by model 1 using wind gust speed and average wind speed values

and 3 are underestimated with respect to the r_{cl} values obtained for person 1. The bigger the r_{cl} values, the bigger the differences between them. In case of large heat deficits, these differences can reach 0.4-0.7 clo. Note that models 2 and 3 do not explicitly show this dependence.

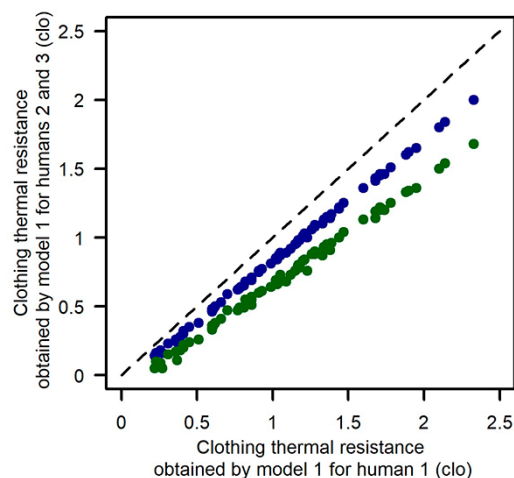


Figure 8. Comparison of clothing thermal resistance values obtained by model 1 for persons 2 and 1 (blue), and for persons 3 and 1 (green)

Discussion

The tested r_{cl} models differ greatly. Each model has its advantages and disadvantages. Model 1 is the most complex because it takes all important environmental and human factors into account. This is both an advantage and a disadvantage. M and r_{cl} are simulated referring to a specific person, whilst thermoregulation processes are not considered at all. In our opinion,

thermoregulatory processes (e.g. sweating, shivering) do not need to be simulated if the model is not for testing human comfort, they are rather to be used in simpler tests like climate classification. However, the number of input variables is large. This is a clear disadvantage, especially if we want to use the model for climate classification. Model 2 is much less complex

than model 1. Model 2 is simple, but the r_{cl} values of the garments that make up the clothing may differ from the literature values and r_{cl} values may vary from case to case. Model 2 has as many input variables as there are garments that make up the clothing. Model 3 is the most simple since r_{cl} depends only upon air temperature. The human is an imagined average person (Błażejczyk et al., 2010, 2013) with a body weight of 73.5 kg, a body fat content of 14% and of a Dubois area of 1.86 m². Sex is not specified. His/her clothing represents the clothing patterns of European and North American urban populations.

We could see that the r_{cl} values obtained with model 1 and model 3 differed to the greatest extent (Figure 5). These differences were the greatest when heat deficit was small according to model 1, while it was greater according to model 3. These cases were seen when in addition to lower air temperatures (higher heat deficit according to model 3), higher solar insolation values (lower heat deficit according to model 1) occurred. Larger r_{cl} differences obtained by model 1 and model 3 could also be observed in conditions of greater heat deficits ($r_{cl} \geq 1.3$ clo). In these cases, heat deficit was greater ($1.6 \leq r_{cl} \leq 2.2$ clo) according to model 1 and smaller ($1.2 \leq r_{cl} \leq 1.5$ clo) according to model 3. These differences are caused by the fact that model 1 takes the effect of radiation balance on thermal load into account, while model 3 doesn't. These cases show that there can be large differences between the thermal insulation of worn clothing (model 3 or model 2) and the thermal insulation of the clothing providing the energy balance (model 1) in case of either a small or a large heat deficit. It seems that a person's clothing is

such that the energy balance of his/her body is rarely completely or approximately fulfilled. More precisely, in 8-10 cases out of 74 cases, the energy balance was fully met (Figure 4, Figure 5). It is most correct to consider each r_{cl} value as an approximate value. Such are the typical seasonal values given in the literature (e.g. Yan, 2005; Yan & Oliver, 1996). The seasonality of the clothing worn can also be seen based on the data presented in this work. According to model 2, the lowest summer r_{cl} values can be around 0.2 clo, the highest winter values are around 1.5 clo, while the autumn and spring values can be often around 0.6-1.0 clo.

Model 1, which is the most complex of the examined models, has highly variable capabilities. It cannot be used in warm climates or in weather situations that provide an excess of ambient heat, in which cases the energy balance equation is not complete, as it does not simulate the process of sweating. However, when it is applicable (cases of lack of heat), it is able to simulate interpersonal variability because of the changes of M . Since the value of M used during walking depends very weakly, that is, to a small extent, on the sex of the person, the difference between the sexes in the variability of the r_{cl} is not noticeable. The interpersonal r_{cl} differences are the smallest in the case of small heat deficits, they increase as heat deficit increases, and they can reach values of 0.4-0.7 clo in cases of large heat deficits. Note that this sensitivity (Figure 8) is comparable with the sensitivity (Figure 7) obtained for wind speed changes. It should be noted that the model is planned to be applied to individuals. The main strength of model 1 is that it eliminates the effect of clothing on the thermal load of human body.

Conclusion

In this work, we compared three different clothing thermal resistance models that can be used either as a stand-alone human biometeorological model (model 1) or as submodels (models 2 and 3). Model 1 is based on energy balance and is therefore the most complex. Model 3 is the simplest one and model 2 is in between the two. To the best of our knowledge, there are no such or similar comparative analyses in the scientific literature. The results obtained show that there is a considerable difference between r_{cl} values obtained by model 1 on one hand and models 2 and 3 on the other.

The results suggest that 1) it is hard to achieve a balance of energy between the human body and the environment because in most of the cases it is either of the following: too much or too little clothing is worn. Based on the results obtained in the study, it is approximately in 10% of the cases that an energy balance is met; 2) the impact of individual differences on r_{cl} is greater with increasing environmental heat deficit. Of course, further studies need to be conducted in order to get a better knowledge of the thermal features of the clothing worn by humans.

References

- Ács, F., Kristóf, E., & Zsákai, A. (2019). New clothing resistance scheme for estimating outdoor environmental thermal load. *Geographica Pannonica*, 23(4), 245–255. <https://doi.org/10.5937/gp23-23717>
- Ács, F., Zsákai, A., Kristóf, E., Szabó, A.I., & Breuer, H. (2021). Human thermal climate of the Carpathian Basin. *International Journal of Climatology*, 41(S1), E1846–E1859. DOI: 10.1002/joc.6816
- Auliciems, A., & de Freitas, C. R. (1976). Cold stress in Canada. A human climatic classification. *International Journal of Biometeorology*, 20(4), 287–294. <https://doi.org/10.1007/BF01553585>
- Auliciems, A., & Kalma, J. D. (1979). A Climatic Classification of Human Thermal Stress in Australia. *Journal of Applied Meteorology* (1962-1982), 18(5), 616–626.
- Błażejczyk, K., Broede, P., Fiala, D., Havenith, G., Holmér, I., Jendritzky, G., Kampmann, B., & Kunert, A. (2010). Principles of the New Universal Thermal Climate Index (UTCI) and its Application to Bioclimatic Research in European Scale. *Miscellanea Geographica*, 14(1), 91.
- Błażejczyk, K., Jendritzky, G., Bröde, P., Fiala, D., Havenith, G., Epstein, Y., Psikuta, A., & Kampmann, B. (2013). An introduction to the Universal Thermal Climate Index (UTCI). *Geographia Polonica*, 86(1), 5.
- de Freitas, C. R., & Grigorieva, E. A. (2015). A comprehensive catalogue and classification of human thermal climate indices. *International Journal of Biometeorology*, 59(1), 109–120. <https://doi.org/10.1007/s00484-014-0819-3>
- Fanger, P. O. (1970). *Thermal comfort. Analysis and applications in environmental engineering*. <https://www.cabdirect.org/cabdirect/abstract/19722700268>
- Fanger, P. O. (1973). Assessment of man's thermal comfort in practice. *British Journal of Industrial Medicine*, 30(4), 313–324. <https://doi.org/10.1136/oem.30.4.313>
- Fiala, D., Havenith, G., Bröde, P., Kampmann, B., & Jendritzky, G. (2012). UTCI-Fiala multi-node model of human heat transfer and temperature regulation. *International Journal of Biometeorology*, 56(3), 429–441. <https://doi.org/10.1007/s00484-011-0424-7>
- Gagge, A. P., Burton, A. C., & Bazett, H. C. (1941). A Practical System of Units for the Description of the Heat Exchange of Man with His Environment. *Science*, 94(2445), 428–430. <https://doi.org/10.1126/science.94.2445.428>
- Havenith, G., Fiala, D., Błażejczyk, K., Richards, M., Bröde, P., Holmér, I., Rintamaki, H., Benschabat, Y., & Jendritzky, G. (2012). The UTCI-clothing model. *International Journal of Biometeorology*, 56(3), 461–470. <https://doi.org/10.1007/s00484-011-0451-4>
- Höppe, P. (1999). The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, 43(2), 71–75. <https://doi.org/10.1007/s004840050118>
- Innova Air Tech Instruments (2002). *Thermal Comfort*. *Innova Air Tech Instruments*, 32 pp. (it is available from the authors on the request).
- Olesen, B. W. (1985). A new simpler method for estimating the thermal insulation of a clothing ensemble. *ASHRAE Transactions*, 91(2B), 478–492.
- Parsons, K. (2014). *Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance, Third Edition* (3rd ed.). CRC Press. <https://doi.org/10.1201/b16750>
- Potchter, O., Cohen, P., Lin, T.-P., & Matzarakis, A. (2018). Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification. *Science of The Total Environment*, 631–632, 390–406. <https://doi.org/10.1016/j.scitotenv.2018.02.276>
- Weyand, P. G., Smith, B. R., Puyau, M. R., & Butte, N. F. (2010). The mass-specific energy cost of human walking is set by stature. *The Journal of Experimental Biology*, 213(Pt 23), 3972–3979. <https://doi.org/10.1242/jeb.048199>
- Yan, Y. Y. (2005). Climate Comfort Indices. In J. E. Oliver (Ed.), *Encyclopedia of World Climatology* (pp. 227–231). Springer Netherlands. https://doi.org/10.1007/1-4020-3266-8_44
- Yan, Y. Y., & Oliver, J. E. (1996). The Clo: A Utilitarian Unit to Measure Weather/Climate Comfort. *International Journal of Climatology*, 16(9), 1045–1056. [https://doi.org/10.1002/\(SICI\)1097-0088\(199609\)16:9<1045::AID-JOC73>3.0.CO;2-O](https://doi.org/10.1002/(SICI)1097-0088(199609)16:9<1045::AID-JOC73>3.0.CO;2-O)

'Gay Space is wherever I am': The Outlines of Pink Consumption Spaces in Zagreb

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Abstract

Based on the dialectical relationship between queerness and homonormativity, the aim of this paper was to outline the spatial framework of pink consumption in Croatia. Since the LGBT community is a specific and sensitive social group, qualitative research methods were used. After calculating the gay index and determining that the city of Zagreb provides the most favourable spatial context for the study of pink consumption, the interview method was used to collect qualitative data. The sample was assembled using the snowball technique (N = 14). The research revealed that there are only few pink consumption places in Zagreb, that they are not even present in all consumption systems, and that they are located in the central part of the city without exception. Although it cannot be argued that they are completely homonormative places, evidence of social exclusivity and sexual conservatism was found. Thus, it has been shown that even fundamentally inclusive places can produce normativity, which deprives them of the potential to achieve equality and emancipation of the Zagreb's LGBT community.

Keywords: pink consumption; LGBT; Zagreb; homonormativity

Introduction

Consumption areas designed specifically and exclusively for the LGBT+ community¹ or places where there is a higher concentration of LGBT persons due to their specific spatial properties, are called pink consumption places. These appear in all four fundamental consumer systems – shopping, health and diet, entertainment, and culture and education – but most of all in the sphere of entertainment (Mak & Jakovčić, 2021). The importance of night clubs in the socialisation of LGBT persons has been documented since the 1920s (Hunt et al., 2019) and these venues are considered key places for the functioning and spatialisation of the LGBT community (Lugosi, 2007; Burmaz, 2014; Mattson, 2015).

The development of pink consumption has been largely affected by the liberalisation of social relations

in Western Europe and Anglo-America in the latter half of the 20th century, and therefore, the majority of research focus has been centred in these parts of the world. It has been widely documented that pink consumption provides a space of freedom and safety for the open communication of LGBT identities (Kates, 2002; Cattani & Vanolo, 2014; Bettani, 2015). However, there is a significant difference between the Western world and post-socialist Europe. While in Western societies pink places contribute to the public visibility of the LGBT community (Baudinette, 2017; Motschenbacher, 2020), in the post-socialist context they are still “in the closet,” i.e., they are not seen from the street (Burmaz, 2014; Dimitrov, 2014). Differences were also found in the openness of pink consumption places to different sexual and gender identities

¹ For the purpose of simplicity, referred to only as LGBT in this paper.

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within the LGBT community. While some authors emphasize that pink consumption places welcome everyone (Cattan & Vanolo, 2014), others argue that such places do not welcome all segments of the LGBT community equally (Kates, 2002; Binnie, 2004; Betani, 2015; Baudinette, 2017; Motschenbacher, 2020). In post-socialist Europe, there are not even studies on the openness of pink consumption spaces to different LGBT identities. Similarly, to date, there is no scientific interest in the consumption and consumption spaces of LGBT persons in Croatia. However, explicitly pink consumption places, for example in Zagreb, started to appear in the late 1990s. This is when the first openly gay club, called Bad Boy, was opened in 1999 in Zagreb's Ksaver neighbourhood (Štulhofer et al., 2003). However, this club was soon closed down and for a longer time (from 2002–2008), a key venue in the night life of LGBT persons was the Global club on Pavla Hatza Street. In the early 2010s, there were three gay clubs operating in Zagreb - g.CLUB on Savska Street, Rush on Amruševa Street, and HotPot on Petrinjska Street. Later, Rush was relocated to Savska Street in the venue of the g.CLUB after it closed (Hermann, 2016), though with the onset of the COVID-19 pandemic, Rush too was permanently closed. The only remaining operational gay club in Zagreb was HotPot. Considering that pink consumption places are typically most developed in the entertainment sphere, and this was reduced to a single gay club in Croatia's largest city, then it can rightfully be said that this is but a silhouette of pink consumption. Therefore, the key task of this paper was to delineate the silhouette of pink consumption in a dominantly non-pink and heteronormative urban space.

Namely, the majority of public spaces are implicitly or explicitly heteronormative, which is then reflected in the assumption of the heterosexual identities, relations and practices as expected and desirable (Motschenbacher, 2020). Heteronormativity is reproduced through the patriarchal social structures, connections and relations (Hubbard, 2001), similar to how hegemonic groups maintain their privileged social position (Jackson Lears, 1985). On the contrary, sexual and gender minorities (in theory) act subversively, thus representing a key (or at least potentially key) point of countering the legitimacy of the patriarchal social structures (Baudinette, 2017). In that way, they become key actors in creating authentic LGBT spaces.

Authentic LGBT spaces, nonconformist LGBT spaces, or simply queer spaces² imply a liminal space that emerges by challenging established (hetero)normative social expectations (Baudinette, 2017). They are marked by a sociability that lies outside the framework of the assumed norms, implying a contention of sexual conservatism and a pronounced solidarity among individuals of varying socioeconomic status (Mattson, 2015). They are organised as places that question the very idea of normativity, by deflecting attention on the fact that normativity nearly always results in violence (Gibson-Graham, 1999 according to Brown, 2009).³ Therefore, queer spaces imply a certain resistance and secure the right to existence for marginalised gender and sexual identities (Hemmings, 2002). The rapid development of these spaces coincides with broader acceptance of sexual and gender minorities in the Western world.

Since the 1990s, there has been a liberalisation of social relations in the Western world and a gradual improvement of the legal position of LGBT persons. Through the gradual abolishment of discriminatory legislation, LGBT individuals are becoming more and more included in the public realm, as persons who can contribute to the community in which they live. Meanwhile, the demands of LGBT movement are also changing, where the socioeconomic solidarity and aspirations for sexual freedom are being replaced with striving towards achieving equal civil rights (Brown, 2009). In parallel with this process, there have been changes to spaces occupied by LGBT persons, particularly those spaces having a commercial function.⁴ Once economically determined, they gradually cease to be devoid of social norms and expectations. With the adoption of the normative impulses, such spaces cease to question (threaten) the dominantly heteronormative social assumptions (Duggan, 2004), and reduce the identity of LGBT persons to merely their consumer choices (Gorman-Murray & Nash, 2017). The homonormativity directs the LGBT community towards individualism and consumerist economic values, while in the private sphere, it favours the norms of the heteropatriarchy, i.e., long-term monogamous relationships with predefined gender roles (Brown & Bakshi, 2011). Accordingly, analogous to heteronormativity, homonormativity creates spaces which are privileged in the economic sense, and conservative in the sexual sense (Kenttama-Squires, 2019). Further, the spatial representations of the LGBT identities

² Queer implies the critical position that acts subversively towards the normative understanding of relationships between spaces, gender and sexuality (Baudinette, 2017) and therefore is a good indicator of the authenticity of LGBT spaces.

³ Normativity implies the socioeconomic layering and conservative social relations, i.e., the separation of accepted (privileged) individuals, and the positioning of undesirable identities in the margins (Brown, 2009).

⁴ Herein lies the contradiction between the previously proclaimed possibility for the flexible and free expression of gender and sexuality, and the appearance of normativity that the space begins to demand (Kates, 2002).

are based on the heteronormative conception of masculinity and femininity (Baudinette, 2017). In so doing, specific forms of homosexuality are incorporated as desirable in the capitalist society⁵ (Brown, 2009), while undesirable forms of sexual and gender identities are pushed to the margins.⁶ Therefore, the emergence of homonormative pink consumption spaces can simultaneously be considered as the emergence of spaces of social exclusion (Brown & Bakshi, 2011; Bettani, 2015). This significantly limits the emancipation potential of the LGBT space as inclusive and open to diversity (Baudinette, 2017).

Homonormativity is a locally specific phenomenon that is manifested in different ways in different spaces (Kenttamaa-Squires, 2019). This makes it a suitable framework for studying the characteristics of pink consumption in a range of socioeconomic contexts. In other words, the concept of homonormativity enables an understanding of the organisation of pink consumption spaces and how they function. Therefore, it should come as no surprise that this is the most common theoretical approach to the study of pink consumption in the past decade (Mak & Jakovčić, 2021).

As stated earlier, a key task of this study was to establish the silhouette of pink consumption in a dominantly non-pink and heteronormative urban space

of Croatia. Therefore, the first task was to determine which regions (counties) are the most relevant for geographical research of pink consumption. This is followed by the selection of the most pertinent spatial unit, i.e., the largest city in that region, and detection and classification of specific places of pink consumption within it. The largest city is typically the location of the most prominent LGBT community, since a largest population allows for greater anonymity and freer conduct, while also reducing stigmatisation, homophobia and violence (Braun et al., 2015). Finally, the characteristics of established pink consumption places are examined to determine the links between the theoretical proclamations of authenticity (subversion against the social order of the heteropatriarchy) and homonormativity.

Fulfilling the set goals would thus provide answers to the following research questions:

1. Where in Croatia is it even possible to study pink consumption places?
2. Where are pink consumption places found within the spatial structure of the city?
3. Which consumer activities (needs) of the LGBT+ community are met by these places?
4. What are the main properties of pink consumption places?

Methodology

For the purpose of achieving the aims of this research, it was necessary to employ a range of methodological procedures. In order to determine in which regions (counties) in Croatia the largest number of pink consumption places could be expected, we calculated the diversity index or gay index (Florida, 2002).⁷ Input data were obtained by the Register of life partnerships, available on the website of the Ministry of Justice and Public Administration. Gay index is a simple locational quotient that measures the number of same-sex households in a smaller spatial unit in comparison with the number of same-sex households in a larger spatial unit, and the obtained value is divided by the population of the smaller spatial unit in relation with the population of the larger spatial unit (Florida, 2002). In Croatia, the index can be formulated as:

$$\text{gay index} = \frac{\frac{\text{no. of life partnerships in the county}}{\text{no. of life partnerships nationally}}}{\frac{\text{county population}}{\text{national population}}}$$

Once the spatial unit that had the highest value of the gay index was determined, LGBT persons could be interviewed. The initial survey participants were proposed by the organisations Zagreb Pride and Iskorak, and the sample was further increased using the snowball technique. A total of 14 semi-structured interviews were held during May and June 2021. Interviews were continued until the same answers were obtained in three consecutive conversations. The interviewees were between 19 and 48 years of age (mean 29 years) and of varying sexual (lesbian, gay man, bisexual person, pansexual person) and gender (male,

⁵ Homonormativity typically favours physically attractive (standardly hypermasculine), young and predominantly white gay men of a higher socioeconomic status (Kates, 2002; Bettani, 2015).

⁶ Exclusion most often functions by the principle “no fats, no fems”. In such a space marked by hypermasculine discourse, excessive body weight and femininity are classified as moral failures in a disciplining the body, and as such as labelled as unattractive and undesirable traits (Kates, 2002). Further, other undesirable elements are typically recognised as older LGBT persons, ethnic minorities, persons with disabilities, different affiliations within the queer community and all other persons who fail to confirm to the strictly set norms (Bettani, 2015).

⁷ Florida (2002) developed the gay index within the framework of his creative class (creative city) theory. For more about the limitations of the gay index, see Mak & Jakovčić, 2021.

female) identities (see Table 1).⁸ The interview protocol consisted of several thematic areas – pink consumption spaces with regard to their (non)normative properties, the significance of those spaces for the LGBT community, the four fundamental consumer systems, and consumption management. In this paper, only those statements pertaining to the properties of pink consumer spaces were addressed.

Table 1. Demographic traits of survey participants

Code	Gender	Sexuality	Age
S1	male	bisexual person	26
S2	male	gay man	32
S3	female	pansexual person	22
S4	male	gay man	25
S5	male	gay man	25
S6	female	lesbian	32
S7	female	bisexual person	24
S8	male	gay man	25
S9	male	gay man	48
S10	male	gay man	37
S11	female	lesbian	33
S12	female	pansexual person	20
S13	female	lesbian	38
S14	male	gay man	19

Source: Interviews

Silhouette of Pink Consumption in Zagreb

Why Research the Geography of Pink Consumption in Zagreb?

As explained before, in determining the spatial scope of the study and the regional units in which pink consumption is most prevalent, the gay index was used. In solely examining the spatial differences in the concentration of life partnerships concluded in Croatia (Fig. 1), there are only three regional units in which there can be any discussion of the geography of pink consumption: City of Zagreb (3.06), Istria County (1.95) and Primorje-Gorski Kotar County (1.46). As in the aforementioned regional units (counties), Zagreb is by far the largest city, it makes the most sense to expect the highest number of pink consumption places there. This is no way means that there are not such places elsewhere in the country, but only that their numbers are substantially lower.

'Not all LGBTQ people are from Zagreb... There are people of that profile in Knin, Zadar, Varaždin, Rijeka, Pula, and everywhere else... they then occasionally come to Zagreb to have any opportunity to visit

Finally, in order to discuss the spatial distribution of LGBT persons within a specific urban area, the gay dating application *Romeo* was used. *Romeo* enables collecting data on the locations of its users, which is important due to the lack of other means of detecting the spatial concentration of LGBT persons. Although the locations provided by *Romeo* are not completely reliable (± 50 metres), which is justified by the need for user security (*Romeo*, 2022), even approximate data can be considered useful within the scope of this research. It is certainly necessary to highlight the methodological limitations of using *Romeo* data. Firstly, the selected application completely excludes LGBT persons who do not gender identify as males. Secondly, not all LGBT persons use this application, and one person may potentially have multiple profiles open. And finally, the location of the person need not necessarily indicate the person's place of residence, as the individual can independently move their location pursuant to their own needs and wants.

The analysis of the spatial distribution of the *Romeo* profiles as well as the visualisation of the spatial distribution of the pink consumption places were made in ArcMap 10.4 software using the Kernel Density function.

their spaces, as there is nowhere except Zagreb, and maybe Rijeka where I'm from, that has any spaces of that type.' (S10)

During April 2022, data on the locations of Zagreb users of the *Romeo* dating application was collected. It was established that there was a total of 3693 profiles active in the city area. The majority of application users are located in the central part of the city (Fig. 2), which, together with the Medvednica foothills makes a traditional residential zone of wealthier inhabitants (Prelogović, 2009). It can be expected that the higher concentration of pink consumption places will also overlap with the spatial distribution of the *Romeo* application users. It is plausible to expect that a certain portion of application users will register at the location of such a place, instead of the location of their actual residence, primarily for safety purposes.

In the case that the *Romeo* users set their location at the place where they in fact reside, then it could be stated that there is a concentration of LGBT persons

⁸ Unfortunately, we were not able to reach and include all gender and sexual minorities in our research.

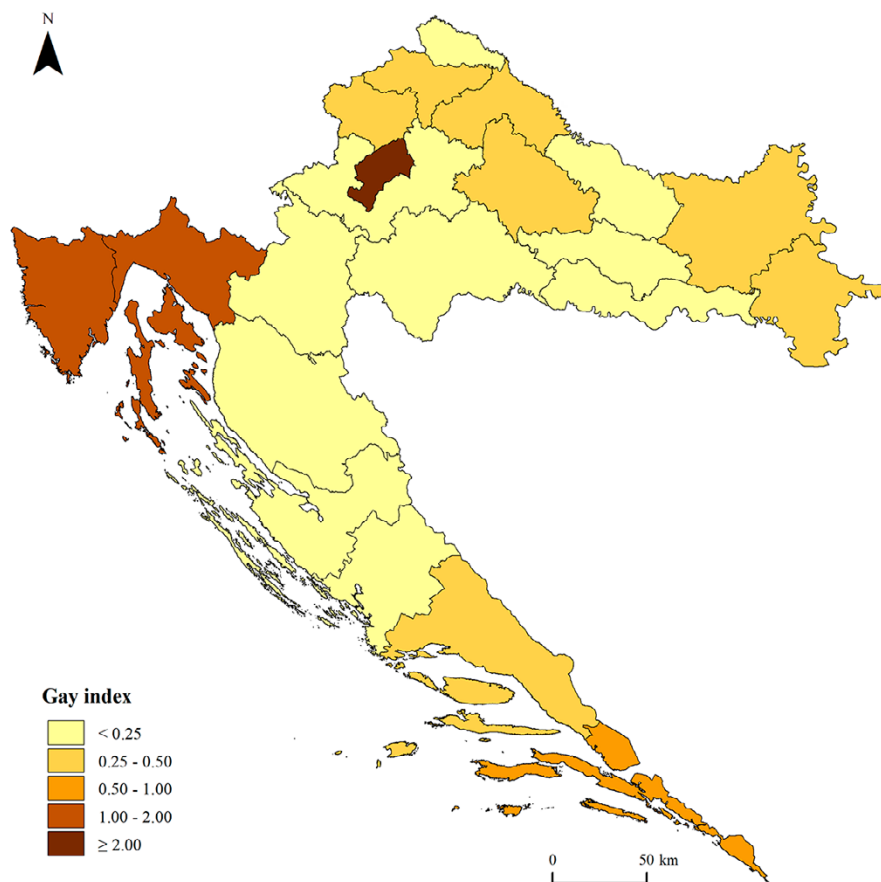


Figure 1. Distribution of concluded life partnerships in Croatian counties (2013–2021)
Sources: CBS, 2022; MJPA, 2022

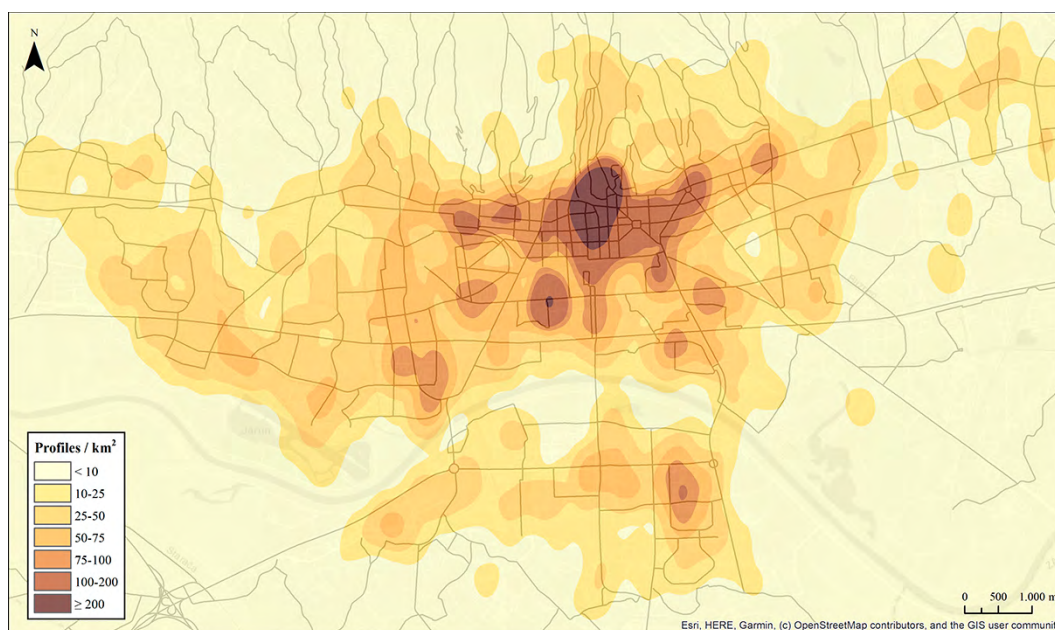


Figure 2. Spatial distribution of profiles on the Romeo dating app in Zagreb in April 2022
Source: Romeo, 2022

around the Zagreb city centre which, through the process of gentrification, could also be associated with the theory of homonormativity (Schulman, 2012). Gentrified LGBT areas are marked by a consumer-oriented population from which all undesirable elements have been removed. Namely, the security offered by such spaces relies on the higher spending power and relative homogeneity of the population (Mattson, 2015).

Position of Pink Consumption Places in the City Spatial Structure

- Nearly all pink consumption places mentioned by the interviewees are positioned in the Zagreb central core⁹ (Figs. 3 and 4), which was noted in several statements together with the remark that there are too few such places.
- 'I've noticed that more of these spaces are appearing around the centre, while there are no neighbourhood friendly cafes. I mean, this is progress (...), but come on, we need more.' (S12)
- 'I think that we need more such places. For people to realise that there are normal people there (...). There really is very little. I wish there were more clubs, cafes. This is lacking.' (S14)

Since the majority of these places are cafes and night clubs, it is possible that their concentration in the city centre is explained in part by the security that a central location offers (Skočir & Šakaja, 2017). Fur-

thermore, security has arisen as one of the fundamental, if not key, properties of pink consumption spaces. Namely

- 'I think that people in Croatian society, which has made a great deal of progress concerning LGBT rights, still don't feel safe and that these spaces offer security above all.' (S5)
- 'Simply put, they are established in such a way that everyone knows it is a safe place.' (S7)
- 'You know that they are safe places, that's how they are labelled. You don't have a feeling of fear.' (S11)

Though they should be (Mattson, 2015), the gay clubs are not a visible stage of the LGBT social scene in Zagreb. While located in the city centre core, their visibility is highly limited, out of the need for security of their visitors. The same occurrence in Belgrade was explained by Dimitrov (2014) as a consequence of exclusion and part of a survival strategy, while Burmaz (2014) interprets it as a form of new closet, i.e., the appearance of internal peripheralization. In any case, the very existence of pink consumption places contributes to the visibility of the LGBT community, though in the Zagreb (Croatian) context, this is certainly not their primary role. Therefore, they are not specially marked, and with their exteriors that give the impression of completely ordinary business premises. They are often located in the city courtyards, passages or basements.



Figure 3. Spatial distribution of pink consumption spaces in the sphere of entertainment in Zagreb in 2021.

Source: Interviewees

⁹ Although they are known to us from the interviews, we did not want to show more precise locations of the pink consumption places, since it was clear it is important to the interviewees that their places remain hidden, and thus safe. That is why we used Kernel Density function instead of just pointing pink consumption places locations on the map.

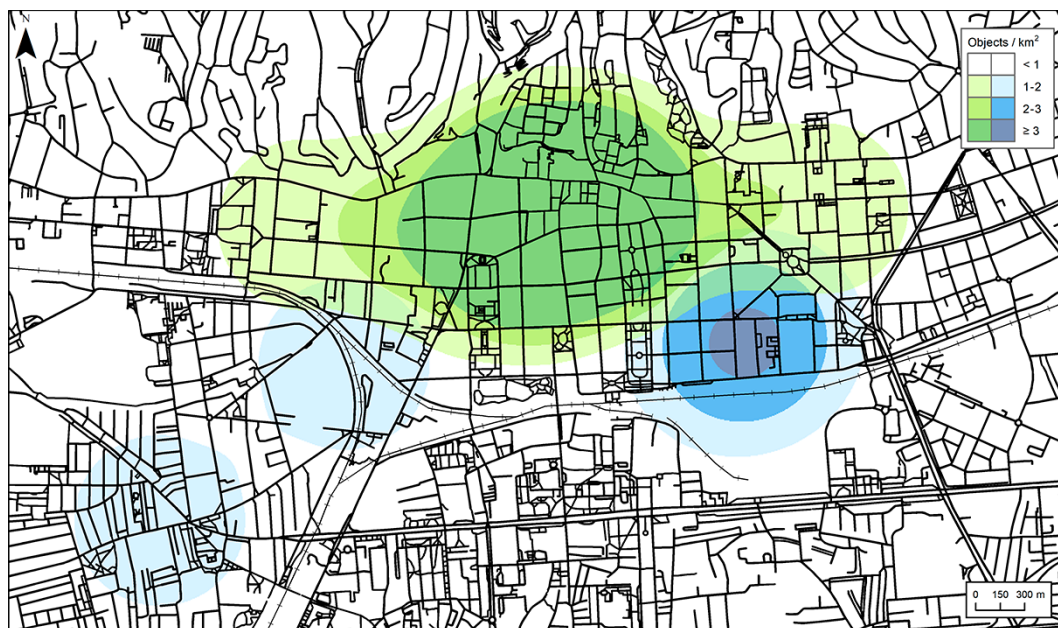


Figure 4. Spatial distribution of pink consumption spaces in the spheres of culture and education (green), and health and diet (blue) in Zagreb in 2021.

Source: Interviewees

- 'It is in the city centre, but in a basement. But still, I think that without them, then it would be even less visible. In this way, the population can meet at that bar on Friday evenings.' (S3)
- 'I have the feeling that they are all quite hidden and that they reduce LGBT visibility. But they still create a safe place. It is not as though they are widely advertised, that they have a rainbow flag on the exterior or in the windows. Instead, they are quite incognito.' (S11)
- 'I bet that if you asked anyone, for example about HotPot, they wouldn't know that it exists.' (S5)
- 'I'm not sure that these spaces are visible to the (...) general public, and so from that position we can question the range of their visibility.' (S10)
- 'I don't know how many people outside our community even notices these spaces or perceive them to belong to the LGBT community. Like Kolaž, Juta or what we talked about. I don't know if the average straight person walked right by would think, 'Aha, just another bar, though perhaps with a disproportionately higher number of women than in others' [laughter]. But I'm not sure they would associate it with the LGBT community. It's not as if there are rainbow flags hanging in the windows.' (S13)

Structure of Pink Consumption Places

Through the interviews, we received some insight into which pink consumption places in Zagreb can be discussed. As already emphasized, there are very few such places – just 29 in the whole city (Figs. 3 and 4) – which can be explained by the fact that Zagreb is

a relatively small city (population less than 700,000) and the social and historical circumstances. Although the process of joining the European Union led to an improvement in the legal status of LGBT people, after joining the EU there was a strengthening of conservative movements directed against the LGBT community (Čemažar & Mikulin, 2017). This is supported by the reports of ILGA Europe (2023), according to which the percentage of realized rights of LGBT persons in Croatia decreased from 71% in 2015 (year after the acquisition of the right to same-sex partnership) to only 45% in 2022. Therefore, the small number of pink consumption venues in Zagreb is a mere reality. Entertainment venues (48.3%) dominate the pink consumption spaces in Zagreb, primarily cafes and night clubs, though their numbers have declined since the early 2010s (Hermann, 2016). The reduction in the number of gay clubs is not isolated to Zagreb, nor was it due exclusively to the COVID-19 pandemic. For example, Collins & Drinkwater (2017) explained that the reduced demand for gay clubs and their subsequent closures is due to the increased use of dating applications that facilitate making personal acquaintances and social networking among LGBT persons outside the framework of physical space. This is also a possible explanation for the situation in Zagreb.

- 'These online platforms actually reduce socialising.' (S9)
- 'Putting COVID aside, I think that online applications certainly have reduced face to face socialising. Before these apps, we spent more time hanging out in different venues, like Global for example. There we actually socialised.' (S10)

Among the interviewees, it was clear that the general opinion is that gay men make up most of the visitors of night clubs, while other gender and sexual identities, and the heteropopulation are a minority. It is interesting that in the case of LGBT friendly cafes, there is a division as to which are more intended for gay men or lesbians. In the area of cultural consumption (34.5% of all specified places), LGBT friendly places were primarily listed as alternative theatres and cinemas, while in the area of health-related consumption (17.2% of all specified places), several gyms, saunas, and places important for sexual and reproductive health were listed.

Finally, there are no sales venues specifically intended for LGBT persons in Zagreb, nor do LGBT persons feel as though shops are particularly open to them.

- *'I think it would be fantastic for a LGBT store to open (...), that there is a shop where you can buy some cool make-up, a little unusual, or wigs, LGBT thermoses and cups, or LGBT merchandise (...). There is a huge chance that the display windows would be broken. It's questionable whether there is anyone brave enough to take on that risk, but I think that the shop would be well visited and would do very well.'* (S7)

Homonormative or Non-conformist (Queer) Spaces?

Physical Properties of Pink Consumption Spaces

According to most of the interviewees, the pink consumption spaces in Zagreb do not physically differ from any other consumer spaces, and this is likely a consequence of the broader socioeconomic situation in Croatian society. Pink consumption spaces however tend to commonly share a somewhat more alternative (more urban) interior style.

- *'They don't differ by anything visible... I don't see any differences in the interior style of pink or non-pink spaces.'* (S2)
- *'If you brought a straight crowd into our gay bars, they wouldn't even notice that it's a gay club. Generally, I would say they look like any other club.'* (S7)
- *'These institutions are more insistent that they are institutions, while smaller theatres (...), you have that welcome feeling that is more on the alternative side. Now, this depends on whether or not this alternative side is associated with queerness, and honestly that is fantastic.'* (S7)
- *'I would say that they are all, how would I put it, more urban.'* (S6)
- *'There are no specific emblems that would indicate (...) the LGTBQ population. At the end of the day,*

we live in Croatia. I think that these venues are also aware of that fact, so they don't stand out too much.' (S10)

Nearly all the night clubs to which the interviewees referred in their interviews are now closed. There is only one gay club currently in operation – HotPot on Petrinjska Street. It is relatively small (just 120 m² in area) and the interviewees stressed its humble appearance.

- *'A dump. Literally. A hole. No windows, inadequate ventilation, packed full of people who have nowhere else to go out... With that, a night out there is enormously expensive, as you have to pay at the door and for the price of drinks.'* (S5)
- *'It's too smelly. And so small, it's a small space so everyone is crammed in. You can't get any air; someone is always coming up to you...'* (S14)
- *'On the other hand, the day-time pink consumption places, above all gay-friendly cafes, are perceived to be more urban. It is possible to identify certain cafes that openly display LGBT+ symbolism, while in some cases, this is displayed only during the pride parade.'*
- *'For example, the difference at the Cat Caffe is that they occasionally put up gay flags to indicate that it is a gay-friendly space. But I have never seen anyone kiss in there, I mean same-sex couples, which would really separate that café from any other that I visit.'* (S4)
- *'For certain events, like the Pride parade, they'll be decorated, but that is only for special events.'* (S7)

Normativity in Comparison with the Heteronormative Space

We have previously observed that pink consumption places are perceived to be safe places for the LGBT community to spend their leisure time. Therefore, it is no surprise that a key role within them is tolerance and mutual respect.

- *'It is definitely a set rule of conduct that there is an anti-hate atmosphere, kindness, understanding and accessibility. At least in my experience.'* (S7)
'I think we respect one another. But that is I guess normal if all of us here are like that. Though it doesn't necessarily have to be. But yeah, we respect one another. Realistically, that is the norm everywhere. Many elsewhere there is less respect.' (S3)

Concerning pink entertainment spaces, these are marked by the looser rules of conduct in comparison with non-pink spaces. This is particularly the case for the night-time consumer landscape (Cattan & Vano, 2014). These looser rules enable freer forms of con-

duct, such as more open displays of affection towards persons of the same sex:

- ‘They are more fun [laughter], crazier, entertaining. In terms of a night out, it’s more fun where the gay people are. Rules? I have no idea. I would say that there aren’t any, though, hm, perhaps they are looser than in other places.’ (S9)
- ‘More relaxed forms of conduct are more widely accepted. So, if I were to go to Kolaž, I knew that I could (...) hug my partner at any time if I wanted to, without any problems (...), without feeling, you know, that someone might attack me or beat me up.’ (S10)
- ‘If you’re with a girl or a guy, you can hold hands or kiss, embrace... that’s not something that I would do in a classical café. In that sense, people are a bit more open. Especially in the clubs.’ (S13)

The more relaxed norms are also seen in a freer style of dressing, and in the possibilities for open discussions about topics concerning the LGBT community. These make pink consumption spaces places of freedom - places in which it is not required to hold back one’s personality or to adapt one’s conduct.

- ‘There’s no dress code like in other clubs. You can wear whatever you like. You can come in a sweat-suit. For example, you can’t do that at Roko.’ (S14)
- ‘I mean, I feel more comfortable there just because I am a LGBT person, because this is a common topic to us all, we can talk about it there, while anywhere else you can’t be one hundred percent certain that you’ll be treated respectfully.’ (S12)

On the other hand, for LGBT persons, spending free time in non-pink consumption spaces often means adapting their behaviour to avoid being “visible” and thereby risking verbal or physical attacks. Therefore, it is clear that there is a lack of a feeling of security.

- ‘I don’t think that you should hide femininity, but only to avoid any insults or threats like “ugh you fagot, gross...” Once I had to meet a guy and we shook hands, and when I went away, I could still hear him saying, “Oh no, now I have to quickly go home and disinfect my hand so that it’s not infectious,” of course, alluding to my sexuality. The thing is that I was really relaxed. I was obvious.’ (S14)
- ‘About straight clubs, let’s call them that, I have never truly felt really safe or like a member of the female sex and gender. There were a lot of situations of sexual harassment from straight men, and over the years I realised that I just didn’t want to do that and that I would rarely go to such a club. Maybe only for a birthday. I would dress up like a real lesbian to make it really clear: fuck

off. Of course, LGB people are looked at, I won’t say with scorn, but with a side look when their sexuality is obvious.’ (S7)

Non-pink consumption places are not as hostile towards all gender and sexual minorities. Judging by the statements of the interviewees, the femme lesbians are the most accepted, though this form of social acceptance often goes hand in hand with their hypersexualization.

‘I think that it’s much easier for lesbians because guys don’t look at them and thing “how gross” but it’s more like “yeah, cool!” You know, they masturbate to lesbian porn. When they see this, they like it, it’s not a threat. On the other hand, if they see two men, there will instantly be a look.’ (S14)

‘I don’t separate spaces into those that are gay, gay-friendly, or non-gay – a gay space is wherever I am. (...) Vivas is a great example, when I was there [with her girlfriend] it was a really gay space (...). I didn’t feel comfortable as I do now, but nor did I get any funny looks. (...) I have honestly only had positive experiences. (...) One girl told me: “Yes ok, you haven’t had any negative experiences because the girls you hang out with all look like girls, you know?” She on the other hand is a little boyish and she has had negative experiences. But when you look at it that way, is that positive discrimination? Because we are getting into the sphere of the “porn category” and whatever else.’ (S6)

Between Inclusivity and Exclusion

The theory of homonormativity lies in creating an accepted gay public space that retracts the marginalisation of undesirable individuals (Bell & Binnie, 2004). The day-time consumer landscape (cafes) is perceived as socially inclusive, while the night-time landscape (night clubs) as isolating (Gorman-Murray & Nash, 2017). Pink consumption places in Zagreb are primarily perceived to be open to diversity, as places in which everyone is accepted equally, and most interviewees did not observe or experience any form of discrimination there.

- ‘I have never experienced that someone was discriminated against for being, for example a Roma person, or visibly, I don’t know, of a low socioeconomic status... I’ve never witnessed it nor would I expect it.’ (S2)
- ‘They are open towards everyone. Trans and bi, and straight. From 18 to 88. Nationality also is not a factor.’ (S5)
- ‘Honestly, I think that they are accessible to everyone, regardless of nationality, race, financial status... I have not heard of any segregation. Really, it’s about equality.’ (S7)

- 'When talking specifically about entertainment, what first comes to mind about the cafés and clubs, hm, is that they are open to that population. (...) They are somehow accessible to everyone, and I think they are open to different socio-economic groups and other groups (...). I have never felt that there is less understanding or less tolerance towards a subculture within that entire population. Perhaps I'm wrong. (...) For example, if you go to HotPot, I've never noticed that a transgender person is viewed or experienced or treated differently.' (S10)
- 'I haven't experienced any, how would I put it, negative comments towards anybody, anywhere.' (S11)

From the aspect of economic viability on the market, it is very important that pink consumption spaces are also visited by heterosexual persons, i.e., that these spaces are open to them.

- 'If they would rely only on the LGTBQ population, I'm afraid they wouldn't survive. I'm not sure how pink consumption spaces could even prosper economically, if they specifically served only that niche.' (S10)
- 'If we were to make plans to meet up for a drink or socialise or whatever, and if it was exclusively a gay crowd, we would probably plan to meet up in a bar like that. Not necessarily because these places are so brilliant or great, but out of a feeling of solidarity. Let's help them out a little, let's bring in people so they can survive, so that places like this can exist.' (S13)

Regardless of the perception of the openness of pink consumption spaces, in line with the "old church split between the gays and lesbians" (S7), there are indications that predominantly gay or lesbian consumer places do exist in Zagreb.¹⁰ However, as in previous research in cities of similar size (e.g., Cattani & Vano, 2014), the majority of visitors in the most frequent pink spaces are gay men.

- 'I consider the Beertija café to be more lesbian than gay. Then there is the Juta/Kota Bar, this is more of a lesbian place.' (S6)
- 'I think that the gay male population is far more represented in all this, they go out more and are more present (...). If you go to HotPot, out of a hundred people, 80 will be guys and about 20 girls. If that (...). Let's say that Juta is more of a lesbian café. There you find mostly girls; I haven't noticed too many guys. There was that place Vimpi, in the

passageway by the Europe cinema, but I think it's been closed for a while.' (S13)

A small number of interviewees warned that the openness of pink spaces has its limits. They can boil down to being more partial to the traditionally defined gender identities and persons of homosexual orientation. Bisexuality and pansexuality are questioned and negated even within the LGBT community, and transphobic comments were also observed.

- 'They are open to everyone, as long as they are not too different from everyone else.' (S11)
- 'The situation still dictates that trans people are not accepted... If someone is clockable, or whatever it's called, you know what I mean, that's them.' (S7)
- 'Trans people, I swear, every one of those people I have met, and it's not just the sexual part, they have so many unresolved issues in their head, they are people who are so unsure of who they are, and what they are. I think the sexual part is the least of their problems.' (S6)
- 'Generally, I think that in the LGBT community, some are more discriminatory towards bisexual people, saying they can't make up their mind, stuff like that. I would say that strictly gay or strictly lesbians get by easier.' (S3)
- 'I have heard it countless times, even from people in the community, "No, you're just confused, you're actually gay". Or "No, you're just confused, you're actually straight". No, I can like both, it's fine. So there are these reactions that these people, pan people are simply straight people looking for attention, or gay people who are still afraid to come out all the way.' (S12)

The fluctuation of visitors in pink consumption spaces is relatively limited. Their visitors are more or less the same people, which does not support the thesis of some great openness.

- 'I rarely see any new faces. (...) during my time, Global was popular, but it's gone now, on Hat-zova Street, there were always the same 50–100 people. It seems as though this is still this small, narrow, closed circle and that internalised homophobia still reigns within it.' (S10)

Additionally, the existence of a cult of youthfulness or the appearance thereof was observed.

- 'Younger people get more respect than older people. There are currently more young people that

¹⁰ The literature states that the key differences between gay and lesbian consumer places is that the latter offer the opportunity for more diverse socialising with regard to age, skin colour, class or other characteristics of their visitors, particularly in early youth and through the outing process (Gieseck, 2016).

are out, and so they are much closer. There are more of them and they can understand each other much easier.' (S3)

– 'The older population, over the age of 35, is viewed differently. It is more difficult for them to access those consumption places. They are more visible among the mostly young population.' (S8)

Conclusions

Taking all the regional units (counties) in Croatia into consideration, the diversity index (gay index) was highest in the City of Zagreb. Therefore, the research on pink consumption is most applicable in that city. The locations of profiles of LGBT persons on the Romeo dating application was concentrated in the city centre, where also the most pink consumption places are located. There are not many of these places, nor are they present in all four consumer systems. The most developed is the entertainment system (in the form of cafes and night clubs), followed by alternative places of cultural consumption, and places that pertain to health-related consumption, while shops intended for LGBT persons were not observed.

Though small in number, the pink consumption places in Zagreb are exceptionally important for the spatialisation of the LGBT community. Since they physically do not differ from any other consumption place, and given their retraction from street view, these places do not act particularly subversively towards the broader heteronormative space of the city. Pink consumption places should be able to mitigate the effects of social and spatial isolation in the heteronormative space (Mattson, 2015). However, their ability to mitigate the undesired characteristics (homophobia, transphobia) of society were found to be quite limited. Contrary to the theory of homonormativity, these are not places that are especially economically privileged, though indications of social exclusivity and sexual conservatism were observed. Therefore, it was found that a generally inclusive place can pro-

duce normativity. There are indications of divisions between lesbian and gay places, and sexual and gender minorities that are not "too different" (S11) are accepted with the detection of a cult of youthfulness and the appearance thereof. Accordingly, the idealistic perception by which pink consumption places are highly inclusive did not prove to be sustainable. In examining the relationship between inclusivity and exclusivity, the pink consumption places in Zagreb are becoming quite normative, thereby losing their full emancipatory potential.

As this work pioneers the study of pink consumption places in Croatia, it opens up wide-ranging possibilities for future research on how sexual and gender identities shape spatial processes, organizations, and economic activities. Continued research is needed both in the sphere of the geography of consumption (comparison of consumption places and/or systems of consumption; refusing consumer services based on a person's sexuality...) and the geography of production (tracing Florida's concept of creative class; from the aspect of the position of LGBT people in the labour market...). For too long, research, especially in post-socialist Europe, has been blind to sexual identity and has neglected its importance in shaping spatial-economic experiences. Placing these issues into the focus of economic-geographical research finally removes the identity blindness, points to neglected but very relevant economic actors, and allows for more effective management of commercial spaces for sexual and gender minorities.

References

- Baudinette, T. (2017). The spatialisation of desire in Japanese gay district through signage. *An International Journal for Critical Geographies*, 16 (3), 500-527.
- Bell, D., & Binnie, J. (2004). Authenticating queer space: citizenship, urbanism and governance. *Urban Studies*, 41 (9), 1807-1820.
- Bettani, S. (2015). Straight subjectivities in homonormative spaces: Moving towards a new, 'dynamic' heteronormativity? *Gender, Place & Culture: A Journal of Feminist Geography*, 22, 239-254, DOI: 10.1080/0966369X.2013.855713
- Binnie, J. (2004). Trading places: consumption, sexuality, and the production of queer space, In: D. Bell, & G. Valentine (Eds.), *Mapping desire. Geographies of sexualities* (pp. 166-181), Routledge, London – New York.
- Braun, K., Cleff, T., & Walter, N. (2015). Rich, lavish and trendy. Is lesbian consumers' fashion shopping behaviour similar to gay's? A comparative study of lesbian fashion consumption behaviour in Germany. *Journal of Fashion Marketing and Management*, 19 (4), 445-466, DOI: 10.1108/JFMM-10-2014-0073.

- Brown, G. (2009). Thinking beyond homonormativity: Performative explorations of diverse gay economies. *Environment and Planning*, 41, 1496–1510.
- Brown, K., & Bakshi, L. (2011). We are here to party? Lesbian, gay, bisexual and trans leiscapes beyond commercial gay scenes. *Leisure Studies* 30 (2), 179-196.
- Burmaz, B. (2014). Gej klubovi u Beogradu: unutrašnja periferizacija kvir prostora [Gay clubs in Belgrade: internal peripheralization of queer space]. In J. Blagojević, & O. Dimitrijević (Eds.), *Među nama: neispričane priče gej i lezbijskih života* (pp. 190-209). Beograd: Hartefakt Fond.
- Cattan, N., & Vanolo, A. (2014). Gay and lesbian emotional geographies of clubbing: reflections from Paris and Turin. *Gender, Place & Culture: A Journal of Feminist Geography*, 21, 1158-1175, DOI: 10.1080/0966369X.2013.810603.
- Collins, A., & Drinkwater, S. (2017). Fifty shades of gay: Social and technological change, urban deconcentration and niche enterprise. *Urban Studies*, 54 (3), 765-785, DOI: 10.1177/0042098015623722.
- Čemažar, S. A., Mikulin, T., 2017: Europeizacija kao (ne)prijateljica: razvoj LGBT pokreta u Hrvatskoj [Europeanization as an Enemy: The Development of the LGBT Movement in Croatia], *Mali levijatan* 4 (1), 29-58.
- Dimitrov, S. (2014). Gej i lezbijski klubovi u Beogradu: društveni prostori, identiteti, otpor [Gay and lesbian clubs in Belgrade: social spaces, identities, resistance]. In J. Blagojević, & O. Dimitrijević (Eds.), *Među nama: neispričane priče gej i lezbijskih života* (pp. 210-226). Beograd: Hartefakt Fond.
- Državni zavod za statistiku (DZS) / Croatian Bureau of Statistics (CBS) (2011). Popis stanovništva, kućanstava i stanova 2011. godine / Census of population, households and dwellings in 2011. Available from: www.dzs.hr (Accessed 8 Sep 2022).
- Duggan, L. (2004). Equality, Inc. *The Twilight of Equality? Neoliberalism, Cultural Politics and the Attack on Democracy* (pp. 43-66). Boston: Beacon Press.
- Florida, R. (2002). The Economic Geography of Talent. *Annals of the Association of American Geographers*, 92 (4), 743-755, DOI: 10.1111/1467-8306.00314.
- Gieseck, J. J. (2016). Dyked New York: The Space between Geographical Imagination and Materialization of Lesbian-Queer Bars and Neighbourhoods. In: Brown, G. and Browne, K., eds. *The Routledge Research Companion to Geographies of Sex and Sexualities*. Oxford: Routledge, 1983-2008.
- Gorman-Murray, A., & Nash, C. (2017). Transformations in LGBT consumer landscapes and leisure spaces in the neoliberal city. *Urban studies*, 54 (3), 786-805., DOI: 10.1177/0042098016674893.
- Hemmings, C. (2002). Bisexual Landscapes. *Bisexual spaces: A geography of sexuality and gender* (pp. 15-52), New York: Routledge.
- Hermann, E. (2016). *Kako se kalio zagrebački LGBT clubbing*. Voxfeminae.net. Available from: <https://voxfeminae.net/pravednost/kako-se-kalio-zagrebacki-lgbt-clubbing/> (Accessed 26 Jun 2022).
- Hubbard, P. (2001). Sex Zones: Intimacy, Citizenship and Public Space. *Sexualities*, 4 (1), 51-71.
- Hunt, G., Antin, T., Sanders, E., & Sisneros, M. (2019). Queer Youth, Intoxication and Queer Drinking Spaces. *Journal of Youth Studies*, 22 (3), 380-400 DOI: 10.1080/13676261.2018.1508826.
- ILGA Europe, 2023: Rainbow Europe, International Lesbian, Gay, Bisexual, Trans and Intersex Association (ILGA) Europe, <https://www.ilga-europe.org/rainbow-europe/> (Accessed 11 Mar 2023).
- Jackson Lears, T. J. (1985). The Concept of Cultural Hegemony: Problems and Possibilities. *The American Historical Review*, 90 (3), 567-593.
- Kates, S. M., (2002). The Protean Quality of Subcultural Consumption: An Ethnographic Account of Gay Consumers. *Journal of Consumer Research*, 29 (3), 383-399, DOI: 10.1086/344427.
- Kentamaa-Squires, K. (2019). Rethinking the homonormative? Lesbian Hispanic Pride events and the uneven geographies of commoditized identities. *Social & Cultural Geography*, 20 (3), 367-386. DOI: 10.1080/14649365.2017.1362584.
- Lugosi, P. (2007). Queer Consumption and Commercial Hospitality. *Communitas, Myths and the Production of Liminoid Space*. *International Journal of Sociology and Social Policy* 27 (3/4), 163-174, DOI: 10.1108/01443330710741093
- Mak, K., & Jakovčić, M. (2021). Ružičasti prostori potrošnje: istraživački dosezi i perspektive / Pink consumption areas: research accomplishments and future perspectives. *Hrvatski geografski glasnik*, 83 (2), 59-77, DOI: 10.21861/HGG.2021.83.02.03
- Mattson, G. (2015). Style and the value of gay nightlife: Homonormative placemaking in San Francisco. *Urban Studies*, 52 (16), 3144-3159.
- Ministarstvo pravosuđa i uprave (MPU) / Ministry of Justice and Public Administration (MJPA) (2022): Registar životnog partnerstva / Register of Life Partnership. Available from: www.mpu.gov.hr (Accessed 8 Sep 2022).
- Motschenbacher, H. (2020). Walking on Wilton Drive. A linguistic landscape analysis of a homonormative space. *Language & Communication*, 72, 25-43.
- Prelogović, V. (2009). Primjena faktorske analize u istraživanju socio-prostorne strukture grada: primjer Zagreba [The application of factor analysis in the study of the socio-spatial structure of the

- city: the example of Zagreb]. *Hrvatski geografski glasnik*, 71 (1), 67-85.
- Romeo (2022). Your GPS-Position, Your Security. Available from: <https://www.romeo.com/en/care/locations/> (Accessed 26 Jun 2022).
- Schulman, S. (2012). The Gentrification of Creation. *The Gentrification of the Mind. Witness to a Lost Imagination* (pp. 81-110), Berkeley: University of California Press.
- Skočir, D., & Šakaja, L. (2017). Prostorni aspekti posjećenosti kafića u Zagrebu: dobne i rodne razlike [Spatial aspects of visiting cafes in Zagreb: age and gender differences]. *Acta Geographica Croatica*, 43/44 (1), 37-58.
- Štulhofer, A., Hiršl-Hećej, V., Mrkšić, Ž., Korać, A., Hoblaj, P., Ivkanec, I., Mamula, M., Tiljak, H., Buljan-Flander, G., Sagasta, S., Bosanac, G., Karlović, A., & Mimica, J. (2003). Croatia. In R. Francoeur, & R. Noonan (Eds.), *The Continuum Complete International Encyclopedia of Sexuality* (pp. 241-258). New York-London: Continuum.

Scientometric Analysis-based Review of Drought Indices for Assessment and Monitoring of Drought

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Abstract

The major cause of a drought is due to the variations in the climatic conditions and the anthropogenic effects. Due to climate change and inadequate rainfall, the moisture in soil gets affected which reduces the supply of water to the vegetation and also to the groundwater resources. The onset of drought is difficult to predict but it can be monitored with the help of various influential parameters. Suitable drought resilience techniques should be adopted to recover the loss and mitigate the effect of drought in a region. Proper monitoring and management of drought mitigation strategies should be followed to prevent the occurrence of such a kind of disaster. In this study, the authors provided a scientometric analysis and a wide-ranging review on drought indices. The scientometric analysis using VOSviewer showcases the current trend in the research using the most frequently used keywords, most cited articles and authors, and the countries that contributed to the field of drought. A total of 175 articles were identified from various databases and initial screening was done to select the full text articles. The eligible full text articles were selected after excluding the least prominent articles. Finally, 45 articles were included for the final exclusive review process. The review article provides an insight on drought categorization and drought indices derived to determine the severity of drought. The best suited index for drought severity assessment is very hard to identify since it requires more time. The drought indices should be selected in such a manner, that it effectively measures and monitors the severity of drought. A widespread, informative examination of drought indices would benefit the researchers worldwide to reduce their time spent on each article. The aim of this review article is to review the scientific articles regarding drought indices and provide the best solution to derive the drought severity conditions.

Keywords: Scientometric Analysis; VOSviewer; Drought assessment; Drought monitoring; Drought indices

Introduction

Various studies illustrate the significance of drought assessment utilizing remote sensing and GIS methodologies. Vulnerability assessment is critical for developing mitigation actions to prevent ecological loss. Monitoring of drought aids in the management of drought conditions and the prevention of loss. They frequently include drought-related met-

rics. Drought indices forecast the likelihood and severity of a drought event. The drought factors are frequently linked to the chance of experiencing drought effects. In India, relatively little work has been done at the district level to analyze and monitor droughts. Water bodies, vegetation, forest cover, and built-up areas characterize the study area. Natural disasters and

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environmental destruction in the study area are likely due to the changes in the climatic pattern and several other parameters. However, only few research works in this area will be groundbreaking and will encourage future scientists to make required preparations. The occurrence of drought does not have a discernible beginning or end and it puts numerous human activities in risk in nearly all climatic regions (Bachmair et al., 2016; Loon et al., 2016).

Drought and aridity should be differentiated to acquire a clear decision on drought condition. Aridity is a naturally occurring imbalance in the water supply due to inadequate rainfall, variation in temperature, and low moisture in the ecosystem. Extreme temperature variations occur in an arid environment are characterized by flash floods, and periods of extremely low or no flow. While aridity is a constant aspect of the climate, drought is a transient anomaly. Drought must be viewed as a state that is relative, not absolute. Nearly all climate regimes and locations with high and low rainfall are affected by it. The effects of drought can be severe at times, having an adverse effect on the economy, the environment, and even people's personal lives.

Drought, unlike other hazards, is different in nature due to its effects, tends to endure for several years (Kim et al., 2019). As a result, the effects of recurrent drought can compound, creating issues to both environments and people (Bachmair et al., 2016). Drought can be defined in a number of ways. Drought concepts can be either theoretical or pragmatic in nature. The descriptions of drought emphasize environmental catastrophes such precipitation that is less than anticipated and are descriptive in character (Kchouk et al., 2021). When drought detection and DEWS activities expand globally, there will be a greater need for reliable, high-quality data sets and assessments to support applications at various regional and global scales. The special characteristics of satellite remote sensing data support in filling this information gap by refining the ability to monitor drought, predominantly on a global scale (Hayes et al., 2012).

Methods

Data retrieval and processing was done starting with the keyword identification and the data was obtained using the keyword search. Manual review was made to include highly cited papers according to selected keywords and also to reject least important and irrelevant papers. The VOSviewer is a tool for creating and displaying bibliometric networks. These networks can be built via citation, keywords, co-citation, co-occurrences, organizations, countries, authorship and co-authorship, and comprises of journals, individual articles and researcher details. VOSviewer also has text

Several research works establish the significance of drought condition assessment by integrating the techniques of remote sensing and GIS. Together with environmental factors, socioeconomic factors influence a community's susceptibility to drought. The changes in the climate can be assessed by the indices which are determined through drought monitoring for a region. These indices are attributed to several drought conditions. The occurrence and severity of drought can be predicted by the drought indices. The drought factors are linearly connected to drought impacts. Very few research has been carried out in India related to drought assessment and monitoring at district level.

The purpose of this study is to carry out a detailed evaluation of drought indices for assessment and monitoring of drought. An attempt was made to review the literatures related to drought indices using scientometric analysis. The scientometric review can address an important drawback of traditional review articles which lacks in terms of precision. The scientometric analysis was used in this study to objectively illustrate the research power structure, such as identifying influential authors, journals, and countries, tracking the keywords, and discovering the knowledge base of drought research. The scientometric analysis was made with co-authorship analysis containing authors, organizations and countries and also with co-occurrence analysis with author keywords. A total of 175 manuscripts published by the Scopus and PubMed database were analyzed. The critical review suggested several research themes and the accompanying issues to support future investigations based on the results of the cluster analysis. The combination of scientometric analysis and critical review can help to prevent subjectivity in the literature review and generate a thorough comprehension of the findings. The findings of this study are intended to provide researchers and practitioners with a thorough understanding of the status and research trends of drought research, as well as to encourage additional research in this domain.

mining tools for creating and visualizing co-occurrence networks of keywords collected from research articles. VOSviewer was used to perform the Scientometric analysis of related literatures. The details from Scopus and PubMed were saved as 'csv' files and given as input to the software.

The co-authorship analysis and co-occurrence analysis were made to visualize the map of various factors such as authors, countries, organization and keywords and the research trend was visualized (Figure 1). Manuscripts were searched in various journal search data-

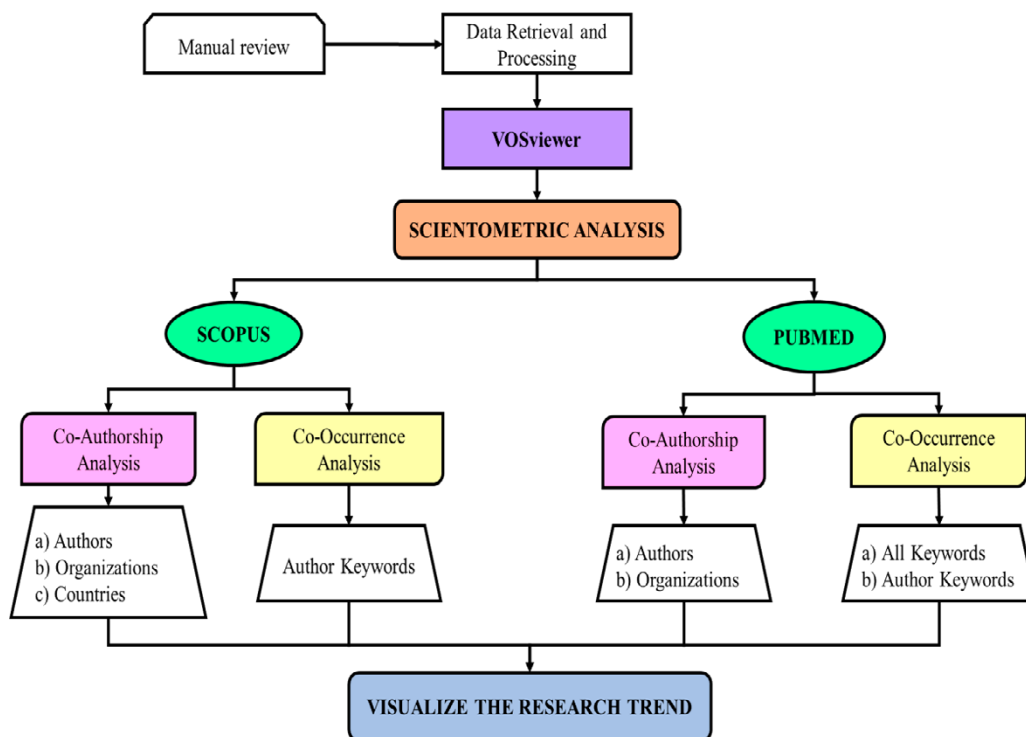


Figure 1. Outline of research

bases, including Springer, Science Direct, MDPI, Taylor & Francis and other journals. A total of 175 manuscripts pertinent to the topic were retrieved. 141 full-text papers were included in the study after an initial screening process, and 34 publications were eliminated due to a lack of relevance to the study's objective. Among 141 full-text papers, 89 were eligible for analysis, and among these 89 articles, 52 were eliminated. The study focused on the assessment and monitoring

of drought using multiple indicators which are derived from both spatial information and non-spatial information. Hence, 52 articles with single indicator did not meet the requirement and were excluded from the study. An effective review was conducted using the remaining 45 full-text papers that best suited the study's significance with high citation count were included in the manuscript after rejecting 44 articles which did not meet the citation count criteria (Figure 2).

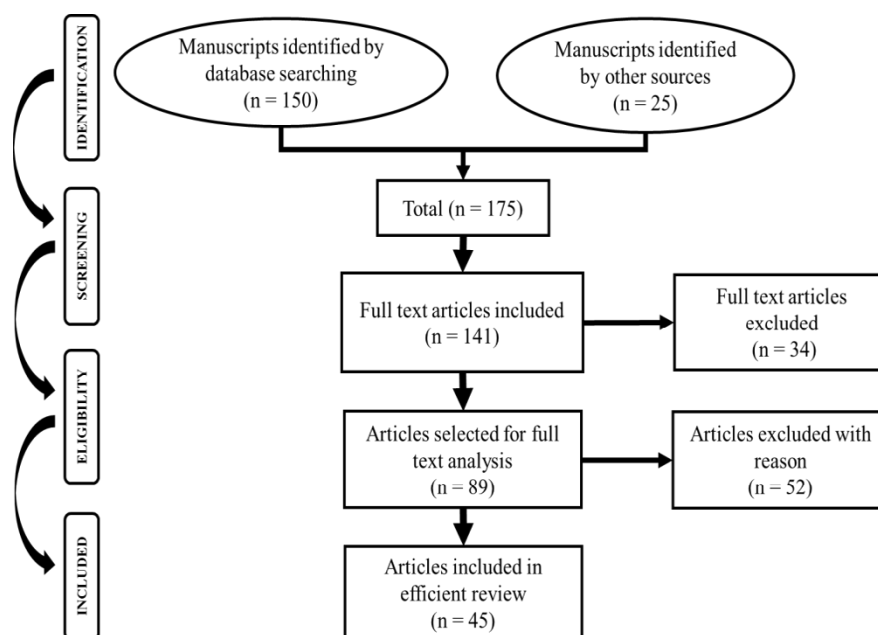


Figure 2. Flowchart showing the identification, screening, eligibility and inclusion of manuscripts for the study

Data collection and processing

The reviewed papers were mostly taken from the Scopus and PubMed databases, which comprises of influential and diverse articles. Because journal papers typically give more complete and high-quality information than other forms of publications, the article type was restricted to journal, journal in press, book chapters, and conference papers. The following keywords were used in the online search databases: (“drought”) OR (“drought assessment”) OR (“drought monitoring”) OR (“drought indicators”). The keyword search was made within the article title, abstract and keywords. The relevant paper appears when the selected keywords are present in the title or abstract or keywords of various manuscripts. The document language was limited to English. The time span of the articles was 1984 to 2021.

After data collection, these articles were downloaded and indexed into Mendeley reference manager. A manual review on search results was adopted to remove the unrelated papers and add some influential papers from other databases in the Mendeley. After manual review, 175 articles were identified for analysis. The search results contained 34 articles which were of least importance for the current research and thus were excluded. In the remaining 141 full text articles, 52 articles were rejected which had only a single indicator to derive drought severity. 89 articles were filtered with multiple indicators of drought. After removing 44 articles with less citation count, only 45 full text articles with high citation count was included which represents the status of drought assessment and monitoring in several regions.

The sources of publication for each research article are represented in Table 1 which shows the retrieval of data from indexed journals database. During the critical review process, the scientometric analysis gave vital information on scientific words. Based on the study results, this analysis indicates several research themes as well as the problems in the research area. Using scientometric analysis, the influential authors, countries interested in the specific study theme, organizations doing the research, and keywords were determined. Figure 3 shows the Network visualization map of Scopus author search. The threshold was fixed with the minimum number of documents and citations per author as 2. The size and color of each circle shows the frequency of occurrence and 170 authors met the threshold among 1272 authors.

Table 1. Source of 175 articles retrieved from various indexed journals, 1984–2021

Nº	Name of Journal	Number of Articles
Science Direct – (53 nos.)		
1	Agricultural and Forest Meteorology	4
2	Journal of Hydrology	5
3	Remote Sensing of Environment	7
4	Science of the Total Environment	5
5	Ecological Indicators	3
6	Agricultural Water Management	1
7	Alexandria Engineering Journal	1
8	Computers and Electronics in Agriculture	1
9	Ecological Engineering	1
10	Geoderma	1
11	ISPRS Journal of Photogrammetry and Remote Sensing	1
12	Applied Geography	1
13	Environmental Modelling & Software	1
14	Atmospheric Research	2
15	Physics and Chemistry of the Earth, Parts A/B/C	1
16	Journal of Arid Environments	1
17	Journal of Environmental Management	1
18	Ecological Informatics	1
19	Modern Cartography Series	1
20	Energy Procedia	1
21	International Journal of Applied Earth Observation and Geoinformation	1
22	Perspectives in Science	1
23	Climate Risk Management	4
24	Weather and Climate Extremes	2
25	ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	2
26	Global and Planetary Change	1
27	Environmental Research	2
MDPI – (33 nos.)		
1	Remote Sensing	16
2	Water	9
3	Sensors	3
4	Sustainability	1
5	Forests	1
6	International Journal of Geo-Information	1
7	Atmosphere	2
Springer – (38 nos.)		
1	SN Applied Sciences	11
2	Arabian Journal for Science and Engineering	3

Nº	Name of Journal	Number of Articles
3	Science China Technological Sciences	5
4	Journal of Central South University	1
5	Iranian Journal of Science and Technology	1
6	KSCE Journal of Civil Engineering	13
7	Smart Water	1
8	Journal of Earth System Science	1
9	Palgrave Communications	1
10	Nature Geoscience	1
Taylor & Francis – (16 nos.)		
1	Journal of Integrative Environmental Sciences	2
2	Geocarto International	4
3	Remote Sensing of Drought: Innovative Monitoring Approaches	10
Others - (35 nos.)		
1	Journal of Sensors	6
2	Wiley Interdisciplinary Reviews	1
3	Asian Journal of Environment and Disaster Management	1
4	AIMS Environmental Science	1
5	International Journal of Environment and Geoinformatics	1
6	Natural Hazards and Earth System Sciences Discussions	2
7	IEEE Access	1
8	Handbook of Drought Indicators and Indices, Integrated Drought Management Program	1
9	IOP Conference Series: Earth and Environmental Science	3
10	Meteorological Applications	5
11	International Journal of Atmospheric Sciences	1
12	The Scientific World Journal	1
13	Atmospheric Science Letters	1
14	American Journal of Climate Change	1
15	Journal of Geography and Geology	4
16	International Journal of Agriculture Sciences	1
17	Journal of Climate and Applied Meteorology	1
18	International Conference on Geoinformatics	1
19	Environmental Reviews	2

Figure 4 shows the Network visualization map of Scopus countries search with the minimum number of documents and citations of a country as 2, and 54 countries met the threshold among 75 countries. Most of the research interests emerged in countries such as United States of America, China, Germany, Spain, Pakistan, Australia etc.

Figure 5 shows the Network visualization map of Scopus author keywords search with the minimum number of occurrences of a keyword as 2, and 130 author keywords met the threshold among 896 author keywords. Most of the author keywords retrieved from Scopus database were Drought, Remote sensing, Drought monitoring, Standardized Precipitation Index, Evaporation, Climate variability, Rainfall etc.

Figure 6 shows the Network visualization map of PubMed author search with a minimum number of documents of an author as 1, and all the 1255 authors met the threshold.

Figure 7 shows the Network visualization map of PubMed author keywords with the minimum number of occurrences of a keyword as 2, and 67 author keywords met the threshold among 800 author keywords. Most of the keywords used by various authors worldwide, retrieved from the PubMed database were Drought, Remote sensing, Climate change, Drought indices etc.

Figure 8 shows the Network visualization map of PubMed all keywords with the minimum number of occurrences of a keyword as 2, and 255 keywords met the threshold among 1243 keywords. While including all keyword searches in PubMed database, most of the common keywords used worldwide were Environmental monitoring, Drought, Temperature, Eco-system, Water pollutants, Drought monitoring etc.

The list of organizations containing highly cited documents were identified using Scopus database search was represented in Table 2. A total of 8 organizations were identified with citation count varying from 6 to 100. Centre for Ecology and Hydrology, UK, contributed 3 papers with the highest citation count of 100. State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, China, contributed 5 papers with next highest citation count of 68. South African Weather Service, South Africa, contributed 3 papers with next highest citation count of 54. The frequency and trend of literature data for different years were retrieved from the database and plotted to analyze the trend in literatures related to the study (Figure 9).

The following section explains the articles included for the final review process that are the same as obtained through Scopus or PubMed databases. These articles include the review of several types of drought indices and discussion on the most appropriate drought index for drought assessment and monitoring.

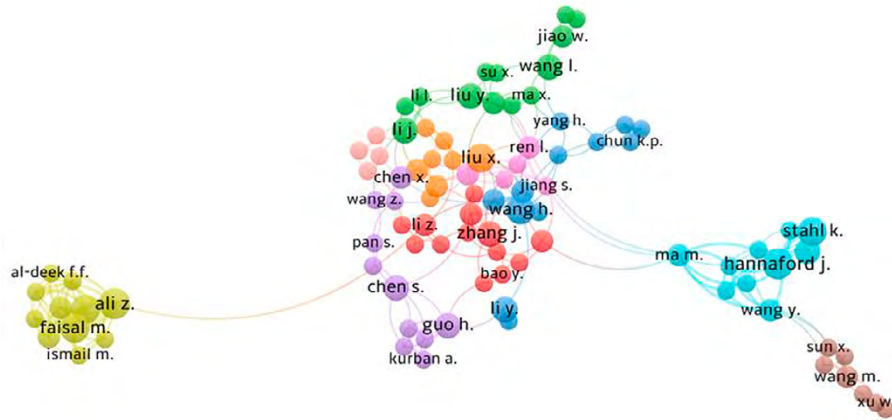


Figure 3. Network visualization – Scopus Author search

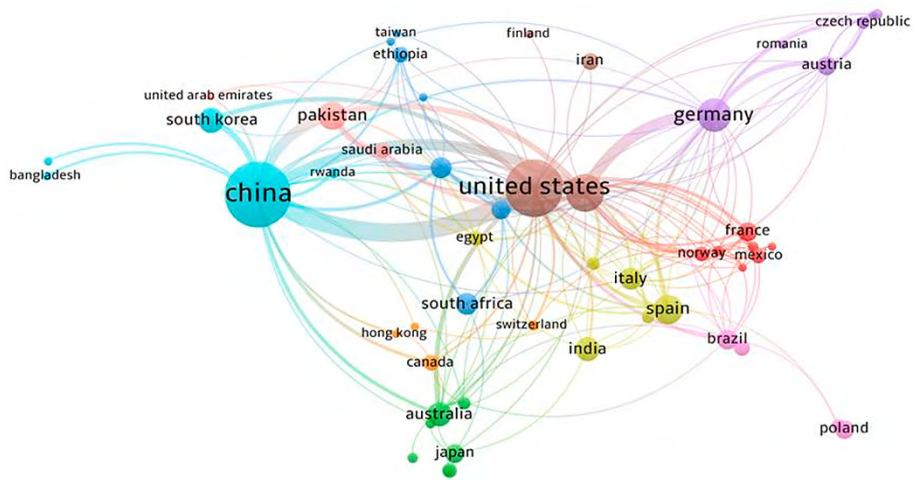


Figure 4. Network visualization – Scopus Country search

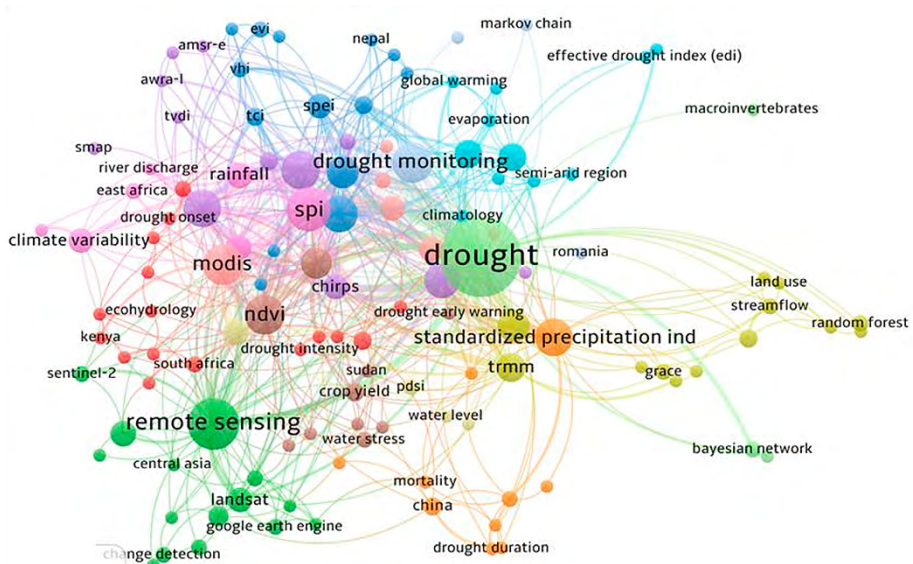


Figure 5. Network visualization – Scopus Author Keyword search

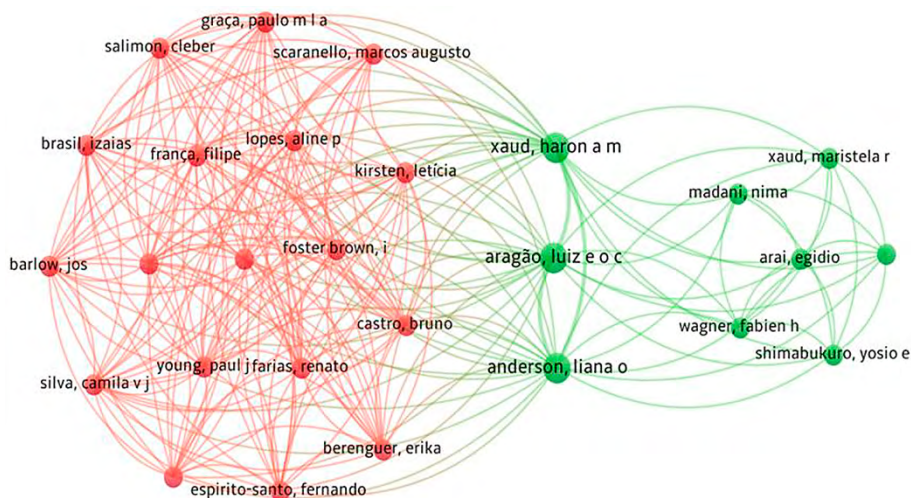


Figure 6. Network visualization – PubMed Author search

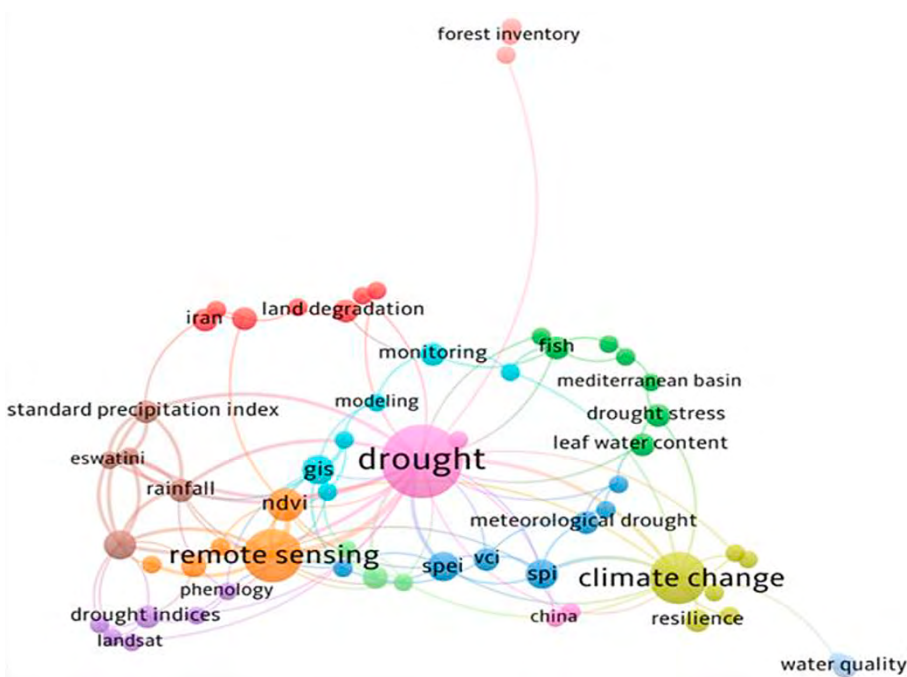


Figure 7. Network visualization – PubMed Author Keyword search

Table 2. Scopus database – Organization details

Nº	Organizations	Documents	Citations
1.	College of Hydrology and Water Resources, Hohai University, Nanjing, 210098, China	3	37
2.	State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing, 210098, China	5	68
3.	Centre for Ecology and Hydrology, Wallingford, United Kingdom	3	100
4.	Department of Statistics, Quaid-I-Azam University, Islamabad, Pakistan	6	17
5.	School of Geodesy and Geomatics, Wuhan University, Wuhan, 430079, China	4	31
6.	South African Weather Service, Private Bag X097, Pretoria, 0001, South Africa	3	54
7.	State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan, 430072, China	3	6
8.	University of Chinese Academy of Sciences, Beijing, 100049, China	3	36

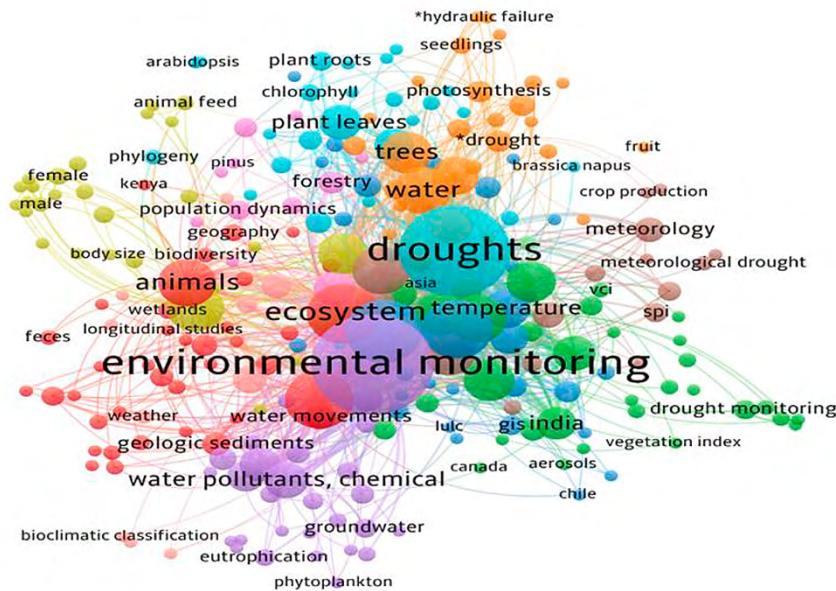


Figure 8. Network visualization – PubMed all keyword search

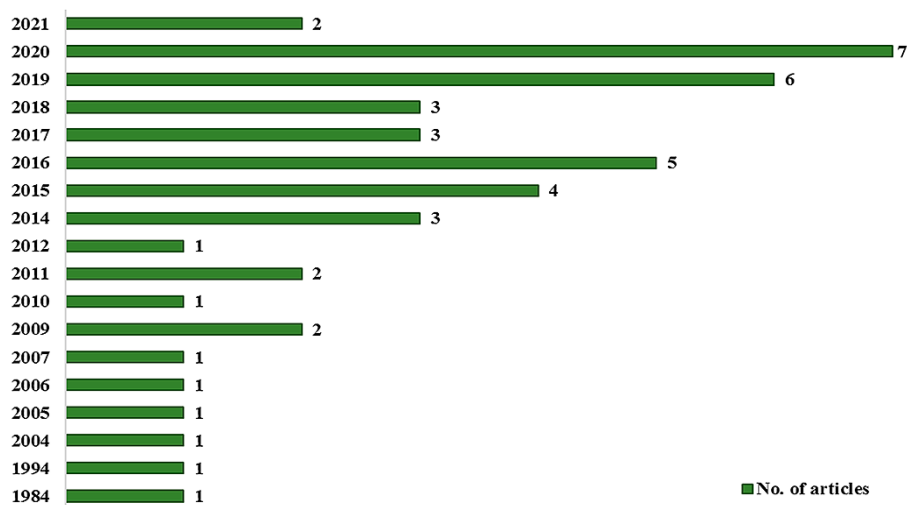


Figure 9. Frequency and trend of literatures

Types of drought indices

Several factors are involved in the characterization of drought which are based on the meteorological, hydrological, and agricultural parameters. The review was carried out for the several drought indices which include meteorological indices, hydrological indices, agricultural indices and composite drought indices. The result of varying rainfall is region specific relating to the atmospheric circumstances of that region, defines the Meteorological drought. The progressive occurrence of precipitation deficiency is defined as a meteorological drought. When there is a prolongation in precipitation drought, it leads to hydrological drought

resulting in reduced water level, decrease in volume of reservoir and shrinkage of rivers. An aridity index (AI) is a measure of dryness in the climate of a particular area. There are a variety of aridity indices that have been derived and these indicators are used to identify, locate the water shortage areas. AI is derived as the ratio of precipitation to the potential evapotranspiration (P/PET), which is a useful indicator of aridity based on long-term climatic water deficiencies. Meteorological indices identified the drought condition of the region, because insufficient rainfall is one of the major influential factors in drought condition assessment.

William M. Alley (1984) investigated the commonly used regional drought index called the Palmer Drought Severity Index, but unfortunately, the index quantified features using random rules. Chopra (2006) identified the limitations of PDSI and resolved it by analyzing the spatial and non-spatial data. The drought risk zones were identified using temporal images of NDVI and SPI using meteorological data. SPI, Rainfall, NDVI and food grain anomaly were used for correlation and regression analysis. From the analysis, it was identified that, the temporal changes in NDVI and precipitation are closely related to each other. The temporal variation of NDVI is not sufficient to identify the deficiency in precipitation. Shukla (2007) formed a drought pattern with the spatial and temporal data using satellite-derived NDVI and SPI to overcome the problem. The classification of drought condition with respect to SPI and SVI clearly explained the drought classes in terms of data descriptors. The future drought pattern identification model called the 3-D Markov random field model was created. Since the region related data was lacking on the basis of NDVI for drought modeling, the understanding on regional drought was incomplete.

Praveen and Ramachandran (2015) simulated the future climate by percent deviation analysis. The result of simulation showed a moderate to mild drought condition in the selected region. 12 months SPI analyzed the severity and frequency of previous drought events. Even though the future climate prediction was done for a coastal stretch, the precipitation deviation was difficult to predict. Proper warning and preparedness programs should be made to deal with the disaster. Oloruntade et al. (2017) studied the drought by analyzing meteorological and standardized runoff index. The result from this study identified that the temperature condition exaggerated the hydrological droughts than that caused by the rainfall. This condition was due to the higher correlation among the reservoir and evapotranspiration index in the basin. The study results provide effective water resource planning and management for the basin. Panda and Sahu (2019) investigated the long-term variations and oscillations in weather across the Odisha districts of Kalahandi, Bolangir, and Koraput. This research looked at weather data from 1980 to 2017. Statistical trend analysis tools were used to discuss and examine the concerns. Rainfall trends were found to be statistically significant, and the findings were shown to be statistically significant from 1980 to 2017. The maximum temperature trend analysis is statistically significant; however, the minimum temperature trend analysis is not statistically significant.

Soundariya and Karunakaran (2019) identified the actual and average rainfall trends using the data for 45

years of district-level monthly rainfall. The findings were used to account for and evaluate the occurrence of extreme weather events. According to the findings, the current climate variability process will raise the occurrence of catastrophic conditions in high-risk zones by 53%. The North East and Southwest monsoons, which provide critical rainfall to Tamil Nadu, vary as much as other seasons. These modifications will have an effect on agricultural planting and harvesting. This report recommends proper technology and strategies to lessen and overcome the consequences of climate extremes. Asfaw et al. (2018) used gridded monthly precipitation and temperature data to examine the change in rainfall and temperature in north-central Ethiopia from 1901 to 2014. The data was examined using the coefficient of determination, PDSI, and anomaly index by the researchers. Furthermore, the trend test identified a time series trend.

Tian, Yuan and Quiring (2018) determined the best approach for drought monitoring, six meteorological indices were estimated: Palmer's Drought Severity Index, Palmer's Z-index, Standardized Precipitation Index, Standardized Precipitation Evapotranspiration Index, Precipitation percentiles, and Percent of Normal indicator. Drought indices were analyzed using agricultural yield and soil moisture data. SPEI was found to be typical for identifying soil moisture. In terms of agricultural yield, the Z-index and SPEI had a stronger association. They demonstrated that there is no sole drought index that can accurately predict drought conditions. Costa and Rodrigues (2017) calculated the Rainfall Anomaly Index (RAI) to analyze the spatiotemporal variation of rainfall in Ceara's Salgado Basin. Seven met stations' daily rainfall data from 1974 to 2015 were used. Using the data provided, the RAI was represented in spatial distribution maps. The historical series represented dry years rather than rainy ones. The RAI varied, with the part near Chapada do Araripe being drier. Extreme anomaly years were linked to events involving sea surface temperature anomalies, which favored their occurrence.

Oloruntade et al. (2017) examined two meteorological drought indicators, namely SPI, SPEI, and hydrologic drought index, the standardized runoff index to determine the drought. Because of the stronger association between the SRI and SPEI in the basin, the results demonstrated that hydrological drought are more exaggerated by temperature than rainfall. A closer look at the rate of the various situations reveals that it has been extra for a normal situation, with excessively dry and wet conditions being extremely unusual. However, given the predicted universal warming conditions, a setback of the existing normalcy may occur soon; the study's findings serve as a foundation for successful water utilization and managing

the watershed. Avdan and Jovanovska (2016) suggested the use of Landsat 8 data and the automatic mapping technique, for measuring land surface temperature. In this technique, the authors employed Landsat 8 band 10 data from a thermal infrared sensor band. This method was found to be a successful technique for LST recovery. The air temperature and the satellite-derived land surface temperature were assessed as a part of the field verification, with a standard deviation of 2.4°C for the first trial and 2.7°C for the second trial.

Praveen and Ramachandran (2015) modelled the future climate of the Thiruvallur coast in South India. Temperatures rose as precipitation fell, according to the data. The drought is moderate to light, according to the percent deviation analysis. SPI – 12 looked into the frequency and severity of previous droughts. The years 1982, 1980, and 1999 were all unusually dry. It is necessary to build drought warning and preparedness systems in order to deal with drought. Nyatuaame, Owusu-Gyimah and Ampiaiw (2014) analyzed the rainfall records from 1981 to 2011, and detected the precipitation trends in the Volta Region and demonstrated climate change. For the study, they acquired monthly and yearly rainfall records from the Ghana Meteorological Department's headquarters in Accra. Statistical analysis was used to evaluate whether there was a statistically significant difference between the months and years analyzed. The northern zone received the greatest rain, followed by the center zone and the coastal zone. Rainfall patterns, on the other hand, were erratic. The yearly mean rainfall was 202.6 mm (highest) and 29.9 mm (lowest).

The limitations of various methods adopted by several researchers showcased that, the use of single indicator such as rainfall will not determine the effect of drought. Also, the meteorological drought indices use only rainfall, temperature and evapotranspiration data and hence it is not sufficient to analyze the drought. Therefore, the use of hydrological drought indices is studied to link the effects of meteorological and hydrological condition, which determines the drought. Hydrological droughts occur in an organized manner along with or after the incidence of meteorological and agricultural droughts. The deficiency in rainfall reflects slowly in the hydrological structure mechanisms like stream flow, soil moisture, reservoir and groundwater. The lack of moisture in the soil, low stream flow, lowering of groundwater leads to hydrological drought condition. Examining the hydrological parameters helps in determining the drought condition of a region.

Narasimhan (2004) calculated the moisture in soil and evapotranspiration using the climate data. The evapotranspiration index was assessed and soil mois-

ture modeling was done using NEXRAD rainfall data. There was a strong correlation identified between the derived indices and wheat and sorghum. This correlation analysis implies that these factors are noble predictors of agricultural drought. The soil moisture modeling using rainfall data improved the drought monitoring. The agricultural drought declaration is made by the past research on meteorological and hydrological drought indices which are the major causes of stress in vegetation. The information identified by the satellite data determines the precise drought condition which provides a near-real time data.

The use of satellite derived vegetation indices and moisture indices compared the depth to groundwater (Seeyan et al., 2014). It was identified that, the values of NDVI at various depth to water level showcased the locations of low groundwater levels which increased the vegetation cover and crop variety. The temperature parameter will be considered for identifying the soil moisture of a location. The limitation of this study was overcome by examining the variation in LST of multi-temporal data (Orhan et al., 2014). The comparison of few satellite-derived drought indices with field observations did not offer much evidence on the hydrological drought. The limitation of previous studies was overcome by various researchers. The identification of spatio-temporal differences of groundwater drought and spotting of drought prone areas were done by deriving a standardized water level index (Ganapuram et al., 2015). The index found the temporal variations of drought characteristics in groundwater. The spatial pattern of drought occurred in the groundwater was interpolated using various techniques in GIS.

Since, deriving one index for hydrological drought identification will not provide much clear information on the drought severity, LST was derived using the Landsat data for drought monitoring (Nugraha et al., 2019). The minimum and maximum LST was used to identify the temperature condition index (TCI) and crop water stress index (CWSI). The results showed a zero TCI signifying the dry condition, and a positive CWSI signifying a wet condition. There was a contradicting result on both the indices values. So, the introduction on Artificial Neural Networks and hybrid optimization techniques were made to predict the short-term hydrological drought (Nabipour et al., 2020). According to the results found, it was identified that, the hybrid model exceeded the traditional ANN technique. The limitation of the study was the data availability to performing ANN technique, involving high training samples for the investigation. To overcome this, the integrated approach was followed to identify the groundwater potential zones which provides necessary details on hydrological drought. The

ArcGIS software was used to create layers such as groundwater level and movement regulating features. The integration of Remote sensing and GIS with Analytical Hierarchy Process (AHP) created different groundwater potential zones, aiding in sustainable use of groundwater. The decision-making process offers finest results using the datasets which were utilized for the analysis (Allafta et al., 2021).

The combined effect of meteorological and hydrological drought showcases the adverse effects of drought. They also possess severe effects on the vegetation and crop growth. Therefore, a proper analysis of agricultural condition should be made to identify the agricultural drought condition of a region. Several agricultural parameters such as crop type, cropping pattern, seasonal crop information should be studied to determine the effect of drought. Agricultural drought links numerous drought characteristics to agricultural impacts both in meteorological and hydrological aspects. Agricultural drought chiefly emphasizes on shortage in rainfall, differences in soil moisture levels, evapotranspiration, and lowered levels of groundwater. Demand in crop water is recognized by the biological features of the crops, the developmental stages, soil properties and weather condition. Multiple criteria analysis should be made to examine the crop stress which showcases the factors responsible for it. Meteorological and hydrological parameters are considered for deciding the occurrence and extent of agricultural drought.

Multi-criteria decision-making analysis in GIS system was made to determine the drought vulnerable areas in Tamil Nadu, India (Chandrasekar et al., 2009). The significant aspects of climate, biotic, edaphic, and social factors were considered for the analysis. The blocks selected by the Drought Prone Area Programme (DPAP) by the Federal Government of India was coinciding with the drought sensitive areas identified from the study. The multi-criteria analysis differentiated the classes of drought and major portion of land was covered by forest. The study was carried for the entire state and this will not provide precise information on the variations in the agriculture. The results were generic for the entire state with least real time information on variations in crop cultivation. Naresh Kumar et al. (2009) used the monthly data of precipitation to calculate precipitation index standardized with the minimum and maximum values. When there is extremely high or extremely low precipitation, the index values under estimated the degree of wetness and dryness with respect to the actual precipitation and deviated precipitation. When the data used is for a longer period, the index values represented a longer range with no improvement in sensitivity of drought years. Haas (2010) assessed and re-

lated the soil moisture in the Stockholm region using hydrological inputs with a remote sensing perspective. Soil moisture modelling uses the elevation data derive the Topographic Wetness Index. Soil moisture measurements in-situ are directly related to the calculated soil moisture indices. After classifying the index values to low, medium and high, it was observed that there was no higher correlation between the value groups. So, it was identified that, thorough analysis of the model should be made to judge the capability of the model. To utilize the model for various forecasts, huge amount of field observations and methods are necessary to make the model efficient for estimating soil moisture over large areas.

Hazaymeh and K. Hassan (2016) identified the significance of drought in agriculture and the procedures to monitor the condition of drought. They found that field data indices provided accurate results than other methods, but the method was not capable of providing spatial dynamics over a large area. To overcome this issue, an examination was made to identify the variation of drought in agriculture over several years (Vaani & Porchelvan, 2018). They used the normalized difference vegetation index to identify the condition and strength of vegetation. The frequently prone and severely prone drought conditions were found at the time of analysis and were used to identify various methods to increase the crop productivity. The frequent drought necessitates the officials to prepare action plans to identify the drought risk areas based on the severity condition. The drought severity maps were created for the entire state, so the results were generic and does not specify the location specific information of drought.

Adi Nugraha, Gunawan and Kamal (2019) initiated the capability of temporal data using surface temperature retrieval methods to monitor the drought. The correlation was performed between PCA, crop water stress and condition of temperature index and a positive relation was identified. The limitation of temporal data in drought assessment is the cloud cover due to which poor results will be obtained. Kalubarme, Acharya and Shukla (2019) used the Remote sensing and GIS techniques to identify the effect of climate change on crop cultivation. Different satellite data products were used for LULC change detection in the regions of crop cultivation. The normalized vegetation index showed the quantity of greenness in vegetation but the results were not sufficient to determine the drought severity in that region. The water stress in vegetation due to temperature variation was tested using Landsat data for determining the drought severity (Lottering et al., 2020).

The T-VWSI was capable of identifying and mapping the drought over large geographical areas. Fur-

ther, Mun et al. (2020) used a framework for climate change to assess the drought vulnerability of reservoirs providing water to crops and developed the vulnerability maps. The results of the study revealed the agricultural drought condition in the selected region. The regional drought vulnerability was also identified to provide mitigation plans and support the drought affected areas. Several algorithms were created to identify the condition of drought (Amina & Rhinane, 2020). Spectral vegetation indices and surface temperature characteristics were evaluated to determine the temperature and moisture indices. Landsat 8 data was used to perform the split-window algorithm to determine the soil moisture information of the study area.

The drought condition assessment will be made effective by deriving various indices of drought. The combination of meteorological, hydrological, and agricultural drought indices derivation proves to be an effective procedure to identify the severity condition of drought in a region. Composite drought indices analysis provides fullest information on the severity condition of drought in a region. The use of composite drought index will be efficient and produces effective results on drought assessment and monitoring. The impact of weather influences the source of various commercial factors like food, water, and hydroelectric power. Due to the climate irregularity, the availability of water is plentiful in some places but inadequate in other places to meet the demand. During the exceedance of demand, the supply is dependent on the deficit in water supply. This excess demand is called as the socio-economic drought which is related to the social and economic factors. The use of multiple drought indices will greatly help in speeding up the decision-making process. By combining the meteorological, hydrological and agricultural drought characteristics, the socio-economic drought condition of a region can be studied.

Chandrasekar, Sessa Sai and Behera (2011) investigated the early drought season in Andhra Pradesh and Tamil Nadu. The soil moisture identification was made during the cropping seasons. The agricultural drought was identified based on the land surface water index which uses shortwave-infrared region and soil water balance model. Soil moisture values were obtained both in temporal manner and across an area. There was a possibility of agricultural drought in the study area. Since the scope of research was confined to huge area, there was only less amount of information on drought. Dhanya and Ramachandran, (2015) conducted focus group talks and semi-structured questionnaire surveys to discover the perception of farmers on climate change and identify the need for adaptation. The salient points highlighted by farmers during the questionnaire survey which affects the

crop cultivation were increased warmness, late onset, consistent dry phases, and weakening soil moisture. The perception of farmers was reliable with the Mann–Kendall test, and Sens' slope estimator test that analyses the trend in rainfall data but the results were not matching with the entire rainfall. Various adaptation requirements were identified by farmers, some of which were field-specific adaptation procedures and policies. Zhao and Hu (2015) observed the drought using vegetation indices, Cloud Parameters Method, and precipitation index. According to the results, the cloud features indicate the drought severity conditions.

Han et al. (2019) created a new combined drought monitoring index. The efficiency of the index in monitoring drought was authenticated using SPI, soil moisture, and other remote sensing drought indices. The combined drought monitoring index was associated with SPI and moisture in soil while comparing to other indices. Combined drought monitoring index utilizes the machine learning to analyze the correlations between various components to identify the drought index, but the limitation of the study was the data availability. A combined drought index was developed to predict the onset of agricultural drought and its origin using land, meteorology and remote sensing-based observations (Chattopadhyay et al., 2020). Weighted overlay analysis was performed by assigning ranks and weights for the selected parameters. With the results from overlay analysis, the severity condition was divided into five classes i.e., no drought to extreme drought condition.

A comprehensive remote sensing drought index (CRSDI) was derived using the strengths of other drought indices derived with respect to remote sensing factors (Shojaei & Rahimzadegan, 2020). CRSDI was found efficient in identifying the drought for a selected region. Further, Balaganesh et al. (2020) used agricultural and dairy indicators to derive a new composite drought vulnerability index (CDVI). The study was made at state level and it was identified with the sensitivity map, that nearly 12 districts were highly prone to drought, whereas 8 districts were moderately prone and 10 districts were least prone to drought severity. Water conservation and suitable agricultural protection plans and protection for the livelihood of dairy should be made by the government to bring down the susceptibility of drought.

The influential factors required to determine the drought severity condition are used in composite drought monitoring indices. The combination of meteorology, hydrology and agricultural drought indices proves to be an efficient and effective way to assess the drought severity assessment for a location.

Results and discussion

The articles identified using proper keywords in various search databases indicates accurate search results. Scientometric analysis provided necessary details on the scientific knowledge on the drought indices and their role in assessment and monitoring the drought condition using the collected article data. Researchers involved in drought monitoring used various approaches to detect and monitor drought conditions around the world. The majority of the research incorporated the use of drought indices to assess drought conditions based on a variety of factors influencing natural features. Rainfall, temperature, and other climatic conditions were the most important elements influencing land surface characteristics. Satellite-derived indices were also used to monitor drought conditions that was found to be more accurate and efficient. Algorithms were developed to assess the drought severity index, as well as an examination of the relationship between the components under consideration for analysis.

Various drought assessment and monitoring research have proven to be effective for assessing susceptibility in a region. The integrated use of spatiotemporal elements and satellite data for drought-related studies were also examined. Drought indices proved to be reliable in measuring the severity of the drought. PDSI forecasts drought in an area based on precipitation and temperature data. Palmer indices were

deemed inadequate for drought underwater management research due to their difficult calibration, lack of transparency, ignorance of water scarcity, and changes in human water balance (Steinemann et al., 2005). Some meteorological indicators, such as SPI, deciles, percent of normal precipitation, EDI, and RAI, are simple to calculate using simply a region's precipitation data. Weaknesses in meteorological drought indices include imprecision in drought beginning, ending, and accumulated stress, failure to account for the aggravating effects of runoff and ET, and inability to monitor in real time due to being monthly based (Zargar et al., 2011). NDVI is a drought-detection metric that is calculated for the majority of places using satellite data (Svoboda & Fuchs, 2016).

Cloud cover produced by climatic circumstances, as well as the effects of the sun's surface geometry on the sensor, can be reduced using NDVI algorithms. As a result, it distinguishes vegetated zones from other types of surfaces in general (Zargar et al., 2011). TCI and VCI employ satellite data and are sometimes encountered with NDVI estimates. TCI and VCI are used by VHI to calculate the health of plants. It is one of the first attempts to use remotely sensed data to detect drought. The water supply vegetation index (WSVI) detects drought by combining vegetation information with remotely sensed temperature data (Chen et al., 1994).

Conclusion

As a result of the reviewing various research articles, it was identified that, a single factor or parameter cannot provide detailed information on drought severity. Drought assessment and monitoring was carried out by various researchers all over the world using the meteorological indices, hydrological indices, and agricultural indices. The result was to assess the particular type of drought. The combined effect of meteorology, hydrology and agriculture proves to be efficient to determine

the onset and will be useful for long term monitoring. The major influential parameters including the meteorological, hydrological, agricultural and socio-economic drought should be combined to assess and monitor the drought condition. Various satellite derived as well as spatio-temporal drought indices are involved in determining the severity of drought in many places. The combined effect of these indices should be analyzed to accurately predict and monitor drought severity of a region.

References

- Adi Nugraha, A. S., Gunawan, T., & Kamal, M. (2019). Downscaling land surface temperature on multi-scale image for drought monitoring. *SPIE 11311, Sixth Geoinformation Science Symposium*, 6. <https://doi.org/10.1117/12.2544550>
- Allafta, H., Opp, C., & Patra, S. (2021). Identification of groundwater potential zones using remote sensing and GIS techniques: A case study of the shatt Al-Arab Basin. *Remote Sensing*, 13(1), 1–28. <https://doi.org/10.3390/rs13010112>
- Amina, S., & Rhinane, H. (2020). Soil moisture and drought monitoring in casablanca-settat region, Morocco by the use of gis and remote sensing. *Proceedings - 2020 IEEE International Confer-*

- ence of Moroccan Geomatics, *Morgeo*. <https://doi.org/10.1109/Morgeo49228.2020.9121871>
- Asfaw, A., Simane, B., Hassen, A., & Bantider, A. (2018). Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. *Weather and Climate Extremes*, 19, 29–41. <https://doi.org/10.1016/j.wace.2017.12.002>
- Avdan, U., & Jovanovska, G. (2016). Algorithm for automated mapping of land surface temperature using LANDSAT 8 satellite data. *Journal of Sensors*, 2016. <https://doi.org/10.1155/2016/1480307>
- Bachmair, S., Stahl, K., Collins, K., Hannaford, J., Acreman, M., Svoboda, M., Knutson, C., Smith, K. H., Wall, N., Fuchs, B., Crossman, N. D., & Overton, I. C. (2016). Drought indicators revisited: the need for a wider consideration of environment and society. *Wiley Interdisciplinary Reviews: Water*, 3(4), 516–536. <https://doi.org/10.1002/WAT2.1154>
- Balaganesh, G., Malhotra, R., Sendhil, R., Sirohi, S., Maiti, S., Ponnusamy, K., & Sharma, A. K. (2020). Development of composite vulnerability index and district level mapping of climate change induced drought in Tamil Nadu, India. *Ecological Indicators*, 113, 106197. <https://doi.org/10.1016/j.ecoind.2020.106197>
- Chandrasekar, K., Sai, M. V. R. S., Roy, P. S., Jayaraman, V., Krishnamurthy, R. R., Sai, M. V. R. S., Krishnamurthy, R. R., Roy, P. S., Chandrasekar, K., K. Chandrasekar, M.V.R. S. S. Sai, P.S. Roy, V. J., & Krishnamoorthy, R. (2009). Identification of Agricultural Drought Vulnerable Areas of Tamil Nadu, India – Using GIS Based Multi Criteria Analysis. *Asian Journal of Environment and Disaster Management (AJEDM) - Focusing on Pro-Active Risk Reduction in Asia*, 01(01), 43. <https://doi.org/10.3850/s17939240200900009x>
- Chandrasekar, K., S. Sai, M. V. R., & Behera, G. (2011). Assessment of Early Season Agricultural Drought Through Land Surface Water Index (Lswi) and Soil Water Balance Model. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVIII-8/, 50–55. <https://doi.org/10.5194/isprsarchives-xxxviii-8-w20-50-2011>
- Chattopadhyay, N., Malathi, K., Tidke, N., Attri, S. D., & Ray, K. (2020). Monitoring agricultural drought using combined drought index in India. *Journal of Earth System Science*, 129(1). <https://doi.org/10.1007/s12040-020-01417-w>
- Chen, W., Xiao, Q., & Shen, Y. (1994). Application of the anomaly vegetation index to monitoring heavy drought in 1992. *Remote Sensing of Environment*, 9, 106–112.
- Chopra, P. (2006). Drought risk assessment using remote sensing and GIS: a case study of Gujarat. In *International Institute for Geo-information Science and Earth Observation*.
- Costa, J. A., & Rodrigues, G. P. (2017). Space-Time Distribution of Rainfall Anomaly Index (Rai) for the Salgado Basin, Ceará State - Brazil. *Ciência e Natura*, 39(3), 627. <https://doi.org/10.5902/2179460x26080>
- Dhanya, P., & Ramachandran, A. (2015). Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi arid region of south India. *Journal of Integrative Environmental Sciences*, 13(1), 1–18. <https://doi.org/10.1080/1943815X.2015.1062031>
- Ganapuram, S., Nagarajan, R., & Chandra Sekhar, G. (2015). Identification of groundwater drought prone zones in Pedda vagu and Ookachetti vagu watersheds, tributaries of the Krishna River, India. *Geocarto International*, 31(4), 385–407. <https://doi.org/10.1080/10106049.2015.1047472>
- Haas, J. (2010). *Soil moisture modelling using TWI and satellite imagery in the Stockholm region* (Issue March).
- Han, H., Bai, J., Yan, J., Yang, H., & Ma, G. (2019). A combined drought monitoring index based on multi-sensor remote sensing data and machine learning. *Geocarto International*, 0(0), 1–16. <https://doi.org/10.1080/10106049.2019.1633423>
- Hayes, M. J., Svoboda, M. D., Wardlow, B. D., Anderson, M. C., & Kogan, F. (2012). Drought monitoring: Historical and current perspectives. *Remote Sensing of Drought: Innovative Monitoring Approaches*, 94, 1–19. <https://doi.org/10.1201/b11863>
- Hazaymeh, K., & K. Hassan, Q. (2016). Remote sensing of agricultural drought monitoring: A state of art review. *AIMS Environmental Science*, 3(4), 604–630. <https://doi.org/10.3934/environsci.2016.4.604>
- Kalubarme, M., Acharya, M., & Shukla, S. H. (2019). Monitoring Drought and its impact on Agriculture using Drought Indices and Geo-informatics Technology in Patan District, Gujarat. *International Journal of Environment and Geoinformatics*, 6(2), 153–162. <https://doi.org/10.30897/ijegeo.554465>
- Kchouk, S., Melsen, L. A., Walker, D. W., & Van Oel, P. R. (2021). A review of drought indices: predominance of drivers over impacts and the importance of local context. *Natural Hazards and Earth System Sciences Discussions*, 152, 1–28. <https://doi.org/10.5194/nhess-2021-152>
- Kim, S., Shao, W., & Kam, J. (2019). Spatiotemporal patterns of US drought awareness. *Palgrave Communications*, 5(1), 1–9. <https://doi.org/10.1057/s41599-019-0317-7>
- Loon, A. F. Van, Gleeson, T., Clark, J., Dijk, A. I. J. M. Van, Stahl, K., Hannaford, J., Baldassarre, G. Di, Teuling, A. J., Tallaksen, L. M., Uijlenhoet, R., Hannah, D. M., Sheffield, J., Svoboda, M., Verbeiren, B., Wagener, T., Rangelcroft, S., Wanders, N., & Lanen,

- H. A. J. Van. (2016). Drought in the Anthropocene. *Nature Geoscience*, 9(2), 89–91. <https://doi.org/10.1038/NGEO2646>
- Lottering, S., Mafongoya, P., & Lottering, R. (2020). Detecting and mapping drought severity using multi-temporal Landsat data in the uMsinga region of KwaZulu-Natal, South Africa. *Geocarto International*, 6049, 1–13. <https://doi.org/10.1080/10106049.2020.1783580>
- M. Svoboda and B.A. Fuchs. (2016). Handbook of Drought Indicators and Indices. In *Integrated Drought Management Program*. Integrated Drought Management Tools and Guidelines Series 2.
- Mun, Y. S., Nam, W. H., Jeon, M. G., Bang, N. K., & Kim, T. (2020). Assessment of vulnerability to drought disaster in agricultural reservoirs in South Korea. *Atmosphere*, 11(11), 1–15. <https://doi.org/10.3390/atmos1111244>
- Nabipour, N., Dehghani, M., Mosavi, A., & Shamshirband, S. (2020). Short-Term Hydrological Drought Forecasting Based on Different Nature-Inspired Optimization Algorithms Hybridized with Artificial Neural Networks. *IEEE Access*, 8, 15210–15222. <https://doi.org/10.1109/ACCESS.2020.2964584>
- Narasimhan, B. (2004). Development of indices for agricultural drought monitoring using a spatially distributed hydrologic model. In *Dissertation* (Issue August). Texas A& M University.
- Naresh Kumar, M., Murthy, C. S., Sai, M. V. R. S., Roy, P. S., Sessa sai, M. V. R., & Roy, P. S. (2009). On the use of Standardized Precipitation Index (SPI) for drought intensity assessment. *Meteorological Applications*, 16(3), 381–389. <https://doi.org/10.1002/met.136>
- Nugraha, A. S. A., Gunawan, T., & Kamal, M. (2019). Comparison of Land Surface Temperature Derived from Landsat 7 ETM+ and Landsat 8 OLI/TIRS for Drought Monitoring. *IOP Conference Series: Earth and Environmental Science*, 313(1). <https://doi.org/10.1088/1755-1315/313/1/012041>
- Nyatuame, M., Owusu-Gyimah, V., & Ampiaiw, F. (2014). Statistical Analysis of Rainfall Trend for Volta Region in Ghana. *International Journal of Atmospheric Sciences*, 2014, 1–11. <https://doi.org/10.1155/2014/203245>
- Oloruntade, A. J., Mohammad, T. A., Ghazali, A. H., & Wayayok, A. (2017). Analysis of meteorological and hydrological droughts in the Niger-South Basin, Nigeria. *Global and Planetary Change*, 155, 225–233. <https://doi.org/10.1016/j.gloplacha.2017.05.002>
- Orhan, O., Ekerin, S., & Dadaser-Celik, F. (2014). Use of Landsat land surface temperature and vegetation indices for monitoring drought in the Salt Lake Basin Area, Turkey. *The Scientific World Journal*, 2014. <https://doi.org/10.1155/2014/142939>
- Panda, A., & Sahu, N. (2019). Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmospheric Science Letters*, 20(10), 1–10. <https://doi.org/10.1002/asl.932>
- Praveen, D., & Ramachandran, A. (2015). Projected Warming and Occurrence of Meteorological Droughts—Insights from the Coasts of South India. *American Journal of Climate Change*, 04(02), 173–179. <https://doi.org/10.4236/ajcc.2015.42013>
- Seeyan, S., Merkel, B., & Abo, R. (2014). Investigation of the Relationship between Groundwater Level Fluctuation and Vegetation Cover by using NDVI for Shaqlawa Basin, Kurdistan Region – Iraq. *Journal of Geography and Geology*, 6(3), 187–202. <https://doi.org/10.5539/jgg.v6n3p187>
- Shojaei, S., & Rahimzadegan, M. (2020). Improving a comprehensive remote sensing drought index (CRSDI) in the Western part of Iran. *Geocarto International*, 6049. <https://doi.org/10.1080/10106049.2020.1783578>
- Shukla, V. (2007). *Modeling Spatio-Temporal Pattern of Drought Using Three-Dimensional Markov Random Field*.
- Soundariya, P., & Karunakaran, K. R. (2019). Climate Risk Analysis in Tamil Nadu : District Level Monthly Rainfall Panel Data Analysis. *International Journal of Agriculture Sciences*, 11(10), 8472–8476.
- Steinemann, A., Hayes, M. J., & Cavalcanti, L. (2005). Drought Indicators and Triggers. In *Drought and water crises: Science, technology, and management issues*, CRC press.
- Tian, L., Yuan, S., & Quiring, S. M. (2018). Evaluation of six indices for monitoring agricultural drought in the south-central United States. *Agricultural and Forest Meteorology*, 249 (June 2017), 107–119. <https://doi.org/10.1016/j.agrformet.2017.11.024>
- Vaani, N., & Porchelvan, P. (2018). Monitoring of agricultural drought using fortnightly variation of vegetation condition index (VCI) for the state of Tamil Nadu, India. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 42(4/W9), 159–164. <https://doi.org/10.5194/isprs-archives-XLII-4-W9-159-2018>
- William M. Alley. (1984). The Palmer Drought Severity Index: Limitations and Assumptions. *Journal of Climate and Applied Meteorology*, 23, 1100–1109.
- Zargar, A., Sadiq, R., Naser, B., & Khan, F. I. (2011). A review of drought indices. *Environmental Reviews*, 19(NA), 333–349. <https://doi.org/10.1139/a11-013>
- Zhao, M., & Hu, W. (2015). Comparative study of four kinds of drought monitoring methods in Yunnan Province. *International Conference on Geoinformatics*, 2016(201). <https://doi.org/10.1109/GEOINF-FORMATICS.2015.7378595>

Climatic Regionalization of Montenegro by Applying Different Methods of Cluster Analysis

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Abstract

To carry out an "objective" regionalization of the climate of Montenegro for the period 1961–2020, this paper used cluster analysis, which is a multivariate technique that classifies a sample of subjects (objects) based on a set of variables into a single number. Based on the results (score), several groups were separated, and similar classes (groups) were grouped into the same cluster. Annual data for mean temperature and total precipitation from 18 meteorological stations were utilized. Temperature and precipitation cluster regions were separated using three different hierarchical agglomerative methods (*Unweighted Pair Group Method with Arithmetic Mean (UPGMA)*, *Single linkage*, and *Ward's*) and one non-hierarchical method (*K-means*). The *Euclidean distance* was used as a measure of distance for hierarchical methods, and the results were represented graphically in the form of dendrograms and thematic maps. The obtained results indicate that the singled-out temperature and precipitation cluster regions largely coincide with the established climate types in Montenegro. The cluster results further showed that the distribution of meteorological stations clearly reflects the largest part of the climatic diversity of Montenegro and indicates the spatial dimension of temperature and precipitation.

Keywords: cluster regions *UPGMA*, *Single linkage*, *Ward's*, *K-means*, Montenegro

Introduction

Cluster analysis is a multivariate technique that classifies a certain sample of subjects (objects) into different groups based on a set of measurable variables and their results (scores), such that similar classes (groups) form the same cluster. There are several reasons for using cluster analysis in statistical data analysis. In addition to uncovering/suggesting hidden structures in the dataset, the primary purpose is reduction, specifically reducing the number of input data, which is crucial for classification purposes. Investigating the climate regionalization of the continental United States (US) based on multiyear monthly values of temperature and precipitation, Fovell and Fovell (1993) reported that solutions of 14, 25, and 8 cluster levels were the best cho-

sen. Together these clusters are called "reference clusterings". At the 14-cluster level, most of the US is divided into four major climate zones: the Southeast, the Central East, the Northeast, and the inner West cluster zone. Previously, this cluster analysis was less frequently used (Wolter, 1987), but there is a growing number of scientific articles in atmospheric science journals that use this technique (Fovell & Fovell, 1993). Clustering of Iran, based on the use of Ward's method and 10 climate components, for the period from 1980 to 2005 based on 64 meteorological stations (MS), distinguishes 4 basic cluster regions (Arbabi, 2011). It can be concluded that the use of multivariate analysis methods (such as factor analysis, *principal component analysis*

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(PCA), cluster analysis, etc.) is very common in modern climate research, because they are used to reduce the amount of climate variables, in order to obtain new variables through their combination and to use the results for subsequent analyses (Appendini et al., 1994; DeGaetano et al., 1990; Johnson, 1998; Moreira et al., 2006; Nassiri et al., 2006; Szép et al., 2005; Van Groenewoud, 1984; Warrington, 1977).

To date, there has been no application of different methods of the multivariate cluster analysis technique in the regionalization of the climate of Montenegro. Three hierarchical and one non-hierarchical method will be used to establish a theoretical model of the distribution of temperature and precipitation cluster regions. Since it is more difficult to find an appropriate pattern for grouping the observed clusters if more variables are included, in this case, only the two most important climatic elements, temperature, and precipitation, will be observed. The disadvantage of this type of multivariate technique is the problem of determining the final number of clusters or the so-called “stopping” rule. There is no statistical criterion or objective standard procedure for this determination. During each object grouping step, a distance plot is generated. However, ultimately, the decision is made by the researcher. There are two equally subjective approaches to determining the final number of clusters: formal tests and the heuristic approach. The first approach refers to the possibility of interpreting the obtained solution, while the second approach concerns the analysis of fusion coefficients (Papić-Blagojević & Bugar, 2009). In this research paper, a strategy of us-

ing hierarchical agglomerative methods was initially applied to gain insight into the number of obtained clusters, and then the results were applied in a non-hierarchical method. The idea is to apply several hierarchical and one non-hierarchical method to determine the complementarity of the obtained results. If they agree to a reasonable extent, the end result will be considered convincing.

This study has two main objectives. The first is to group precipitation and temperature regions into a specific, smaller, and “reasonable” number of clusters, based on which the “objective” theoretical assumptions of climate regions in Montenegro will be established. It will suggest the relationships that exist between the obtained cluster regions in the observed period and how the results of different methods of cluster analysis affect the already known spatial distribution of temperature and precipitation, conditioned by the dominant physical-geographical factors in the area. According to the Köppen climate classification (KCC), Burić et al. (2014) distinguished two basic climates, three climate types, and five climate subtypes in Montenegro for the period 1961–1990, using data from 23 meteorological stations. The second goal of this study is to perform a comparative analysis with the previously mentioned climate regionalization in Montenegro. Therefore, in the case of cluster analysis, the regions are distinguished by means of joining algorithms, while in the case of climate classification, the regions are based on physical characteristics, such as the influence of physical-geographical factors on the regime of temperature and precipitation.

Research area, database and methodology

Research area

The area of research is Montenegro, a country located in Southeastern Europe and which extends to the southernmost part of the Adriatic Sea in a length of about 100 km. This small Mediterranean country (area 13,812 km²) stretches between 41°50′–43°50′N, i.e. between 18°26′–20°21′E. Apart from the mathematical-geographical position, the main factors that influence the climate of this country are: relief, air mass variations and the influence of the Mediterranean Sea (Burić et al., 2013). The significant relief dissection has made it possible to distinguish several types and subtypes of climate in this small area. Montenegro is predominantly mountainous, with numerous valleys and a terrain that extends from 0 m a.s.l. to 2534 m a.s.l.

Database and methodology

To determine the cluster regions for temperature and precipitation in Montenegro, data from a 60-year period (1961–2020) were used from 18 meteorological stations. This data included mean annual values of air temperature and annual precipitation sums, as shown in Figure 1. The homogeneity of the temperature and precipitation data was tested using two software packages, *MASH v3.02* and *MISH v1.02*, which are recommended by the World Meteorological Organization (WMO) and developed by Szentimrey (2003) and Szentimrey and Bihari (2007).

While applying cluster analysis, it is very important to carry out grouping analysis, i.e., dispersion of MS included in the analysis. Therefore, the Point Pattern Analysis-nearest neighbors procedure was used in Past4.12 software. The procedure tests overdispersion of points as two-dimensional (2D) coordinate values (Davis, 2002). The calculation of this statistic is based



Figure 1. Presentation of meteorological stations used in the analysis

Source: Burić & Doderović, 2022

on nearest neighborhood analysis¹. The null hypothesis (h_0) is a random Poisson process, giving a modified nearest-neighbor exponential distribution with mean:

$$\eta = \frac{\sqrt{R/t}}{2} \quad (1)$$

- where R is the area and t is the number of points.

The probability that the distribution is random (a Poisson process, given as an exponential distribution) is represented by the value of P when:

$$P = \frac{\bar{w}}{\eta} = \frac{2\bar{w}}{\sqrt{R/t}} \quad (2)$$

- where P is the nearest neighbor value, and \bar{w} is the observed mean distance between nearest neighbours. Table 1 shows the value of the coefficient P in the Poisson distribution.

Table 1. Values of coefficient P offered by PAST

P	Distribution
<1	Clustered points
~1	Poisson patterns
>1	Overdispersed points

The theoretical distribution under the null (h_0) hypothesis is plotted as a continuous curve with a histogram of observed distances. The expected probability density function as a function of distance r is (Clark & Evans, 1954):

$$g(r) = 2\rho\pi r \exp(-\rho\pi r^2) \quad (3)$$

- where ρ , that is, r is point density.

The obtained results, shown on the x/y graph, indicate that the points are not clustered in an area (Figure 2). The value of the coefficient R in this case is 1.39, which means that the points (meteorological stations) are scattered or dispersed in an area, indicating a statistically significant overdispersion of points.

Temperature and precipitation cluster regions were separated using three different hierarchical agglom-

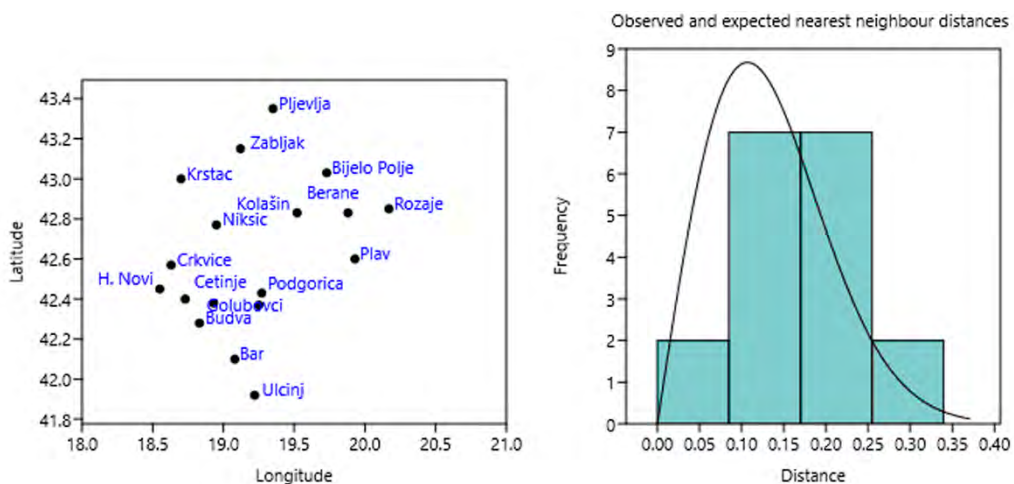


Figure 2. Display of meteorological stations on the XY graph in PAST (left) and histogram of observed and expected distances between nearest neighbors (right)

¹ <https://www.nhm.uio.no/english/research/resources/past/downloads/past4manual.pdf>

erative methods and one non-hierarchical (*K-means*) method. The *Euclidean distance* was used as a measure of distance for hierarchical methods², which is a robust and widely applicable measure. When a measure such as the *Euclidean distance* is used, it should be decided before the actual clustering whether the variables will be transformed, or whether the original values will be kept. Standardization of the results is done if the variables used were measured on different measurement scales³. *Euclidean distance* is converted to similarity by changing the sign:

$$Euclidean\ dist_{.jk} = \sqrt{\sum_{i=1}^s (x_{ij} - x_{ik})^2} \quad (4)$$

The choice of variables (in this case, temperature and precipitation) included in the cluster analysis must be determined based on the assumed conceptual model since the analysis itself does not distinguish important from irrelevant variables, and this can greatly affect the final result. Hierarchical agglomerative methods are those in which the variables begin the clustering in their own separate clusters. Then, the two most similar clusters are grouped together, and this is repeated until all variables are in one cluster. The optimal number of clusters is obtained from all cluster solutions. The hierarchical cluster routine produces a “dendrogram” that shows how the data points (rows) can be grouped into clusters. For this analysis, three different algorithms were used by selecting the appropriate options in the software *Past4.12* (Table 2): *UPGMA* (Unweighted Pair Group Method with Arithmetic Mean), *Single linkage and Ward’s method*, as well as the non-hierarchical clustering method (*K-means*).

The set of symbols used is as follows: Let X_{ijk} the value for variable k in observation j belonging to cluster i . Furthermore, for this particular method it must

be defined like this (The Pennsylvania State University, 2004):

$$ESS = \sum_i \sum_j \sum_k |X_{ijk} - \bar{X}_{.ik}|^2 \quad (5)$$

- where *ESS* is the Error Sum of Squares;

$$TSS = \sum_i \sum_j \sum_k |X_{ijk} - \bar{X}_{.k}|^2 \quad (6)$$

- where *TSS* is the Total Sum of Squares;

$$r^2 = \frac{TSS - ESS}{TSS} \quad (7)$$

The value r^2 is interpreted as the proportion of variation that is explained by a particular clustering of observations. Referring to the explanations given in the *PAST* manual (V.4.12) (<https://www.nhm.uio.no/english/research/resources/past/downloads/past4manual.pdf>), one method is not necessarily better than the other, although some do not recommend *Single linkage*, which can be useful in comparing dendrograms obtained by different algorithms to informally determine clustering strength.

K-means clustering⁴ is a non-hierarchical cluster method that was first mentioned under this name in 1967 (MacQueen, 1967). The number of clusters to be used is predetermined, usually according to some hypothesis such as the existence of two meteorological variables (temperature and precipitation), 4 climate regions, or three types of objects in the data set. It is sometimes preferred because it allows subjects to move from one cluster to another (this is not possible in hierarchical cluster analysis where a subject, once placed, cannot move to another cluster) (Everitt et al., 2001; Rencher, 2002). Today, the well-known algo-

Table 2. Joining algorithms used in the analysis

UPGMA	Single linkage	Ward’s method
Unweighted pair-group average (UPGMA). Clusters are joined based on the average distance between all members in neighboring clusters.	Single linkage (nearest neighbor). Clusters are joined based on the smallest distance between 2 groups. This method is relatively simple, but it is better than other methods when natural clusters are not spherical or elliptical in shape.	Clusters are joined so that within-group variance growth is minimized. It is also very sensitive to outliers. Nevertheless, this is one of the most popular methods, along with the average link between groups method. This method includes an agglomerative cluster algorithm. Ward’s method* starts with n clusters of size 1, continues until all observations are included in one cluster. This method is best suited for quantitative variables, but not for binary ones.

Source: Everitt et al., 2001; Rencher, 2002

* <https://online.stat.psu.edu/stat505/lesson/14/14.7>

² For *Ward’s method*, the *Euclidean distance* is inherent to that algorithm. (<https://www.nhm.uio.no/english/research/resources/past/downloads/past4manual.pdf>)

³ <http://www.statstutor.ac.uk/resources/uploaded/clusteranalysis.pdf>

⁴ <https://www.nhm.uio.no/english/research/resources/past/downloads/past4manual.pdf>

rithm using *K-means* clustering has been defined by many authors (Bensmail et al., 1999; Fraley & Raftery, 1998; Hartigan & Wong, 1979):

Given a set of observations $X = (x_1, x_2, \dots, x_n)$, partition the n observations into k partition $S = \{s_1, s_2, \dots, s_k\}$, such that:

$$\arg \min \sum_{i=1}^k \sum_{x \in S_i} \|x - \mu_i\|^2 \quad (8)$$

The digitization of the temperature and precipitation cluster regions obtained using the aforementioned methods of cluster analysis was carried out using Voronoi diagrams. The appropriate options were run in the *QGIS 2.8.1* package to produce the results shown in Figure 3.

Voronoi diagrams were first mentioned in the 17th century when René Descartes argued that the solar system consists of vortices, whose decay produces convex regions rotating around fixed stars, in the field of computational geometry. Their next use was by the mathematician Dirichlet in 1850, and Voronoi gave them a wider meaning in 1907, 1908, and 1909. They have different names and uses in various scientific disciplines, such as the transformation of the mean axis in biology and physiology, *Wigner–Seitz* zones in chemistry and phys-

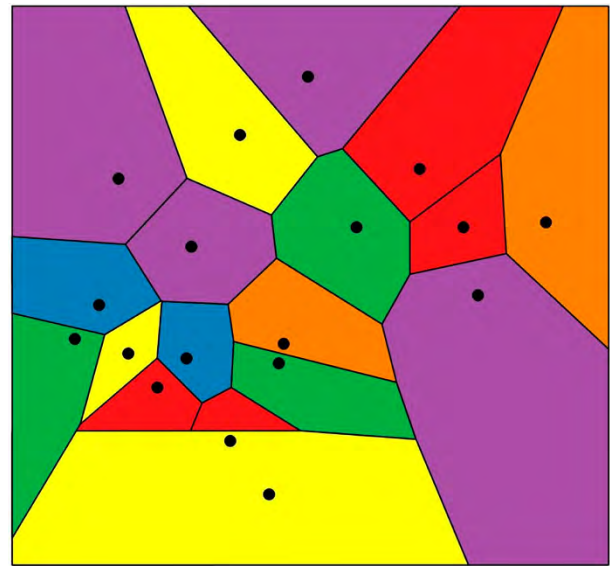


Figure 3. Voronoi diagram of 18 points (meteorological stations included in the analysis) in the *Euclidean* plane

ics, domains of action in crystallography, and Thysen polygons in meteorology and geography. A Voronoi diagram is also known as a Dirichlet square plate. The cells are called Dirichlet regions or Voronoi diagrams, Delaunay tessellation or Delaunay triangulation (Aurenhammer & Klein, 2000; Barber et al., 1996; Guibas & Stolfi, 1985; Okabe et al., 2000; Preparata & Shamos, 1985).

Results and discussion

First of all, it should be emphasized that understanding the term “climate cluster” requires a good (or excellent) knowledge of the climate diversity in Montenegro. Only with such knowledge can high-quality theoretical propositions for an adequate climate regionalization of this country be presented. In order to implement such an analysis, hierarchical agglomerative methods that are dominantly used in research (*UPGMA*, *Single linkage* and *Ward’s* method) and non-hierarchical clustering method (*K-means*) were applied. The standard *Euclidean distance* for hierarchical agglomerative methods was chosen as a measure of similarity/distance. The two most important variables of the climate system, average annual values of temperature and precipitation, were observed for a series of 60 years (1961–2020) from 18 meteorological stations in Montenegro.

Applying the above-mentioned hierarchical methods and *Euclidean distance*, by running the appropriate options in the *PAST* software, 6 dendrograms were obtained. In this particular case, it means that the variability of temperature and precipitation has its own spatial dimension, as does every variable of the climate system, and this influenced the determination

of the distance, that is, the separation of temperature and precipitation regions. Based on the non-hierarchical *K-means* method (the default number of clusters is 3), appropriate clusters were formed, as in the previous case. Based on the grouping of MS and by running the appropriate options in the *QGIS* software, a total of 8 thematic maps were obtained on which the digitized regions were previously defined by clusters using the method of Voronoi diagrams.

Hierarchical agglomerative cluster methods for temperature (*UPGMA*, *Single linkage* i *Ward*)

According to the *UPGMA* method, 8 cluster temperature regions were distinguished. **The first cluster** consists of 4 MS located in the mountainous southwestern and northeastern parts of Montenegro, mostly at altitudes of 600–700 m. According to Burić et al. (2014) these are places with a modified Mediterranean climate, dry and hot summer (*Csb*). This climate cluster accounts for 22.2% of the total number of MS included in the analysis. **The second cluster** included 3 MS, mostly located in the altitude zone between 800–900 m. According to the Köppen climate classification, it is a belt with a moderately warm climate (*C*), which

is represented by two subtypes of climate: a moderately warm and humid climate with hot summers in the far north of Montenegro (*Cfb*) and a transitional variant of the Etesian climate (*Csb*). Both regions are mountainous and should be considered transitional between Mediterranean and moderately warm and humid climates. This cluster makes up 16.7% of stations. Only one MS (Nikšić) is classified in the **third cluster**, and it is located at an altitude of about 650 m and has a *Csb* subtype of climate. Therefore, MS classified in the three mentioned clusters have moderately warm summers, while winters are due to the influence of altitude and distance from the sea.

The **fourth cluster** consists of 2 MS (11.1%), located at an altitude of 944 m and 1012 m. Burić et al. (2014) just mention an altitude of about 1000 m as a transition between a moderately warm (*C*) and a mountainous or moderately cold (*D*) climate. At higher altitudes, the *D* climate dominates, so the **fifth cluster** includes only one MS (Žabljak), the only one at an altitude of 1450 m. It is a humid boreal climate with fresh summer (*Dfc* climate subtype). The southern part of Montenegro includes the Adriatic coast and the plain area around the capital (Podgorica). In this part, all MS are located at a low altitude (1–44 m) and are under the strong influence of the Adriatic (Mediterranean Sea), with a typical Mediterranean climate, characterized by dry, sunny and hot summers, while winters are rainy and mild (*Csa* climate subtype). Nevertheless, the *UPGMA* method separates three clusters (Figure 4) with: 3 MS (**sixth cluster**, 16.7%) and with 2 MS each (**seventh and eighth cluster**, with 11.1% each).

Similar results were obtained using the other two methods (*Single linkage* and *Ward's method*), which

confirms the fact that temperature has its own spatial dimension and that there is a correlation between the hierarchical methods in cluster analysis. It could be concluded that this type of multivariate techniques is suitable for research in climatology. Comparing the results of cluster analysis for temperature obtained by *UPGMA* and *Single linkage*, i.e. *Ward's method*, the following differences are observed:

- Compared to *UPGMA*, there are 7 cluster regions in the *Single linkage* method.
- The *Single linkage* method classifies 5 MS in one cluster: Herceg Novi, Ulcinj, Podgorica, Bar and Budva (Figure 5), making it the largest cluster region in percentage terms (27.8%), while according to *UPGMA* the mentioned MS are classified into 2 cluster regions.
- Compared to the *UPGMA* method, there are also 7 cluster regions in the *Ward's method*.
- According to the *Ward's method*, MS Cetinje and Nikšić now constitute a separate cluster region with 11.1%. Also, MS Kolašin, Rožaje and Žabljak form one cluster region with 16.7% of the total number of stations (Figure 6). As a reminder, according to the *UPGMA* method, MS Nikšić and MS Žabljak each form one cluster region.
- In contrast to the results obtained using the *UPGMA* and *Single linkage* methods, in the *Ward's method* there is no cluster of regions consisting of only one MS.
- Percentage-wise, the largest cluster region obtained by the *UPGMA* method includes 22.2% of stations, by the *Single linkage* method 27.8%, while with the *Ward's method*, four regions make up 16.7% of the total number of stations.

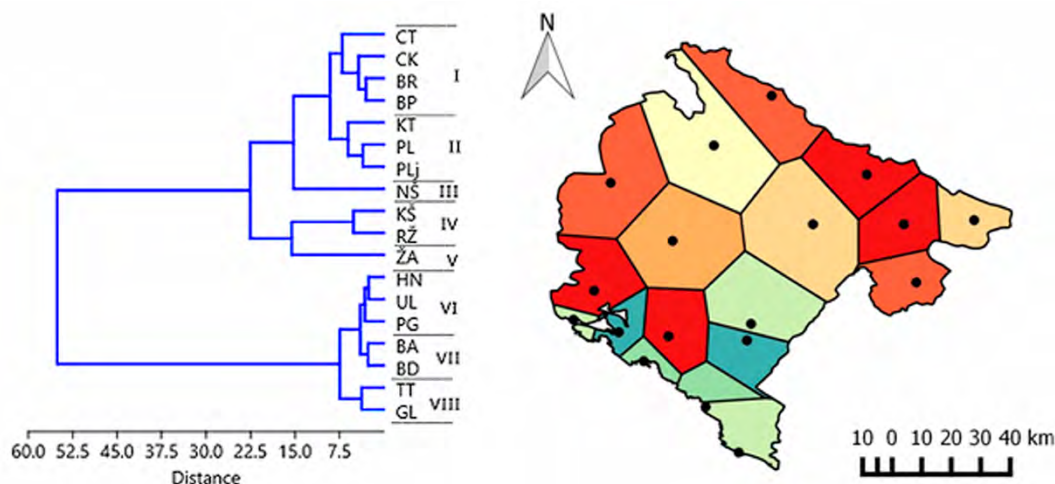


Figure 4. Results of the *UPGMA* method for the period 1961–2020: dendrogram of meteorological stations (left) and temperature regions (right).

(CT – Cetinje, CK – Crkvice, BR – Berane, BP – Bijelo Polje, KT – Krstac, PL – Plav, PLj – Pljevlja, NS – Nikšić, KŠ – Kolašin, RŽ – Rožaje, ŽA – Žabljak, HN – Herceg Novi, UL – Ulcinj, PG – Podgorica, BA – Bar, BD – Budva, TT – Tivat, GL – Golubovci)

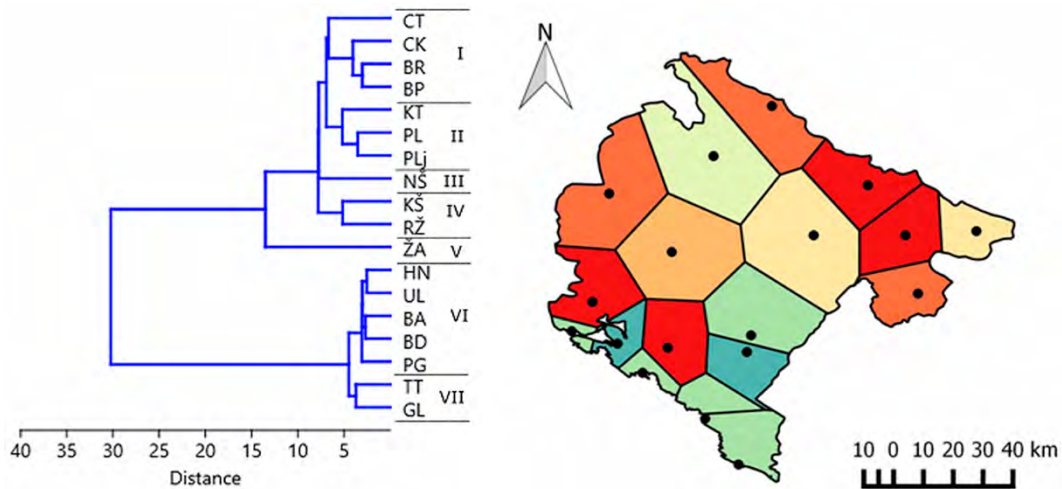


Figure 5. Results of the *Single linkage* method for the period 1961–2020: dendrogram of meteorological stations (left) and temperature regions (right)

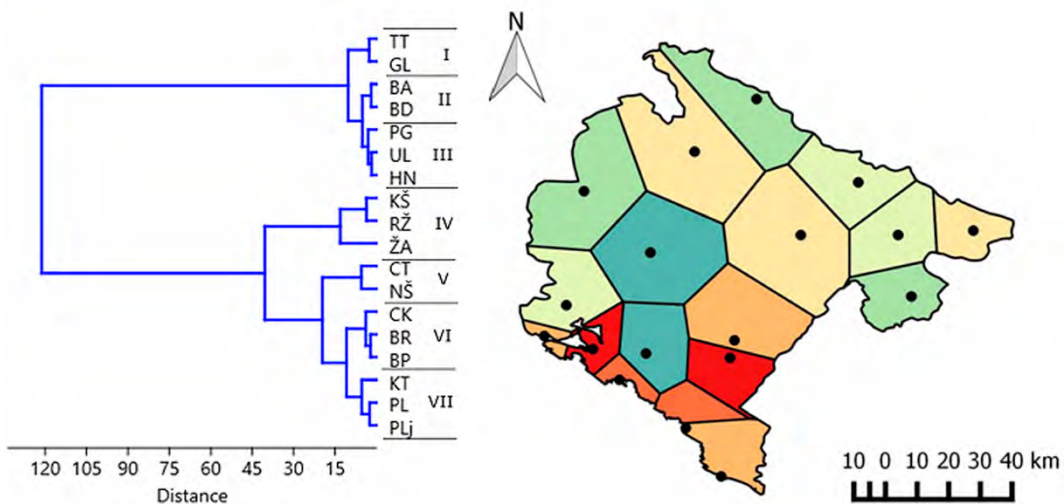


Figure 6. *Ward's method* results for the period 1961–2020: dendrogram of meteorological stations (left) and temperature regions (right)

A non-hierarchical K-means cluster method for temperature

Unlike the previous hierarchical agglomerative methods, the non-hierarchical *K-means* cluster procedure does not produce a dendrogram as a graphical representation of the MS included in the analysis. The default number of clusters in this case is 3, and the algorithm connects the stations to the cluster with the smallest distance to its centroid. The given number of clusters in this case will facilitate the analysis because only similar cluster regions will be observed in all three cases, regardless of the numerical designation of the stations that make it up.

The results of the analysis indicate the following:

I temperature cluster region groups the mountainous MS Rožaje, Žabljak and Kolašin, making up 16.7% of the share (Figure 7). Percentage-wise, this is the smallest cluster region. Common for the men-

tioned MS is that they are located at altitudes of about 1000 to 1450 m, located at a relatively short distance from each other, as well as in the mountain climate zone, in general. In addition to these common physical-geographical features, the similarity can also be observed in the thermal aspect, so all three MS register a negative mean temperature in winter, while the average summer is around 14–15°C.

II temperature cluster region includes 8 MS, i.e. it is the largest in percentage (44.4%). These are the stations located in the zone of moderate-continental climate and at an altitude of 650 m to 1000 m. In the thermal regime, the predominant influence in these places is the physical-geographic features of the surrounding area, first of all the elevation, the dissection of the relief and the distance from the sea. Therefore, the stations have moderately warm summers and moderately cold winters. Average summer tempera-

tures range from 17–20°C, while average winter temperatures range from –1°C to 3°C.

III temperature cluster region groups 38.8% of MS included in the analysis (7 out of 18 MS). What these stations have in common is that they are located in the zone of predominant influence of the Mediterranean, and two climatic areas are distinguished: Adriatic–Mediterranean and modified Mediterranean. A modified Mediterranean climate is represented in the Podgorica–Skadar basin and the Bjelopavlići plain (MS Podgorica and Golubovci). Other MS are located along the Montenegrin coast of the Adriatic, and it is a narrow zone with a typical Mediterranean climate (short, mild and rainy winters with rare frosts, long and warm summers, average annual insolation is about 2600 h). The average summer temperature is 24–26°C, and the winter temperature is around 6–9°C.

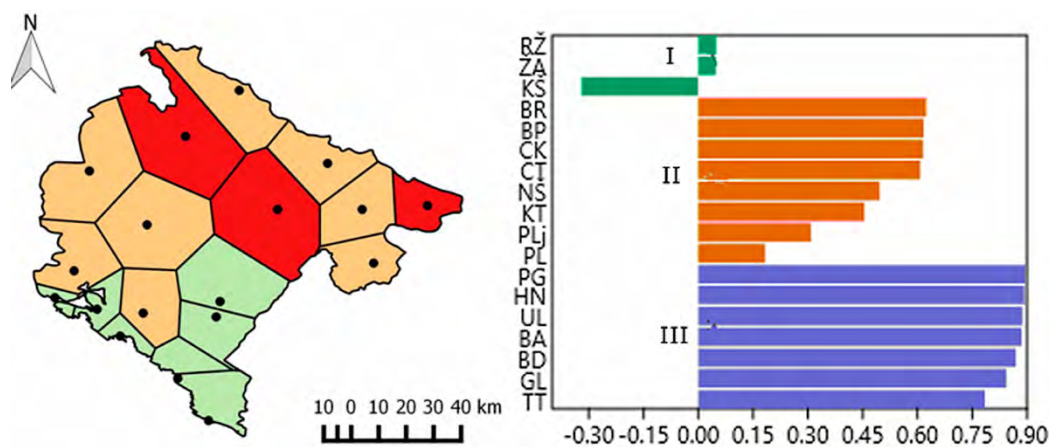


Figure 7. Temperature regions for the period 1961–2020 obtained by the *K-means* method (left) and Silhouette plot (right)

(x-axis: on a scale from –1 to 1, where 1 means a perfectly suitable assignment to a group; –1 means that the object would be better placed in another group; 0 means that the object is on the border between two clusters)

The results obtained using the *K-means* cluster method correspond to a large extent with previous research by Burić et al. (2014). Namely, in the I temperature cluster region there are mountain stations that belong to the *D* climate (*Dfb*, *Dfc*), as well as MS Kolašin, which is at the transition between *C* and *D* climates. The II temperature cluster region consists of the largest number of stations distributed in climate class *C* and in different climate types *Cs* and *Cf*, depending on the physical–geographical features there is also a climate differentiation. Also, the stations in the III temperature cluster region belong to the same climate class, type and subtype (*C*, *Cs*, *Csa*). In general, based on the comparative analysis of the results of climate regionalization according to the Köppen climate classification, given by the aforementioned authors, and presented in this paper, which were obtained us-

ing the non–hierarchical agglomerative method and the hierarchical method, it is concluded that the multivariate technique is suitable for research in climatology, because the analysis indicated a logical grouping of MS, primarily based on real physical–geographical factors in geographical area.

Hierarchical agglomerative cluster methods for precipitation (UPGMA, Single linkage i Ward)

The *UPGMA* method distinguishes 6 clusters of precipitation regions. **The first cluster** is the largest, because it groups five MS (27.8% of the total number of stations). These are places in the extreme north and northeast of Montenegro, which have a continental (MS Pljevlja and Rožaje) and a Mediterranean–continental pluviometric regime (MS Bijelo Polje, Berane and Plav). These are the most continental regions of Montenegro with the lowest annual rainfall (average

800–1000 mm). The difference in seasonal rainfall is smaller than in the rest of the country. **The second cluster** consists of three MS (Herceg Novi, Nikšić and Kolašin) or 16.7%. This cluster includes the parts of Montenegro that are closer to the sources of moisture (the Atlantic and the Mediterranean Sea) and that have a typical Mediterranean pluviometric regime. The average annual amount of precipitation is about 1900–2100 mm, of which about 32–34% falls in winter, in general. The least precipitation is in summer, only about 10–12% of the annual average. And **the third cluster** groups three MS (Figure 8): Tivat, Golubovci and Podgorica. These are regions with a *Csa* subtype of climate and a Mediterranean precipitation regime. However, compared to the previous cluster, there is less precipitation in these places – the annual average is around 1600 mm.

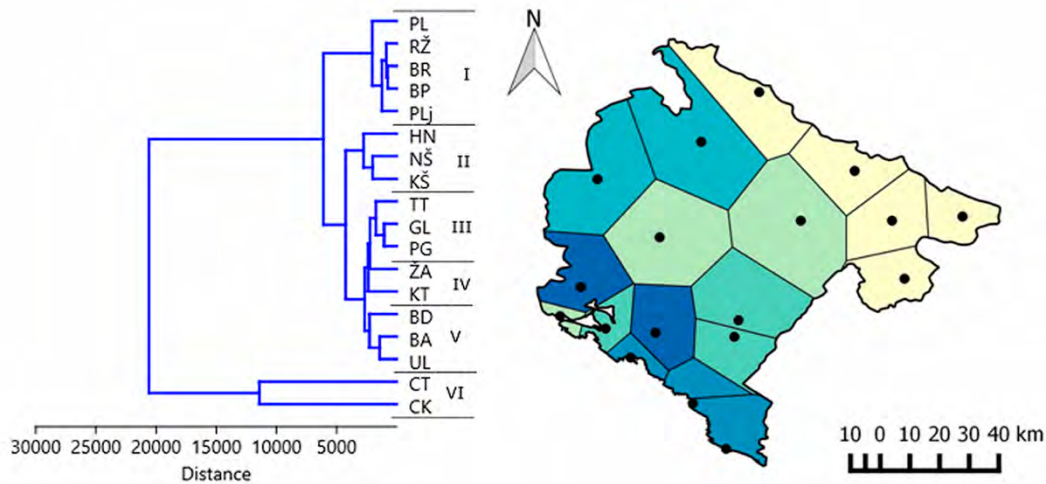


Figure 8. Results of the *UPGMA* method for the period 1961–2020: dendrogram of meteorological stations (left) and precipitation regions (right)

The western part of Montenegro with two MS belongs to **the fourth cluster**. These are the mountain MS (Žabljak and Krstac) with an annual average of about 1500–1650 mm of precipitation. This cluster is also characterized by minimal precipitation in summer, but still in this season about 15–17% of precipitation falls compared to the annual average. Compared to the previous clusters, the difference is that MS Žabljak receives maximum precipitation during the fall, and not in the winter season. **The fifth cluster** consists of three MS on the Montenegrin coast (Budva, Bar and Ulcinj) or 16.7% of the total number of stations (18). The coastal region of Montenegro has a true Mediterranean climate (*Csa*) with a typical Mediterranean pluviometric regime. In this part of Montenegro, the annual average precipitation is around 1300–1500 mm. In summer it is about 10%, and in winter about 33% of the annual precipitation. The last **sixth cluster** includes the rainiest part of Montenegro, which is the southwestern part where MS Crkvice and Cetinje are located (11.1%). For the period 1961–2020, the annual average precipitation in Crkvice is about 4600 mm, and in Cetinje about 3320 mm. It is one of the rainiest regions of Europe, with a Mediterranean precipitation regime, and due to the altitude, the climate formula is *Csa*.

In relation to the clusters obtained by *UPGMA*, the number of cluster regions obtained by the *Single linkage* method is twice as large (12 cluster regions). This fact supports the justification of using multiple methods for extracting cluster regions, especially for precipitation, because it is a very variable climatic element, especially in an area with a dissected relief, as is the case with Montenegro. According to the *Single linkage* method, the changes in the cluster regions are as follows:

- Clusters group the Žabljak and Krstac stations into special rainfall regions with 5.6% of the total number of stations. The *UPGMA* method grouped these two MS into one region.
- Plav and Pljevlja now form a separate cluster region without Rožaje, Berane and Bijelo Polje, so in this case there were changes to 5.6% compared to 27.8% from the first method.
- Budva and Tivat now form separate precipitation regions with 5.6% participation.
- Also, both Cetinje and Crkvice now form separate clusters, and in the first case (*UPGMA* method) those two MS were an integral part of one cluster.

Therefore, the main difference is that the *UPGMA* method does not distinguish clusters with one MS each, while according to *Single linkage* there are as many as 8 cluster regions with one MS each (Figure 9). In other words, out of a total of 12 cluster regions, the percentage share is mostly occupied by clusters with one MS each (8/12 clusters), followed by clusters with two stations each (2/12 clusters) and clusters with three stations each (2/12 clusters).

The smallest number of cluster regions was obtained using the *Ward's method* (5 regions in total), and the results are very similar to the *UPGMA* method. Comparing the results of these two methods, *UPGMA* and *Ward's*, for the period 1961–2020, the following facts can be observed:

- *Ward's method* separates 5 cluster regions (Figure 10), i.e. one less than *UPGMA*.
- According to the *Ward's method*, MS Krstac and Žabljak do not now form a common cluster region, but are part of other cluster regions (station Krstac is part of the fourth and Žabljak of the fifth clus-

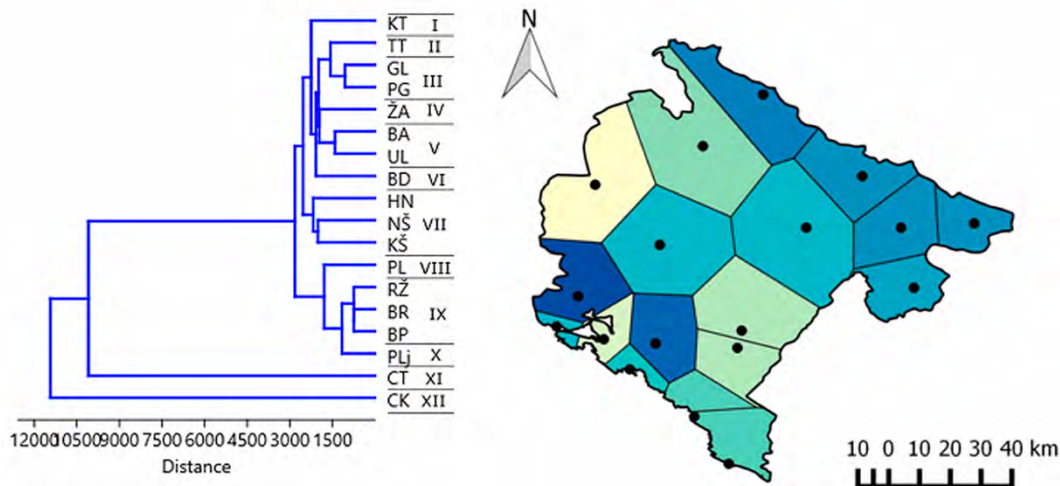


Figure 9. Results of the *Single linkage* method for the period 1961–2020: dendrogram of meteorological stations (left) and precipitation regions (right)

ter region). Recall that the *UPGMA* method groups these two MS into one cluster region.

- In contrast to the results obtained using the *UPGMA* and *Single linkage* methods, in the *Ward's method* clusters with four stations each dominate (22.2% participation).
- Percentagewise, the largest cluster region obtained by the *UPGMA* and *Ward's* methods is 27.8% of the stations (1 cluster region with 5 MS each), and 16.7% by the *Single linkage* method (2 cluster regions with 3 MS each).

(in this case, the default number of clusters is 3, as in the case of temperature regions), which will facilitate comparative analysis (see Figure 11). The following is a comparison of the cluster regions that include the largest number of the same MS in both groups of methods.

The results of the comparative analysis of the obtained cluster regions in the first and second group of methods indicate the following:

I precipitation cluster region groups 5 stations with 27.8% share, located in the far north and north-

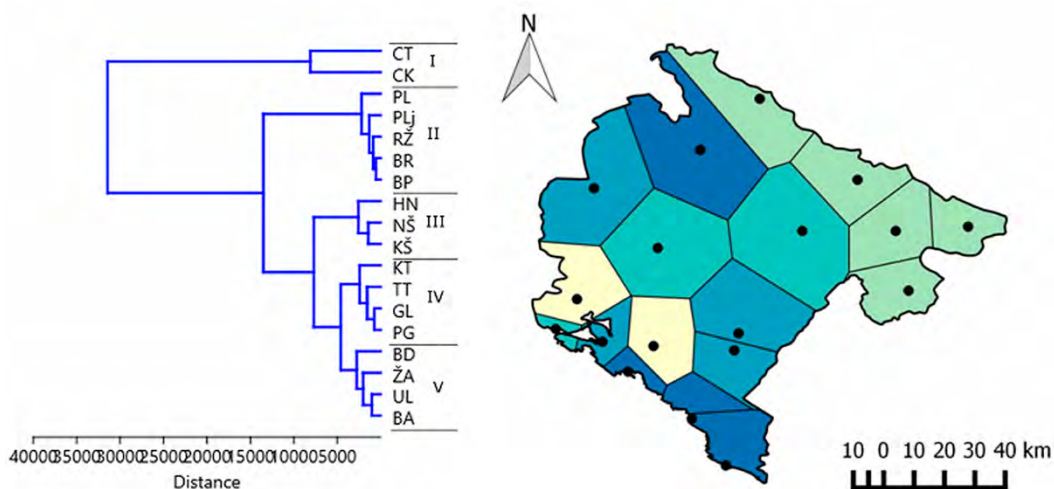


Figure 10. *Ward's* method results for the period 1961–2020: dendrogram of meteorological stations (left) and precipitation regions (right)

A non-hierarchical K-means cluster method for precipitation

In contrast to the results obtained by applying hierarchical methods of regionalization, the *K-means* cluster procedure produces a uniform number of clusters

east of Montenegro. It is an area with a moderate continental and mountain climate. This part of Montenegro is the farthest from the Adriatic Sea, so the influence of continentality is felt the most. Continental and Mediterranean-continental precipitation re-

gimes are represented. This part has the lowest annual precipitation in Montenegro, an annual average of 800–1000 mm.

II precipitation cluster region includes only two spatially close MS: Cetinje and Crkvice. Percentage-wise, it is the smallest cluster region, and what both stations have in common is that they are located in a mountainous region, in the hinterland of the Adriatic Sea. Due to the specific morphology of the terrain, the two mentioned MS register the highest amount of precipitation in Montenegro (Crkvice about 4600 mm, Cetinje 3320 mm). Therefore, this smallest cluster region logically groups stations that differ in precipitation sums from all other MS included in the analysis, that is, they form a separate precipitation cluster region.

Comparing the results of the formed precipitation cluster regions presented in this paper with the researches of climatic regionalization of Montenegro, given by the mentioned authors, it can be concluded that the precipitation cluster region consists of MS located in the area with a continental precipitation regime and with similar annual sums precipitation. The border of this cluster region coincides with the border between the Mediterranean and continental pluviometric regime defined by the mentioned authors. Around that conditional border, the influences of continentality and maritimeness on the pluviometric regime are interwoven. Therefore, these results undoubtedly indicate the validity of the multivariate techniques used, both the hierarchical and non-hierarchical cluster methods, which were the focus of this

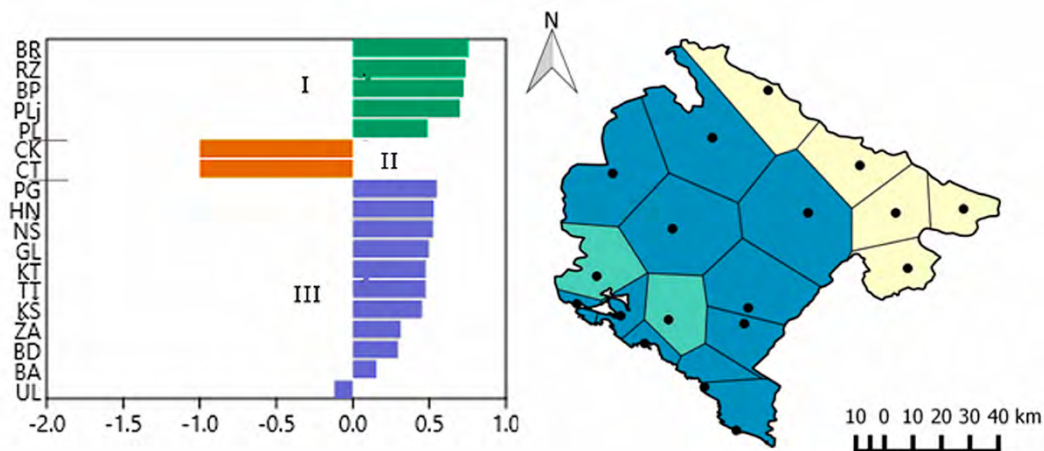


Figure 11. Precipitation regions for the period 1961–2020. obtained by the *K*-means method (right) and Silhouette plot (left)

(x-axis: on a scale from -1 to 1, where 1 means a perfectly suitable assignment to a group; -1 means that the object would be better placed in another group; 0 means that the object is on the border between two clusters)

III precipitation cluster region groups the other 11 MS with a total of 61.1% participation, i.e. this is the largest cluster precipitation region in percentage terms. It is a region that has several climate types (Mediterranean, modified Mediterranean, temperate-continental and mountain climate), but air masses within the cyclone from the Mediterranean Sea and from the west have the dominant influence on precipitation. Within this region, therefore, the Mediterranean precipitation regime is common to all MS. The average annual precipitation in this cluster region ranges from about 1300 mm to 2000 mm.

The II precipitation cluster region is comprised of the rainiest stations in Montenegro, which belong to the *Csbx* climate subtype. Finally, the III precipitation cluster region comprises the largest number of stations characterized by a Mediterranean pluviometric regime and relatively similar annual precipitation sums. Therefore, it is important to note that the separated climate regions based on two different criteria (physical factors used by Burić et al. (2014) in their climatic regionalization of Montenegro and the results of the statistical technique used in this study based on only two climatic variables) match each other.

Conclusion

In this research paper, one of the multivariate techniques used in modern climatology research was applied to achieve the set goals. Hierarchical agglomerative methods and the non-hierarchical *K-means* method were utilized, with *Euclidean distance* as the distance measure. A series of data from the period 1961–2020 was observed, and multi-year values of temperature and precipitation from 18 MS were used as variables. Furthermore, a comparative analysis was carried out based on the results obtained in this study and the climatic regions identified by Burić et al. (2014), which are based on the dominant physical factors in the geographical area of Montenegro.

The research results indicate that the distribution of stations reflects the majority of the climatic diversity of Montenegro. The cluster regions extracted using *UPGMA*, *Single linkage*, and *Ward's* methods show spatial similarity. As these methods agree to a certain extent, the presented research results can be considered convincing. In other words, the temperature and precipi-

tation cluster regions extracted using different hierarchical agglomerative methods show a high degree of similarity. In both cases (for both temperature and precipitation), the clustering results (i.e., selection of cluster regions) presented in this paper are highly compatible with the climatic regionalization of Montenegro, i.e., the identified climatic types and subtypes given by Burić et al. (2014). Regarding the *K-means* analysis, noticeable logical grouping of meteorological stations is based on real physical-geographical factors in the area. Particularly, this method (*K-means*) clearly separates the precipitation cluster regions in correlation with annual sums and pluviometric regime. Further research on this issue should include other climatic variables (e.g., relative humidity, number of hours of sunshine, average effective precipitation, average wind speed, number of frosty days, etc.) and various multivariate techniques, such as factor analysis, analysis of principal components (*Principal Component Analysis-PCA*) of empirical orthogonal functions, etc.

References

- Appendini, K., & Liverman D. (1994). Climate change and food security in Mexico. *Food Policy*, 19(2), 149–164. [https://doi.org/10.1016/0306-9192\(94\)90067-1](https://doi.org/10.1016/0306-9192(94)90067-1)
- Arbabi, A. (2011). Cluster-based method for understanding the climatic diversity of Iran. *African Journal of Agricultural Research*, 6(31), 6525–6529. <https://doi.org/10.5897/AJAR11.1321>
- Aurenhammer, F., & Klein, R. (2000). Voronoi Diagrams. Ch. 5. In J.R. Sack & J. Urrutia (Eds.), *Handbook of Computational Geometry* (pp.201–290 pp). Amsterdam: Elsevier. <https://www.researchgate.net/publication/279959776>
- Barber, C. B., Dobkin, D. P., & Huhdanpaa, H. (1996). The quickhull algorithm for convex hulls. *ACM Transactions on Mathematical Software (TOMS)*, 22(4), 469–483. <https://doi.org/10.1145/235815.235821>
- Bensmail, H., Celeux, G., Raftery, A., & Robert, C. (1999). Inference in Model-Based Cluster Analysis. *Statistics and Computing*, 7(1), 1–10. <https://www.researchgate.net/publication/2844935>
- Blaney, H.P., & Cridle, W.D. (1950). *Determining water requirement in Irrigated areas climatological and Irrigation Data*. Washington, USA: USDA Soil Conservation Service. <https://ia800300.us.archive.org/4/items/determiningwater96blan/determiningwater96blan.pdf>
- Burić D., Ducić V., & Mihajlović, J. (2013). The climate of Montenegro: Modifiers and types – part one. *Bulletin of the Serbian Geographical Society*, 93(4), 83–102. <https://doi.org/10.2298/GSGD1304083B>
- Burić D., Ducić V., & Mihajlović, J. (2014). The climate of Montenegro: Modifiers and types – part two. *Bulletin of the Serbian Geographical Society*, 94(1),73–90. <https://doi.org/10.2298/GSGD1401073B>
- Burić D., & Doderović M. (2022). Trend of Percentile Climate Indices in Montenegro in the Period 1961–2020. *Sustainability*, 14(19), 12519. <https://doi.org/10.3390/su141912519>
- Clark, P. J., & Evans, F. C. (1954). Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology*, 35, 445–453. <https://doi.org/10.2307/1931034>
- Davis, J. C. (2002). *Statistics and Data Analysis in Geology, 3rd Edition*. New York: John Wiley & Sons, pp. 656. <https://www.bookdepository.com/Statistics-Data-Analysis-Geology-John-C-Davis/9780471172758>
- DeGaetano, A. T., & Shulman, M. D. (1990). A climatic classification of plant hardiness in the United States and Canada. *Agricultural and Forest Meteorology*, 51(3–4), 333–351. [https://doi.org/10.1016/0168-1923\(90\)90117-O](https://doi.org/10.1016/0168-1923(90)90117-O)

- Everitt, B.S., Landau, S., & Leese, M., Stahl, D. (2011). *Cluster Analysis, Fifth edition*. UK: John Wiley & Sons. https://cicerocq.files.wordpress.com/2019/05/cluster-analysis_5ed_everitt.pdf
- Fovell, R. G., & Fovell, M. Y. C. (1993). Climate zones of the conterminous United States defined using cluster analysis. *Journal of Climate*, 6(11), 2103–2135. <https://www.jstor.org/stable/26198599>
- Fraley, C., & Raftery, A. (1998). How Many Clusters? Which clustering method? Answers via Model-Based Cluster Analysis. *The Computer Journal*, 41(8), 578–588. <http://dx.doi.org/10.1093/comjnl/41.8.578>
- Guibas, L., & Stolfi, J. (1985). Primitives for the manipulation of general subdivisions and the computation of Voronoi. *ACM transactions on graphics (TOG)*, 4(2), 74–123. <https://doi.org/10.1145/282918.282923>
- Hartigan, J. A., & Wong, M. A. (1979). Algorithm AS 136: A K-Means Clustering Algorithm. *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, 28(1), 100–108. <https://doi.org/10.2307/2346830>
- Johnson, D. E. (1998). *Applied multivariate methods for data analysts, edit 2*, New York: Duxbury Press. ISBN-10: 0534237967; ISBN-13: 978-0534237967.
- Moreira, E. E., Paulo, A. A., Pereira, L. S., & Mexia, J. T. (2006). Analysis of SPI drought class transitions using loglinear models. *Journal of Hydrology*, 331(1–2), 349–359. <https://doi.org/10.1016/j.jhydrol.2006.05.022>
- MacQueen, J. B. (1967). Some methods for classification and analysis of multivariate observations. In L. M. Le Cam & J. Neyman (Eds.), *Proceedings of the fifth Berkeley symposium on mathematical statistics and probability* (pp. 281–297). California: University of California Press. https://digitalassets.lib.berkeley.edu/math/ucb/text/math_s5_v1_article-17.pdf
- Nassiri, M., Koocheki, A., Kamali, G. A., & Shahandeh, H. (2006). Potential impact of climate change on rainfed wheat production in Iran: (Potentieller Einfluss des Klimawandels auf die Weizenproduktion unter Rainfed-Bedingungen im Iran). *Archives of agronomy and soil science*, 52(1), 113–124. <https://www.researchgate.net/publication/233020291>
- Okabe, A., Boots, B., & Sugihara, K. (2000). *Spatial Tessellations: Concepts and Applications of Voronoi Diagrams, 2nd ed.* New York: Wiley. ISBN: 978-0-471-98635-5
- Papić-Blagojević, N., & Bugar, D. (2009). Osnovne premise analize grupisanja. *Škola biznisa: Naučnostručni časopis*, 4, 166–173. <http://www.vps.ns.ac.rs/SB/2009/4.18.pdf>
- Preparata, F. R., & Shamos, M. I. (1985). *Computational Geometry: An Introduction*. New York: Springer-Verlag, pp. 390. ISBN: 978-1-4612-1098-6
- Rencher, A. C. (2002). *Methods of Multivariate Analysis, Second edition*. Wiley, pp. 715. <https://doi.org/10.1002/0471271357>
- Szép, I. J., Mika, J., & Dunkel, Z. (2005). Palmer drought severity index as soil moisture indicator: physical interpretation, statistical behavior and relation to global climate. *Physics and Chemistry of the Earth*, 30(1–3), 231–243. <https://doi.org/10.1016/j.pce.2004.08.039>
- Szentimrey, T. (2003). Multiple analysis of series for homogenization (MASH); Verification procedure for homogenized time series, in: Fourth seminar for homogenization and qualitycontrol in climatological databases. Budapest, Hungary, WMO-TD No. 1236, WCDMP No. 56, 193–201.
- Szentimrey, T., & Bihari, Z. (2007). Mathematical background of the spatial interpolation methods and the software MISH (Meteorological Interpolation based on Surface Homogenized Data Basis), *Proceedings of the Conference on Spatial Interpolation in -Climatology and Meteorology* (pp. 17–27), Budapest, Hungary.
- The Pennsylvania State University (2004). *Ward's method*. Available at: <https://online.stat.psu.edu/stat505/lesson/14/14.7>
- Van Groenewoud, H. (1984). The climatic regions of New Brunswick: A multivariate analysis of meteorological data. *Canadian Journal of Forest Research*, 14(3), 389–394. <https://doi.org/10.1139/x84-069>
- Warrington, A. (1977). Crop phenological stages. *Australian Journal of Agricultural Research*, 28(1), 11–27. <https://doi.org/10.1071/AR9770011>
- Wolter, K. (1987). The Southern Oscillation in surface circulation and climate over the tropical Atlantic, Eastern Pacific, and Indian Oceans as captured by cluster analysis. *Journal of Applied Meteorology and Climatology*, 26(4), 540–558. [https://doi.org/10.1175/1520-0450\(1987\)026<0540:TSOISC>2.0.CO;2](https://doi.org/10.1175/1520-0450(1987)026<0540:TSOISC>2.0.CO;2)

Roma Communities in Međimurje, Croatia: From Spatial Segregation toward Spatial Integration and Back

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Abstract

Spatial segregation of Roma population is a dynamic category that changes its characteristics over time. This paper investigates changes in indicators of spatial segregation of the Roma national minority in Međimurje, the northernmost county of the Republic of Croatia. The spatial analysis of Roma in the researched area, based on the last three consecutive population censuses, indicates changes in the Roma distribution patterns. Through the last two inter-census periods, spatial dispersion of the Roma population is noticeable as a beginning of more intensive spatial integration process. On the other hand, quantitative indicators point to the conclusion that spatial segregation as a phenomenon and fundamental feature of Roma population is increasing.

Keywords: Međimurje; Roma; spatial segregation; integration; Croatia

Introduction

Although it is primarily an object of sociological research, segregation in its spatial manifestations occupies an important place in geography research as well. Segregation as a spatial phenomenon is a socio-ecological process that refers to the concentration of a certain population group in one space or the uneven distribution of certain population groups in the observed area (Vresk, 2002). The phenomenon of segregation reflects social inequality and, through its changes, speaks about how these inequalities are changing. Additionally, understanding segregation is important because of its impact on society and social relations (Yao et al., 2019). Understanding the degree and nature of the segregation of a certain social group in a specific area is crucial for the creation of effective policies, measures and activities aimed at achieving social equality (Johnston et al., 2014).

Roma people historically encounter “otherness” through a number of cultural, political, economic and

spatial dimensions (Powell & Lever, 2017). From the very beginning of their settlement in the Europe, the Roma have faced non-acceptance, marginalization, discrimination and various forms of segregation. The social non-acceptance of Roma in European countries had its spatial reflection consequently. Powell and Lever (2017) point out that the appearance of Roma ghettoization, in the investigated case in the form of segregated Roma settlements, is a spatial manifestation of Roma stigmatization. On the other hand, speaking about the Roma, Sibley points out that “space is an integral part of the outsider problem. The way in which space is organized affects the perception of the “other”, either as foreign and threatening or as simply different” (Sibley, 1992). The characteristics of the Roma ethnic space and the elements of their spatial segregation form a closed cause-and-effect circle with social forms of segregation, discrimination and marginalization. Although spatial segregation is often cited as

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the cause of other forms of segregation and marginalization, some studies show that significant prejudice and discrimination against Roma, despite the historically multicultural environment, exist even in the absence of spatial segregation (Creţan et al., 2023). The above contributes to the challenges of designing integration policies that are primarily aimed at reducing the spatial forms of Roma segregation.

Some forms of spatial segregation characterize the residential patterns of Roma in numerous European countries. In Slovenia, Zupančić (2007) investigates the patterns of Roma distribution and defines the term “Roma settlement” as a specific nationally concentrated form of settlement of the Roma population. The population of Roma in the wider space of the European post-socialist countries where the largest number of European Roma live is characterized by certain forms of spatial segregation. For example, that is a situation in Hungary (Virag & Varadi, 2018; Creţan et al., 2020; Zsolt Farkas et al., 2017; Pásztor et al., 2016), Slovakia (Rochovská & Rusnáková, 2018), Serbia (Vuksanović-Macura, 2020), the Czech Republic (Matoušek & Sýkora, 2011; Toušek, 2011) or Croatia (Šlezak, 2009). Romania is also an example of the emergence of Roma spatial segregation patterns (Picker, 2013; 2017). Recent research shows that only Roma have had upward values in terms of fractionalization and polarization indices compared to other ethnic groups in the Romania post-communist times due to the large traditional families of Roma communities (Rotaru et al., 2023). Spatial segregation of Roma is not reserved exclusively for post-socialist Europe. Western European and Mediterranean countries also record spatial segregation of Roma, such as Italy (Claps & Vitale, 2011; Picker, 2013; 2017), Spain

(Gay Y Blasco, 2016), France (Picker, 2017), England (Picker, 2017) or Portugal (Alves, 2017). Even Türkiye, as a Eurasian country, is not spared of the phenomenon of Roma segregation (Gültekin, 2009).

As in the wider European space, spatial segregation characterizes the Roma population settlement in Međimurje County, the northernmost county of the Republic of Croatia (Fig. 1) (Šlezak, 2009). The majority of the Roma population lives in a small number of local self-government units, and in relation to the entire county, their spatial concentration is noticeable. At the settlement level, Roma mostly live in twelve “Roma” settlements, i.e. locations populated exclusively by Roma (Šlezak, 2009). In his work, Šlezak states that the majority of Roma settlements are additionally separated from parts of the settlement with a majority Croat population by some physical barrier such as a canal, forest, or railway (Šlezak, 2009).

In Međimurje County, Roma are the most numerous national minority. It is also the county with the largest number and the largest concentration of Roma population in Croatia. According to the last census from 2021 (CBS, 2022), Roma in Međimurje reached a share of 6.61% of the total population. Roma population of Međimurje County makes up as much as 38.7% of all Roma in the Republic of Croatia. From a once nationally very homogenous area, Međimurje is becoming a county with more distinct multicultural and multi-ethnic characteristics. In 2001, the share of national minorities was 3.61% (CBS, 2002). Twenty years later, the share of national minorities members grew to 8.12% (CBS, 2022) and Roma make up 81.4% of all declared members of national minorities.

Additionally, the data of the last census indicate certain changes in the distribution of Roma in

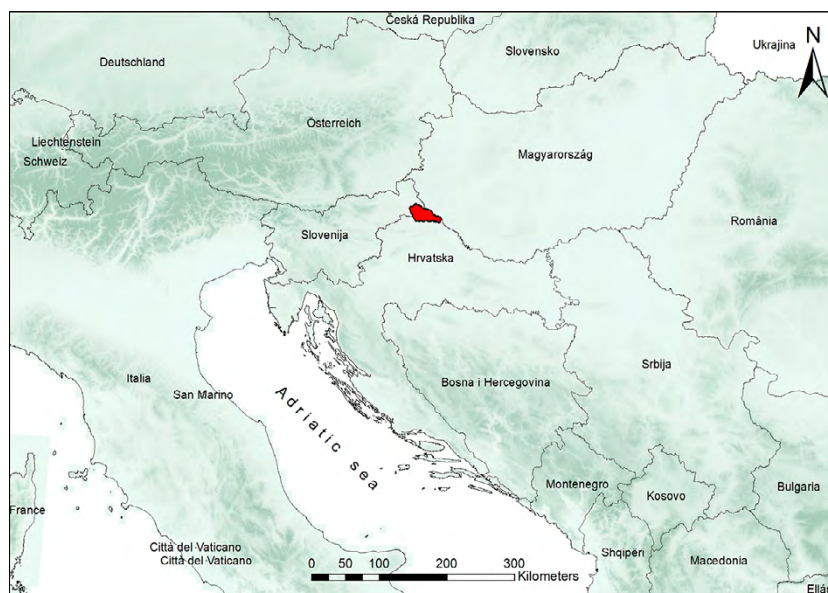


Figure 1. Geographical location of Međimurje County

Međimurje County. The presence of Roma in a larger number of local self-government units (cities and municipalities) than during previous censuses points to the spatial expansion of the Roma and thus to a possible process of reducing spatial segregation, i.e. the beginning of the process of spatial integration of the Roma population.

This paper tries to reveal changes in indicators of spatial segregation over a period of twenty years, during two most recent inter-census periods. Quantitative analysis of various indicators of spatial segregation through three consecutive population censuses (2001, 2011 and 2021) aims to reveal the direction of changes in Roma residential patterns in Međimurje County.

Spatial segregation of Roma in Međimurje has been studied in more detail by Šlezak (2009) using data from the 2001 population census. His work is an important contribution to the understanding of spatial segregation as a phenomenon related to the Roma national minority in Međimurje County and the Republic of Croatia. However, the results of his research provide only a static situation in 2001. This paper, building on the mentioned research, emphasizes the changes and directions of changes in the level of spatial segregation of the Roma in the period of twenty

years. Recognizing the direction of change in Roma residential patterns can be good indicators of the (in) correctness of certain policies and measures aimed at reducing all forms of segregation of the Roma population, including aspects of spatial segregation.

Roma distribution and concentration in very small and limited parts of Croatia “is both a consequence and a cause of social separation from the rest of Croatian society” (Šlezak, 2009). The importance of recognizing the occurrence of Roma spatial segregation and noticing changes in the value of its indicators is visible in addressing spatial segregation as an important element of the fight against Roma poverty at the level of the entire European Union. One of the measures listed in the Urban Poverty Partnership Action Plan (2018) refers to strengthening the principle of desegregation in EU urban areas. When elaborating the mentioned measure, spatial segregation of the Roma was listed as one of the important priority areas the member states should deal with. The chapter on Roma vulnerability states: “This action proposes that the desegregation principle should be strengthened and mainstreamed into the legislation on the use of EU funds at national level. Desegregation should become a priority in all housing and education programs” (Urban Poverty Partnership Action Plan, 2018).

Spatial segregation measures used

From the very beginning of the study of spatial segregation, there have been discussions about the (un) acceptability of certain indicators of this spatial phenomenon. Simplifying the calculation of certain indicators also brings with it the problem of neglecting certain spatial relationships that are important for the quality interpretation of the obtained results. In addition, the discussion is also about defining the basic dimensions of spatial segregation. Massey and Denton (1988) propose five dimensions of segregation: evenness, isolation - exposure, concentration, centralization and clustering. Reardon and O’Sullivan (2004) indicate that the phenomenon of spatial segregation can be seen through only two basic dimensions: evenness - clustering and isolation - exposure. Two spatial-segregation dimensions are also proposed by Brown and Chung (2006): evenness - concentration and clustering - exposure.

One of the first and most commonly used indicators of spatial segregation is the Dissimilation Index (Duncan & Duncan, 1955). This indicator considers the representation of the observed groups in the territorial units of the lower order in relation to their representation in the territorial unit of the higher order. The dissimilation index D is expressed by the formula

$$D = 0,5 \sum | p_{ir} / R - p_{ih} / H |$$

where

- p_{ir} is the population of Roma in a certain city or municipality i ,
- p_{ih} population of the non-Roma population in city or municipality i ,
- R total Roma population, and
- H the total population in Međimurje County.

The value of this indicator ranges from 0 to 1. The maximum value indicates complete segregation, that is, separation of the observed groups. The value 0 indicates complete integration in the sense of equal representation of the minority community in administrative units in relation to its representation in the higher-ordered administrative unit.

Criticism of the mentioned indicator refers to its “non-spatiality”, i.e. failure to recognize the actual spatial distribution of the observed group in the larger investigated administrative spatial unit, the so-called “chessboard” problem (White, 1983). Mentioned indicator with its value very roughly indicates the level of segregation of the observed group within the higher-order administrative unit. Although a certain number

of researchers offer adapted indicators in which they have incorporated certain spatial relations (White, 1983; Morill, 1991; Wong, 2003; 2004; 2005; Reardon & O'Sullivan, 2004; Feitosa et al., 2007), the original form of the dissimilation index remains the most commonly used indicator of the spatial segregation. This is especially the case in situations of research on the mutual segregation relations of two groups that share a common space. Such an original version of the dissimilation index is proposed by Somogyi and Horvath (2018) as a research method in the support document of the Urban Poverty Partnership Action plan for the analysis of the spatial segregation of the Roma population.

The spatial-segregation dimension of evenness-clustering is well represented by the location quotient (Isard, 1960). It indicates the relative representation of the minority group in the observed spatial unit in relation to the total representation in the higher ordered territorial unit. It is calculated by a formula

$$LQ_i = (r_i / p_i) / (R / P)$$

where, in the specific researched case, r_i and p_i represent the number of Roma and the total population of a certain city or municipality, and R and P the total number of Roma and the total number of inhabitants of the entire researched area of Medimurje County. Possible values range between 0 and ∞ , while the value 1 indicates a situation in which the representation of the researched group in the observed territorial unit is identical to its representation in the higher ordered territorial unit. $LQ < 1$ indicates a lower representation, and $LQ > 1$ a higher representation of the observed group in a certain territorial unit compared to the representation in a higher-ordered territorial unit.

Global Moran's I is also common indicator in the dimension of spatial clustering. Global Moran's I is a measure of the overall clustering of the investigated spatial data, in this particular case spatial distribution of the Roma population in cities and municipalities in Medimurje County. It investigates the spatial autocorrelation based on the locational features and concrete values of the investigated phenomenon in individual administrative units of wider researched territorial area.

Quantitative indicators of spatial segregation in the exposure dimension used in this paper are the inter-

connected Isolation Index and Interaction Index. "Exposure measures the degree of potential contact or possibility of interaction, between minority and majority group members" (Massey & Denton, 1988). It points to the probability that a member of the Roma national minority shares a local self-government territorial unit with a member of the researched majority group. The interaction index expresses the exposure of the members of the Roma national minority to the members of the majority population, and the isolation index shows the extent to which the members of the Roma minority are directed to themselves in a specific investigated spatial unit.

The Interaction index is calculated by the formula:

$$I_n = \sum (p_{ir} / R) (p_{ih} / P_i)$$

where

- p_{ir} is the number of members of the Roma national minority in the spatial unit i
- p_{ih} is the number of members of the majority population in the spatial unit i
- R is the total number of members of the Roma national minority in the observed area
- P_i is the total number of inhabitants in spatial unit i .

The Isolation index is calculated according to the above:

$$I_z = \sum (p_{ir} / R) (p_{ir} / P_i)$$

A higher value of the Isolation index indicates the existence of spatial segregation of a certain group, while a higher value of the Interaction index indicates a reduced occurrence of spatial segregation of the researched group.

The clustering dimension can be well represented by Local Moran's I , an indicator proposed by Anselin (1995). „The value of Local Moran's I at spatial unit i reflects how the proportion of a group in i is similar to the proportions in neighboring units. A high value of local Moran's I indicates a clustering of similar proportions (either high proportions reflecting a hot spot or low proportions reflecting a cold spot) and a low value indicates a clustering of dissimilar proportions“ (Yao et al., 2019). This indicator is part of the basic functionality of the ArcGIS software, version 10.1, which was also used to create all thematic maps in this paper.

Changes in the distribution of the Roma population

The basic change in the characteristics of the Roma population distribution in the last two inter-censal periods in Međimurje County, which can be observed at the level of cities and municipalities, is the expansion of the area in which the Roma were recorded by the census (Fig. 2, Fig. 3, Fig.4). In 2001, out of 25 local self-government units in Međimurje County, Roma were recorded in only 12 cities and municipalities, in less than half of their number. Ten years later, in 2011, Roma were present in 18 local self-government units, and in 2021 in 19 of them. Expanding the area inhabited by the Roma population is noticeable. Additionally, there is a significant increase in the share of the Roma population in certain local self-government units. In 2001, the highest recorded share of Roma was 13% in the municipality of Pribislavec. Twenty years later, already five municipalities have surpassed that value. During the last census, the highest share of Roma was in the municipality of Orehovica, 33.68%. With the aforementioned share, the municipality of Orehovica became the first municipality in Croatia where Roma, having reached a share of 1/3 of the total population, formally exercised the right to official use of the minority language in accordance with the provisions of the Constitutional Law on the Rights of National Minorities (Croatian Parliament, 2002).

The observed increase in the share of the Roma population in the cities and municipalities of Međimurje County is, on the one hand, a consequence of the signif-

icant emigration process of the majority population that has affected Croatia since joining the European Union. On the other hand, it is a consequence of the nationally differentiated demographic characteristics of the natural trends of the majority and Roma population. While the majority population records a very low fertility rate and a negative natural change, the Roma population, due to a very high fertility rate and a high positive natural change, records a significant increase in the number of members (Šlezak, 2010; 2013; Šlezak & Belić, 2019).

Cities and municipalities where Roma were recorded in 2001, except for the municipality of Belica, in their administrative boundaries have Roma settlements spatially segregated from the majority Croat population (Šlezak, 2009). There are 12 settlements inhabited exclusively by the Roma, whose population in 2001 varied from a few dozen to over a thousand inhabitants (Šlezak, 2009). As most of the municipalities in question consist of only one settlement of the same name, it can be assumed that almost the entire Roma population of the Međimurje County in observed year was settled in Roma settlements. In terms of methodology, it is important to note that during the 2001 census, the Roma settlement of Sitnice was part of the Municipality of Selnica. After the later changes in the administrative borders, the said settlement was annexed to the City of Mursko Središće.

During the 2011 census, 1.27% of all Roma in Međimurje County lived in municipalities and cit-

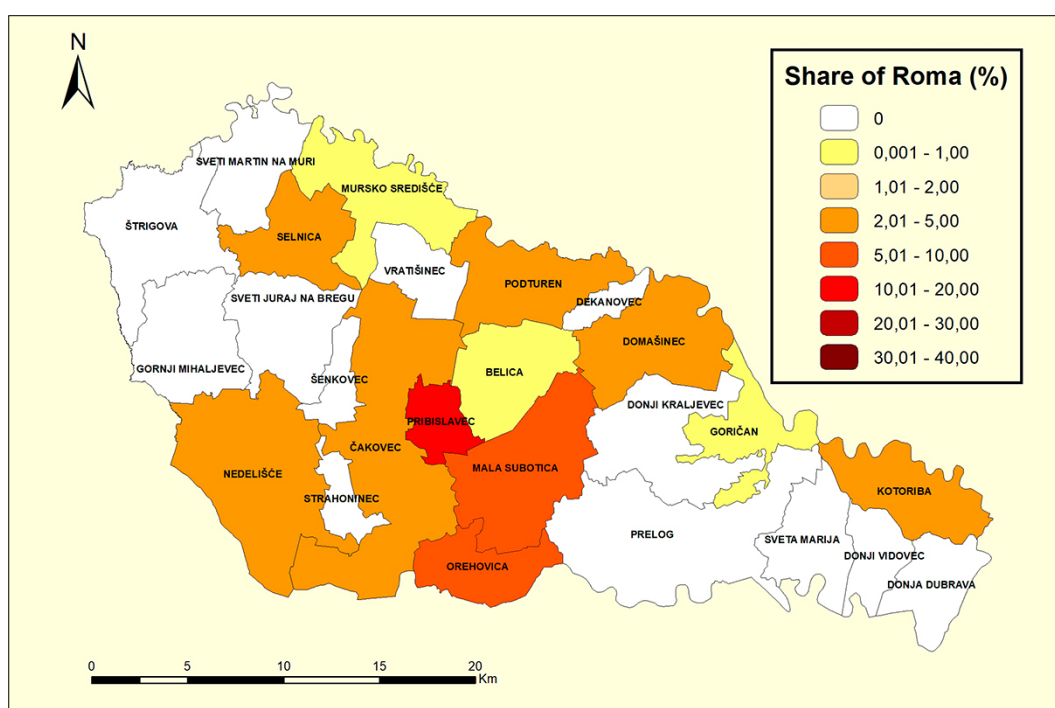


Figure 2. Share of Roma population in cities and municipalities of Međimurje County in 2001

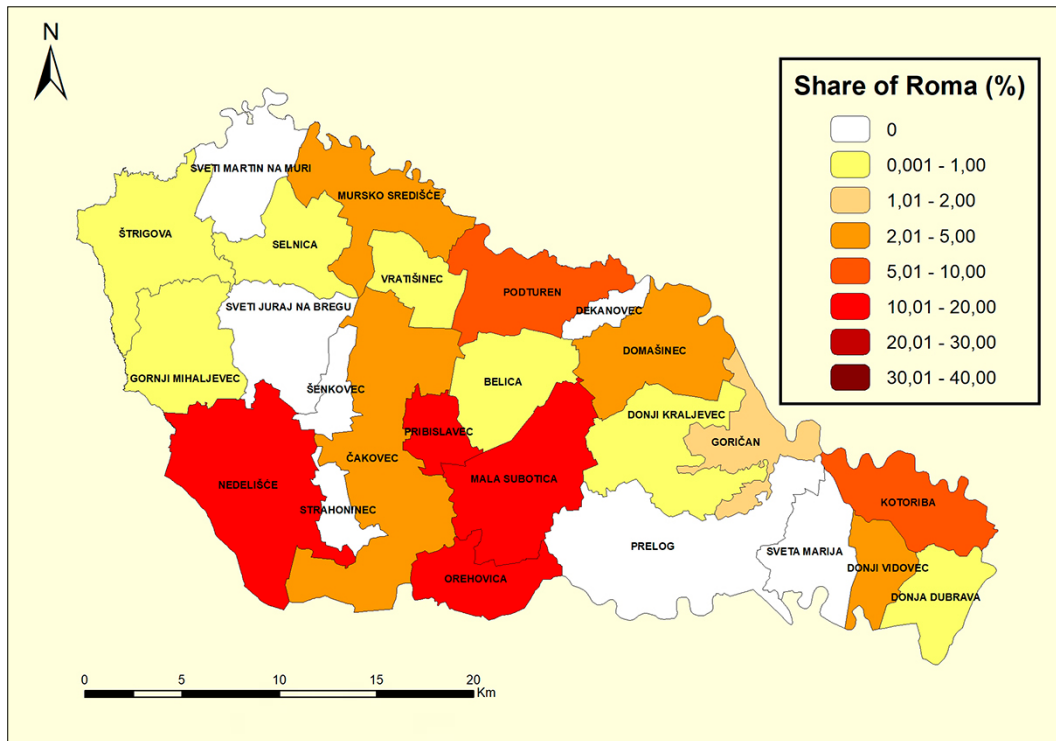


Figure 3. Share of Roma population in cities and municipalities of Međimurje County in 2011

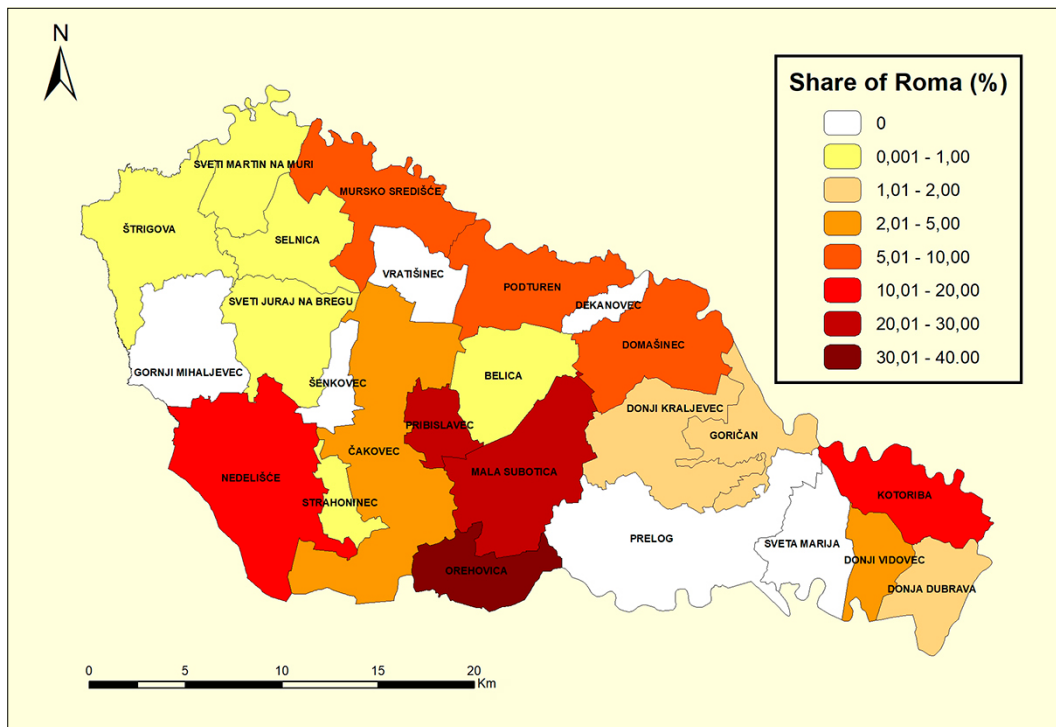


Figure 4. Share of Roma population in cities and municipalities of Međimurje County in 2021

ies that do not have a Roma settlement within their borders. Ten years later, 2.26% of Roma lived in cities and municipalities without a spatially segregated Roma settlement in their composition. From the initial distribution connected exclusively to the concentrated localities of Roma settlements, in the period of the last 20 years, Roma have slowly settled in the sur-

rounding area of the neighboring towns and municipalities of Međimurje County. Although we are not talking about large numbers, it is important to recognize the beginning of a process of change in the Roma population distribution. In terms of spatial segregation, the observed process reflects a decrease in concentration as one of the dimensions of spatial

segregation. The departure of Roma from Roma settlements (Šlezak, 2022) as concentrated locations of population and their settlement in the surrounding

cities and municipalities represents the beginning of the process of the Roma population spatial integration.

Spatial segregation measures of the Roma population

The basic quantitative indicator of spatial segregation in the dimension of evenness, the Dissimilation Index, at the level of Međimurje County records the values listed in tab. 1. Through the last three censuses, the index of dissimilation (D) recorded constant growth. The 2001 values indicate that more than 43% of the Roma population had to move to achieve an even distribution of the Roma population in Međimurje County. In 2011, it was hypothetically necessary for more than 45%, and in 2021, more than 48% of the Roma population to change their place of residence within Međimurje County to reflect an even distribution, i.e. not to reflect spatial segregation.

Table 1. Dissimilation index of the Roma population in Međimurje County in 2001, 2011 and 2021

Year	2001	2011	2021
D	0,43684511	0,454347688	0,480280971

The increase of the Dissimilation index is constant despite the expanded area of the Roma population compared to the initial researched year. Obviously, significant increase in the number and share of the Roma population in the few Roma settlements not only nullified, but also surpassed the impact of the

spatial expansion of the Roma population throughout the researched period.

In the exposure dimension, Interaction and Isolation indexes indicate an increase in the spatial segregation of the Roma population (tab. 2). Throughout the researched period, the interaction index recorded a constant decline, and analogously, the isolation index recorded a constant increase.

Table 2. Interaction index and Isolation index of the Roma population in Međimurje County in 2001, 2011 and 2021

Year	2001	2011	2021
Interaction Index	0,942245	0,896705	0,839602
Isolation Index	0,057755	0,103295	0,160398

Over time, members of the Roma national minority are less directed towards potential contact with the majority population, that is, they are increasingly directed towards members of their own minority community.

Location quotient quantitatively represents the dimension of concentration. It indicates the relative representation of the minority group in the observed spa-

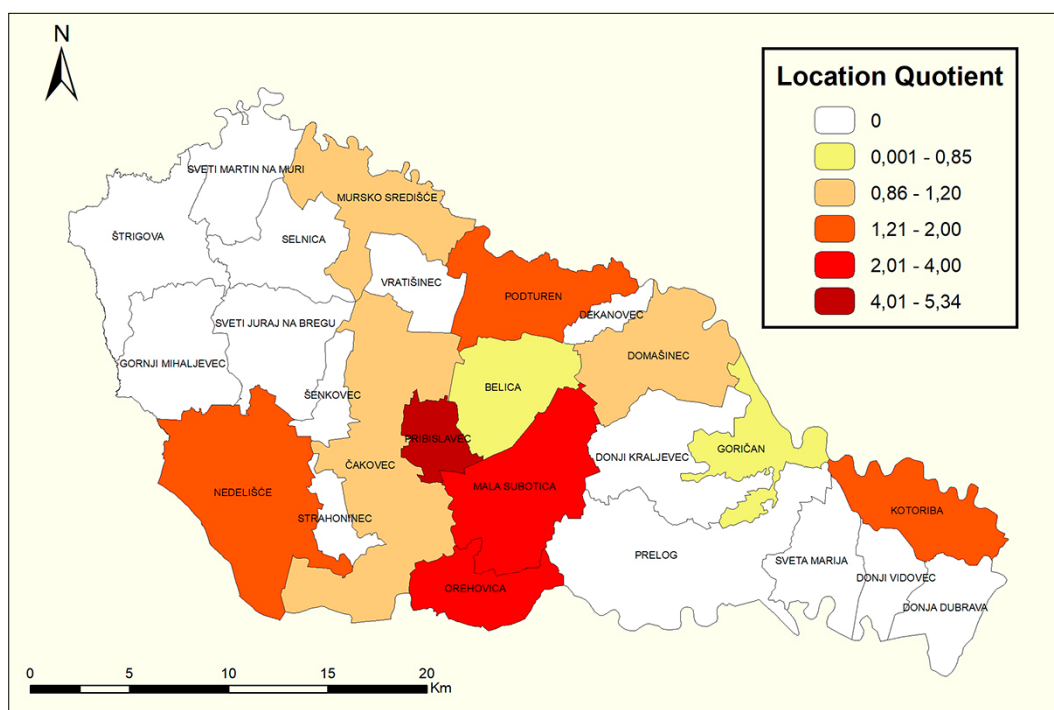


Figure 5. Location quotient of the Roma population in Međimurje County in 2001

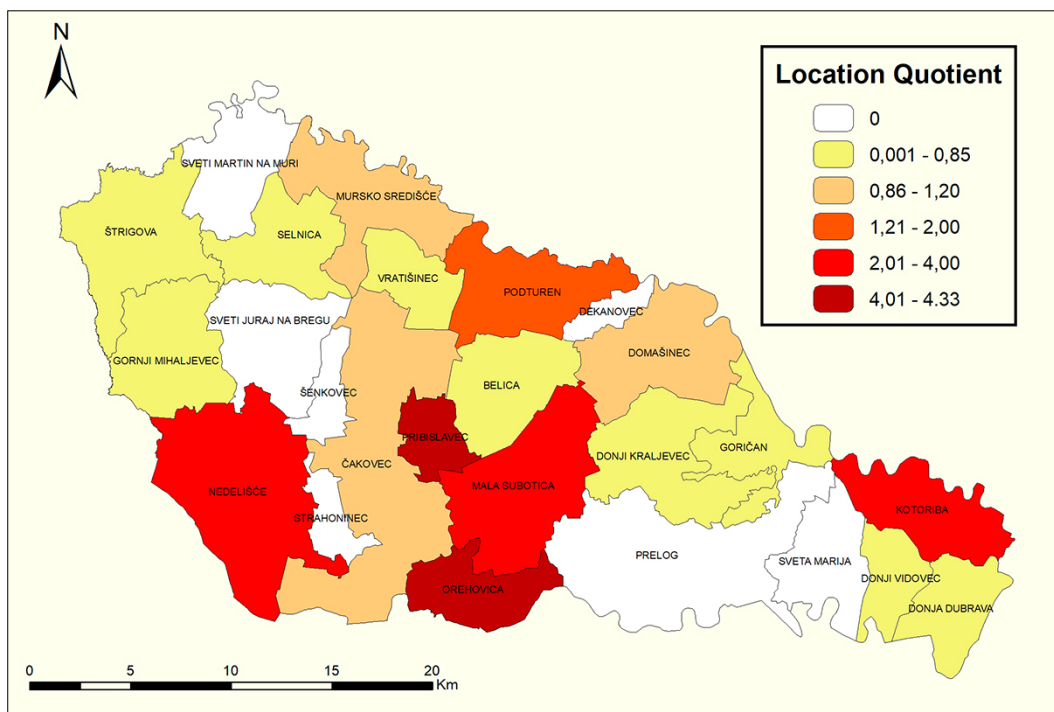


Figure 6. Location quotient of the Roma population in Međimurje County in 2011

tial unit in relation to the total representation in the higher ordered territorial unit. The values of LQ are significantly higher than 1 in some territorial units or significantly less than 1 in some other administrative-territorial units. It proves the significant concentration of the researched group, and thus of its spatial segregation.

Comparative cartograms (Fig. 5, Fig. 6, Fig. 7) graphically present Roma population location quotient in Međimurje County through the three observed pop-

ulation censuses. With the aim to observe the change in the level of Roma spatial distribution, the value classes on all three views are set in identical limits. A big change can be noticed between 2001 and 2011, while in the last inter-census period (2011 - 2021) the observed trend of change has slowed down considerably.

In the first observed inter-census period (2001 - 2011), the expansion of the area inhabited by Roma is noticeable. In self-government units of previously

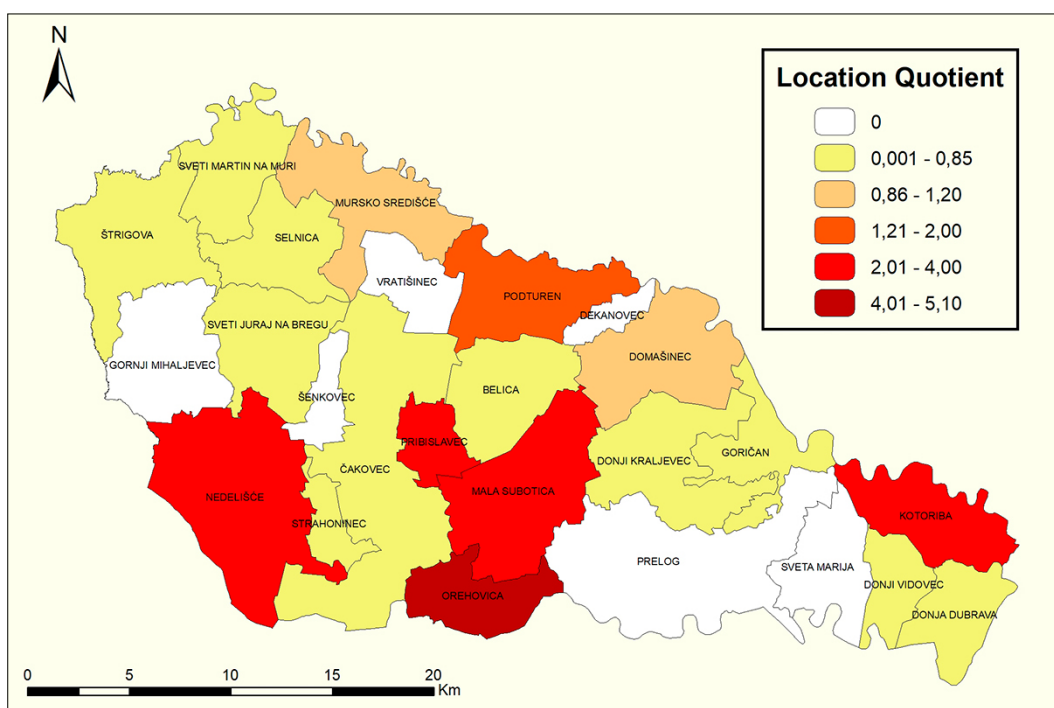


Figure 7. Location quotient of the Roma population in Međimurje County in 2021

high concentration, concentration of Roma remains constantly high. In the second period (2011 – 2021), the changes are very small. Roma are represented for the first time in two new municipalities (Strahoninec and Sv. Martin na Muri), but there are no longer any Roma in the municipality of Vratišinec. At the same time, the concentration of Roma in the municipality of Pribislavec was lowered where LQ value dropped below 4, as well as in the city of Čakovec, where the LQ value fell below the level of 0.85.

In all three census moments, there were the same six municipalities that recorded an above-average representation of the Roma population with a value of LQ >1.2. The biggest difference is in the increase of the number of municipalities in which the phenomenon of below-average representation is recorded, which is a consequence of the previously mentioned expansion of the area inhabited by Roma.

Global Moran's I can represent the segregation dimension of clustering (tab. 3). According to its values, it is possible to see a decrease of spatial segregation in the period 2001-2011, which can be attributed to the fact that in 2011, Roma were recorded in a significantly larger number of municipalities than ten years earlier. As the used indicator in the matrix of spatial relations takes into account the mutual relations of neighboring investigated spatial units, a larger number of Roma in previously unrecorded local self-government units influenced the reduction of this indicator in 2011. Nevertheless, in the following inter-census period, the mentioned indicator increased,

which indicates an increase in the spatial segregation of the Roma population in the investigated dimension of clustering.

Table 3. Global Moran's I of the Roma population in Međimurje County in 2001, 2011 and 2021.

Year	2001	2011	2021
Global Moran's I	0,121463	0,076421	0,092573
p-value	0,337493	0,487439	0,438303
z-score	0,959131	0,694388	0,775062

The occurrence of statistically significant clusters in the researched area can represent Local Moran's I. The value of the indicator was calculated for each individual self-governing unit and visually displayed as hot spots and cold spots in the observed area. The mark HH refers to a statistically significant cluster of high values and LL for a statistically significant cluster of low values. Spatial units with a high number of Roma surrounded by spatial units with low Roma numbers are marked HL. Spatial unit of low number of Roma surrounded by spatial unit with high Roma number is marked LH.

One hot spot and one cold spot are distinguished in Međimurje County in 2001 and 2011 (Fig. 8). Municipality of Pribislavec represents the hot spot and Strahoninec represents the cold spot. In 2021, the mentioned municipalities remained hot and cold spots, but the municipality of Orehovica joined Pribislavec as a new hot spot (Fig. 9).

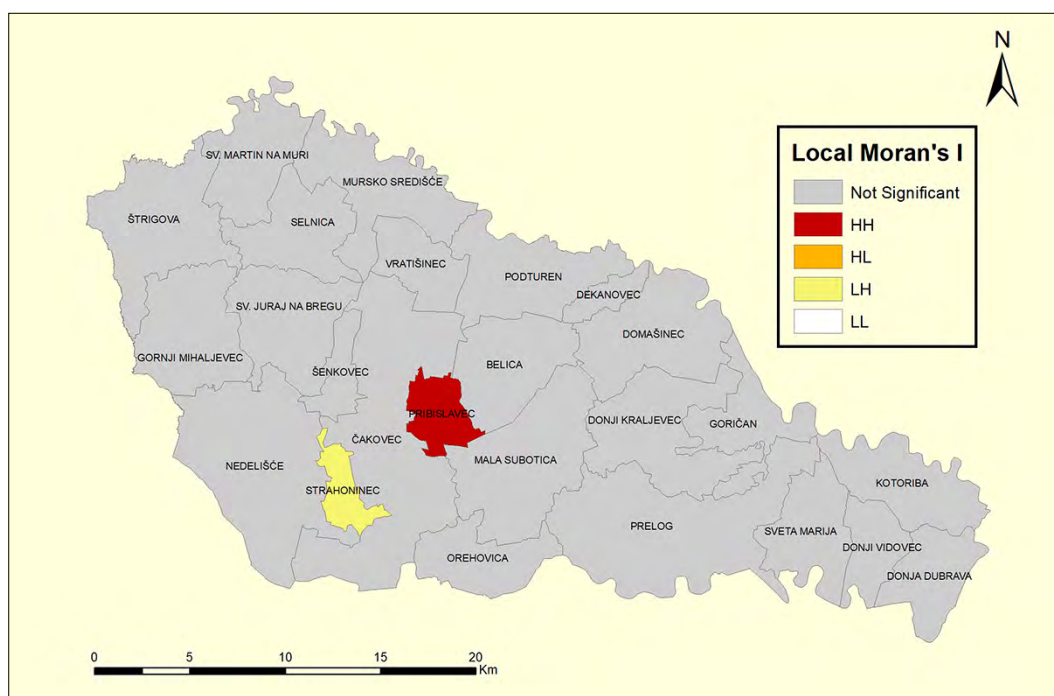


Figure 8. Hot and cold spots of Roma population in Međimurje County defined by Local Moran's I in 2001 and 2011

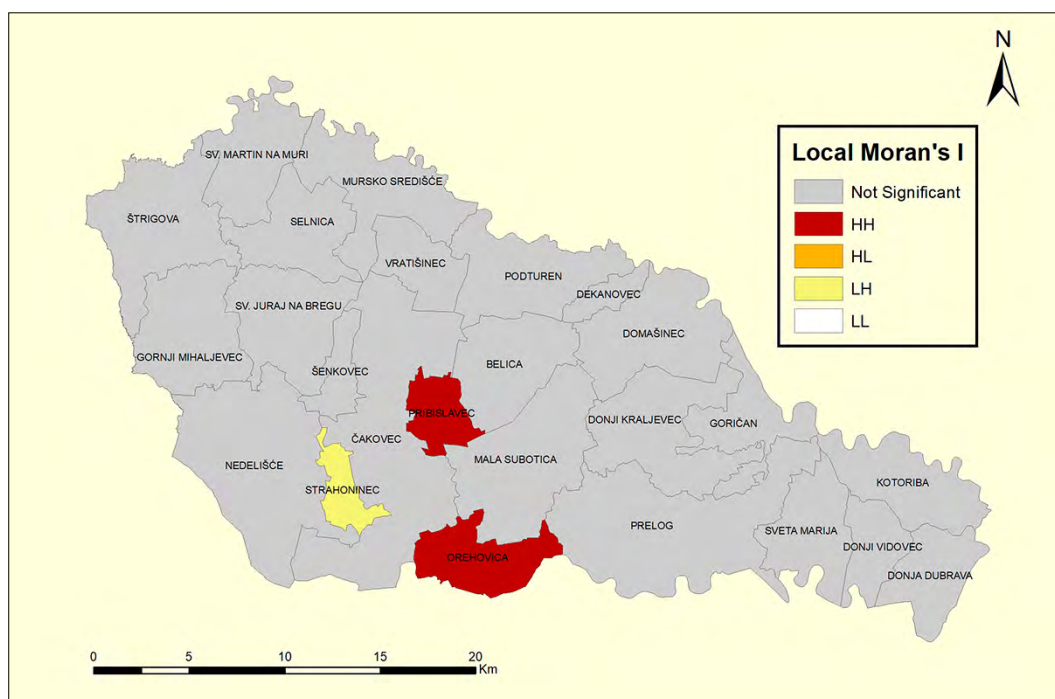


Figure 9. Hot and cold spots of Roma population in Međimurje County defined by Local Moran's I in 2021

Conclusion

Spatial segregation of Roma population is both a state and a process. If observed at one point in time, the above phenomenon represents a state. In this sense, Šlezak (2009) correctly points to the appearance of spatial segregation of Roma in Međimurje County based on the 2001 population census. Nevertheless, spatial segregation should also be seen as a process, as a dynamic category that changes its characteristics over time. It is not only important to detect segregation, but also to discover the directions of its change. The results of the conducted research look at segregation precisely from the perspective of a dynamic process, taking into account the data of three consecutive censuses twenty years apart.

The results of the conducted research indicate the simultaneity of two mutually opposite processes. On the one hand, the members of the Roma national minority in Međimurje County are expanding the area of their population. While in 2001 they were present in less than half of the cities and municipalities of Međimurje, today they are present in 76% of them. The expansion of the area inhabited by Roma in the absolute sense represents a spatial integration process. Their appearance in areas where they were previously absent indicates the beginning of the spatial integration process of Roma national minority. The appearance of Roma in previously nationally homogenous local self-government units points to the departure of Roma individuals from the previous areas of concen-

tration and marked spatial segregation (Šlezak, 2022). Their settlement in municipalities and cities where they were not recorded during previous censuses is an indicator of the Roma spatial integration process.

On the other hand, on the contrary, quantitative indicators of spatial segregation in all observed dimensions indicate the increase of Roma spatial segregation in Međimurje County. In the dimension of evenness, the dissimilation index recorded constant growth. In the dimension of exposure and isolation, the Interaction Index recorded a constant decline, while the Isolation Index recorded a constant increase in its values in the researched period. In the dimension of clustering, the Global Moran's Index was lowered in the first inter-census period (2001-2011), which points to a decrease in spatial segregation in the mentioned dimension. Nevertheless, in the second intercensal period (2011-2021), the mentioned indicator in the presented dimension records growth and indicates the intensification of the further spatial segregation process of the Roma. Through the three time points of the research (2001, 2011 and 2021), the number of local self-government units (cities and municipalities) that record a below-average representation of the Roma population in relation to the entire investigated area of Međimurje County is increasing. This is a consequence of the aforementioned phenomenon of the expansion of the Roma population in municipalities and cities where there was none before. At the same time, the number

of municipalities and cities that record an above-average population of Roma in relation to their representation in Međimurje County is also increasing. The increase in the number of administrative units with significantly higher values of LQ and the enlargement of the value of the mentioned indicator in units where it has already been high so far indicates an increase in the concentration of the Roma population. This allows us to conclude that spatial segregation is growing in the mentioned dimension as well.

Despite the recorded occurrence of the spatial expansion of the Roma as a self-initiated process of spatial integration, the presented results indicate that the Roma as a very vulnerable group in Međimurje County are increasingly spatially segregated. The lack

of interest of local authorities in this spatial aspect of Roma segregation and leaving spatial processes to inertia can have considerable negative consequences. The integration of Roma, both in the social and spatial sense, must be institutionally supported. The results of this work must be an invitation to the local authorities to urgently start discussions on measures and activities with the aim of reducing the spatial segregation of the Roma and encouraging the process of their spatial integration. Otherwise, given that the social perception of Roma depends on the area of their settlement (Šlezak, 2021), further social stratification and difficulties in terms of social integration of members of the Roma national minority in Međimurje County are to be expected.

References

- Alves, S. (2017). Ethnic Housing Segregation and the Roma/Gypsy population: A Portuguese Perspective. In *Spaces of Dialog for Places of Dignity, Fostering the European Dimension of Planning*, (pp. 1-12). Lisbon: AESOP.
- Anselin, L. (1995). Local indicators of spatial association—LISA. *Geographical analysis*, 27(2), 93–115.
- Brown, L.A., & Chung, S.Y. (2006). Spatial segregation, segregation indices and the geographical perspective. *Population space and place*, 12(2), 125-143.
- Claps, E., & Vitale, T. (2011). Not Always the Same Old Story: Spatial Segregation and Feelings of Dislike against Roma and Sinti in Large Cities and Medium-size Towns in Italy. In *Multi-Disciplinary Approaches to Romany Studies*, (pp 228-253). Central European University Press.
- Crețan, R., Malovics, G., & Mereine Berki, B. (2020). On the Perpetuation and Contestation of Racial Stigma: Urban Roma in a Disadvantaged Neighborhood of Szeged. *Geographica Pannonica*, 24(4), 294–310.
- Crețan, R., Covaci, R. N., & Jucu, I. S. (2023) Articulating 'otherness' within multiethnic rural neighbourhoods: encounters between Roma and non-Roma in an East-Central European borderland, *Identities*, 30(1), 93-111.
- Croatian parliament (2002). Ustavni zakon o pravima nacionalnih manjina [Constitutional Law on the Rights of National Minorities]. <https://www.zakon.hr/z/295/Ustavni-zakon-o-pravima-nacionalnih-manjina>
- Državni zavod za statistiku (DZS) [Croatian Bureau of Statistics (CBS)] (2002). *Popis stanovništva, kućanstava i stanova, 31. ožujka 2001.: Stanovništvo prema narodnosti, po gradovima / općinama [Census of population, households and dwellings in 2001: Population by nationality, by cites and municipalities]*. https://web.dzs.hr/Hrv/censuses/Census2001/Popis/H01_02_02/H01_02_02.html (11. 02. 2023.)
- Državni zavod za statistiku (DZS) [Croatian Bureau of Statistics (CBS)] (2013). *Popis stanovništva, kućanstava i stanova 2011. godine: stanovništvo prema narodnosti, po gradovima / općinama [Census of population, households and dwellings in 2011: Population by nationality, by cites and municipalities]*. https://web.dzs.hr/Hrv/censuses/census2011/results/html/H01_01_04/h01_01_04_RH.html (11. 02. 2023.)
- Državni zavod za statistiku [Croatian Bureau of Statistics (CBS)] (2022). *Popis stanovništva, kućanstava i stanova 2021., Stanovništvo prema narodnosti po gradovima/općinama [Census of population, households and dwellings in 2021, Population by nationality, by cites and municipalities]*. https://podaci.dzs.hr/media/td3jvrbu/popis_2021-stanovnistvo_po_gradovima_opcinama.xlsx (11. 2. 2023.)
- Duncan, O. D., & Duncan, B. (1955). A Methodological Analysis of Segregation Indices. *American Sociological Review*, 20(2), 210-217.
- Feitosa, F.F., Camara, G., Monteiro, A. M. V., Koschitzki, T., & Silva, M. P. S. (2007). Global and Local Spatial Indices of Urban Segregation. *International Journal of Geographical Information Science*, 21(3), 299-323.
- Gültekin, N. (2009). The Impact of Social Exclusion in Residential Segregation: A gipsy Neighborhood Fevzi Pasa in Turkey. *G.U. Journal of Science*, 22(3), 245-256.
- Gay Y Blasco, P. (2016). It's the best place for them?: normalising Roma segregation in Madrid. *Social Anthropology*, 24, 446-461.
- Isard, W. (1960). *Methods of Regional Analysis*. Cambridge: MIT Press.

- Johnston, R.J., Poulsen, M. & Forrest, J. (2014). Segregation matters, measurement matters. In C.L. Lloyd, I.G. Shuttleworth & D.W.S. Wong (Eds.), *Social-Spatial Segregation* (pp.13–44). Bristol: Policy Press.
- Massey, D. S., & Denton, N. A. (1988). The Dimensions of Residential Segregation. *Social Forces*, 67, 281-315.
- Matoušek, R., & Sýkora, L. (2011). Environmental justice and residential segregation in Czechia: the case of Roma resettlement in the town of Vsetín. *AUC Geographica*, 46(2), 81–94.
- Morill, R. L. (1991). On the measure of geographic segregation. *Geography Research Forum*, 11, 25-36.
- Pásztor, I.Z., Péntzes, J., Tátrai, P., & Pálóczi, A. (2016). The number and spatial distribution of the Roma population in Hungary –in the LIGHT of different approaches. *Folia geographica, Acta facultatis studiorum humanitatis et naturae Universitatis Prešovensis*, 58(2), 5-21.
- Picker, G. (2013). Policy Logic and the Spatial Segregation of Roma in Europe. The Cases of Florence and Cluj-Napoca. In G. Zincone, & I. Ponzio, (Eds.), *How European Cities Craft Immigrant Integration. Something to Learn* (pp. 40-57). Foundation for European Progressive Studies.
- Picker, G. (2017). *Racial Cities, Governance and the Segregation of Romani People in Urban Europe*. London and New York: Routledge.
- Powell, R., & Lever, J. (2017). Europe's perennial 'outsiders': A processual approach to Roma stigmatization and ghettoization. *Current Sociology*, 65(5), 680-699.
- Reardon, S. F., & O'Sullivan, D. (2004). Measures of spatial segregation. *Sociological Methodology*, 34(1), 121-162.
- Rochovská, A., & Rusnáková, J. (2018). Poverty, segregation and social exclusion of Roma communities in Slovakia. *Bulletin of Geography. Socio-economic Series*, 42, 195-212.
- Rotaru, M. A, Crețan R, & Ianăș A.N. (2023). Ethnicities in Post-Communist Romania: Spatial Dynamics, Fractionalisation, and Polarisation at the NUTS-3 Level. *Land*, 12(6), 1133.
- Sibley, D. (1992). Outsiders in society and space. In K. Anderson, & F. Gale, (Eds), *Inventing Places: Studies in Cultural Geography* (pp. 107-122). Melbourne: Longman Cheshire.
- Somogyi, E., & Horvath, V. (2018). *Checklist for cities to address residential and educational segregation of Roma*. Metropolitan Research Institute, Urban Poverty Partnership https://futurium.ec.europa.eu/system/files/migration_files/checklist_for_cities_to_address_residential_and_educational_segregation_of_roma.pdf
- Šlezak, H. (2009). Prostorna segregacija romskog stanovništva u Međimurskoj županiji [Spatial Segregation of the Roma Population in Međimurje County]. *Hrvatski geografski glasnik*, 71(2), 65-81.
- Šlezak, H. (2010). Prirodno kretanje romskog stanovništva u Međimurskoj županiji – slučaj romskog naselja Kuršanec [Natural Demographic Trends in the Romani Population of Međimurje County – Case Study of the Kuršanec Romani Settlement]. *Hrvatski geografski glasnik*, 72(2), 77-100.
- Šlezak, H. (2013). Uloga Roma u demografskim resursima Međimurske županije [The Role of the Roma in the Demographic Resources of Međimurje County]. *Sociologija i prostor*, 51(1), 21-43.
- Šlezak, H. (2021). Percepcija romskog etničkog prostora i socijalna isključenost [Perception of Roma ethnic space and social exclusion]. In R. Mirić (ed), *Zbornik radova petog kongresa geografa Bosne i Hercegovine* (pp. 276-288), Sarajevo, Bosna i Hercegovina.
- Šlezak, H. (2022). Kamo su nestali Romi? Promišljanje o prvim rezultatima popisa 2021. na primjeru usporedbe prirodnog i ukupnog kretanja broja stanovnika romskih naselja Parag i Piškorovec u Međimurskoj županiji [Where Did the Roma Go? Reflection on the First Results of the 2021 Census on the Example of Comparing the Natural and Total Population Trends of the Roma Settlements of Parag and Piškorovec in Međimurje County]. *Sociologija i prostor*, 60(2), 341-356.
- Šlezak, H., & Belić, T. (2019). Projections of change of the Roma population in Međimurje-from minority to majority. *Geoadria*, 24(2), 141-167.
- Toušek, L. (2011). Purification of space: Spatial segregation of Roma in the Czech Republic. *RESPECT Research Project* (GA no. 244549).
- Urban Poverty Partnership (2018). *Final Action Plan*. https://ec.europa.eu/futurium/en/system/files/ged/action_plan_urban_poverty.pdf (11.02.2023.)
- Virag, T., & Varadi, M.M. (2018). Spatial exclusion and boundary-making in different Roma neighbourhoods in Hungarian rural small towns. *Tijdschrift voor Economische en Sociale Geografie*, 109(4), 485-498. DOI:10.1111/tesg.12300
- Vresk, M. (2002). *Grad i urbanizacija. Osnove urbane geografije [City and urbanization. Basics of urban geography]*. Zagreb, Školska knjiga.
- Vuksanović-Macura, Z. (2020). Spatial Segregation of Roma Settlements Within Serbian Cities. Examples from Belgrade, Novi Sad, and Kruševac. In V. Mihaylov (Ed.) , *Spatial Conflicts and Divisions in Post-socialist Cities* (pp. 211-224). Cham: Springer.
- White, M. J. (1983). The Measurement of Spatial Segregation. *American Journal of Sociology*, 88(5), 1008-1018.

- Wong, D. W. S. (2001). Desktop and Internet GIS Development for Spatial Segregation Analysis. *21st Annual ESRI International User Conference*, San Diego, California, July 9-13, 2001.
- Wong, D. W. S. (2003). Spatial Decomposition of Segregation Indices: A Framework Toward Measuring Segregation at Multiple Levels. *Geographical Analysis*, 35(3), 179-194.
- Wong, D. W. S. (2004). Comparing traditional and spatial segregation measures: a spatial scale perspective. *Urban Geography*, 25(1), 66-82.
- Wong, D. W. S. (2005). Formulating a general spatial segregation measure. *The Professional Geographer*, 57(2), 285-294.
- Yao, J., Wong, D.W.S., Bailey, N. & Minton, J. (2019). Spatial segregation measures: a methodological review. *Tijdschrift voor Economische en Sociale Geografie*, 110(3), 235-250. doi: 10.1111/tesg.12305
- Zsolt Farkas, J, Lennert, J., Donát Kovács, A. & Kanalas, I. (2017). Impacts and consequences of residential segregation of Roma in urban spaces: Case studies from Hungary. *Urbani Izziv*, 28(2), 136-148.
- Zupančič, J. (2007). Romska naselja kot poseben del naselbinskega sistema v Sloveniji [Roma settlements as a special part of the settlement system in Slovenia]. *Dela*, 27, 215-246.

Challenges of Sustainable Mobility: Context of Car Dependency, Suburban Areas in Thailand

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Abstract

Urbanization and transportation have caused two critical issues in the challenge of sustainable development, particularly, challenges to sustainable mobility in the context of car dependency. This is due to all aspects of environmental, social, and economic has been continued influenced by transportation related issues. The challenges of sustainable mobility in the context of suburban areas have become aggravating situation due to massive migrations, thus Pathumthani province, represented as vicinity area of Bangkok, Thailand was selected as a case study. Data were collected from 1,998 respondents by questionnaire survey and analyzed using statistical analysis and visualization based on geographic information system, GIS application. The study results revealed that the urbanization process has led to an increase in urban development that attracts enormous migrations in searching for their opportunities (working and education trips). This phenomenon has positioned Pathumthani to serve as a supportive area for the spillover of rapid urbanization in the country's capital area which has led to the development of private car-dependent travel and public transport network, mainly concentrated in urban areas with exclusion to residents in remote areas. On the other hand, most areas sprawl with a scattered density of residential settlements, which existing transportation system development can no longer serve the continued rising travel demand as before. The findings confirmed that the current development pattern could not promptly meet the needs of suburban development, requiring the policymakers to launch an effective plan to meet appropriate transportation demands and promote good quality of travelling for the residents and commuters.

Keywords: auto dependency; peri-urban areas; public transportation; sustainable development; transportation impact: urbanization

Introduction

The phenomenon of urban transformation from rural to urban (urbanization) occurs worldwide, whereby populations relocate from rural to urban areas, enabling cities and towns to grow. In 2022, the rate of urbanization worldwide was at 57 percent, and turning to 70 percent of the global population living in cities in 2050. However, some statistics illustrate how urban living differs from suburban and rural living (Statista Research Department, 2022). Accordingly, urbanization is widespread in developing and developed

worlds as more people tend to relocate closer in proximity to towns and cities. Thailand is presented as one of the countries where that phenomenon occurs, especially Bangkok (Iamtrakul et al., 2023a). From the analysis of urban area expansion, it was noticeably found that the development of urban areas was vastly concentrated in Bangkok. From 2000 to 2020, the trend of changes in urban areas has continued to expand due to changes in urbanization (Iamtrakul et al., 2021). The land use from green spaces to urban areas

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has been extended to contiguous territories, i.e., metropolitan areas, as a result, Bangkok and its vicinities have become sprawling cities. Its speedy development results from several problems arising from urbanization, such as uncontrolled population growth and growth along the urban infrastructures (Ammapa et al., 2022; Iamtrakul et al., 2022). The crucial issues that arise are often related to mobility in the urbanized area, especially as it concerns the availability of transportation system. Furthermore, with the problematics mentioned above, both issues of the population growth and the difficulties of urban management have been increasing at a critical stage (Iamtrakul & Chayphong, 2023). Most of the commuting options preferred by dwellers are private cars as represented as their primary choice. This presents the commuting demand by residents in a critical condition, leading to unsolved traffic congestion. This phenomenon has not arisen only in the Bangkok, however the scope of the problem has extended to the surrounding provinces, consisting of Bangkok, Nakhon Pathom, Nonthaburi, Pathum Thani, Samut Prakan, and Samut Sakhon. Suburbanization occurred in these areas affected by the rapid and fragmented urban development in sprawling pattern, resulting in attracting factors (pull factor) for immigrants to enter the city in terms of access to jobs, education, utilities, public utilities, and public services.

Consequently, Pathum Thani Province which is represented as a peri-urban area supporting population expansion from Bangkok which induced massive

potential in terms of allocation of facilities and services and a large concentration of activities, e.g., agricultural, commercial/industrial areas, and higher education institutions (Iamtrakul & Chayphong, 2021). However, over 70 percent of the province's gross domestic product is generated from the industrial sector which is also significant driven based on commercial divisions as well, thus causing the instant growth of the adjoining areas. However, when urban planning and management are considered, it was found that there needs to be more efficient traffic network systems and effective transport management, resulting in numerous problems, especially traffic complications. This is evidence that Pathum Thani's traffic volume ratio to road capacity (Vehicle Ratio (VCR)) during the morning and evening rush hour is more significant than 1.00. Furthermore, road safety statistics showed that Pathum Thani has a road accident fatality rate of 9.6 per 100,000 people and is ranked number 1 in the metropolitan area. (Thai Roads, 2017). Without a doubt, there is also the problem of air pollution with an average PM_{2.5} as of 2019 with more than 160 micrograms per cubic meter, which is considered at a health risk. Therefore, supporting a seamless travel connection model within the nodes of activity and surrounding areas is necessary to fill the planning gaps and, in turn, reduce the need to travel with a personal car. Therefore, it is necessary to tackle these problems and prepare for better future transportation development opportunities in Pathum Thani province.

Literature review

Increasing global urbanization brings challenges and opportunities for sustainable development, particularly in developing countries (Haider & Iamtrakul, 2022). Urban transport is one of the significant elements in the primary production process to drive economic development, especially in urban areas of megacities. Connectivity among routes and vehicles for travelling are necessary for more convenience and efficiency. The availability of such linkage should be designed to sufficient support passenger travel and freight and goods for transportation, including the development of urban economic agglomeration areas. Therefore, the development of transportation systems should be considered as the priority of urban development planning, which is the key factor that makes the transportation system particularly important to the development of urban areas. Urbanization brings several challenging impacts within urban/city, such as medical services and health dimension (Liu et al., 2017; Godfrey & Julien, 2005; Iamtrakul & Chayphong, 2023), urban heat

island (Wang et al., 2021; Wu et al., 2020), transportation impact (Iamtrakul & Hokao, 2012; Iamtrakul et al., 2023b), environmental impact (Ponce De Leon Barido and Marshall, 2014; Ergas et al., 2016;), social inequality problems (Nguyen Minh et al., 2019; Kanbur & Zhuang, 2013), etc. That is to say, urbanization has been one of the dominant factors influencing economic, environmental, and social changes related to sustainable urban development.

For transportation impacts issues, the rapid urbanization process has produced a series of transportation impacts, such as energy consumption, environmental problem, a lack of transportation facilities, mobility problems, road safety, traffic congestion, land take, etc. (Chen et al., 2016; Iamtrakul & Hokao, 2012; Poumanyvong et al., 2012; Rodrigue et al., 2006). Urban mobility problems have increased proportionally and, in some cases, exponentially with urbanization (Rodrigue, 2020). This phenomenon needs holistic view-based solutions and searches for more sustainable

solutions. Consequently, transportation issues have become a significant problem for cities' and regions' spatial configuration associated to economic development. Since transportation stipulates the movements of people, goods, and information which are the fundamental components of urbanization and transportation development and also influences the attractiveness and desirability of urbanized areas (Banister, 1995). This may result to increase traffic volumes and frequent commuters, causing higher travel demand with appropriate and efficient planning and management. Significantly, it has been understood that the movement trend increases and shifts towards motorized transport modes or car dependency. It can also be noticed that car dependency plays a key role as one of the most influential contributing factors to air pollution, traffic congestion, risk of health problems, and energy consumption (Li & Zhao, 2017; Frederick et al., 2018). This is seriously hindering the development of sustainability.

Materials and methods

Study area

This paper intends to study the challenges of sustainable mobility in the context of car dependency in suburban areas in Thailand. Pathum Thani province was selected as a case study of suburbanization development. This is due to the characteristics of the site, which can be considered as a peri-urban province to support the rapid urban development of Bangkok metropolitan. As a result, within the study area, it was found a variety of activities attract migrants to commute into the area; such activities include the prospects for jobs, housing, and education (Iamtrakul et al., 2022). In addition, urban development results in essential activities that appeal many trip makers to commute to the study area. Pathum Thani Province, however, provides transportation systems and services to support the use of diverse populations, both residents and employees (e.g., walk, bicycle, bus, sky train, commuter rail, and various para transit systems). Although there are many transportation options and modes of transportation systems, the coverage of these services is yet to meet the demands of commuters in areas far from urban areas, particularly the accessibility to connect (feeder) and link to services providing affordable public transport. As a result, travelling by private car is the most popular mode of transportation in the study area.

Data Collection

The input data for the analysis process in this study consists of two parts which can be categorized into primary and secondary data, as demonstrated in Fig-

ure 1 and Figure 2. The primary data was gathered by questionnaire survey which the details of data collection is divided into two parts which are;

1. *Socioeconomic profile of respondents*: There are 5 data sets comprises of gender, age, education level, occupation, income level (average income per month per person);
2. *Travel behavior of respondents*: There are 3 data sets which are travel time (minutes), vehicle possession, and trip purposes.

The secondary data was a collection of databases which is divided into 2 parts which are;

1. *Socioeconomic profile of the study area*: was collected from secondary data by Official statistics registration systems (Official statistics registration systems, 2022). There are 8 data attributes comprising of population (Persons), number of households (households), number of houses (house), density of population (persons per area), in-migration on house registration (persons), out-migration on house registration (persons), number of employed people in formal (persons) and number of employed people in informal (persons).
2. *Physical characteristics and its developments*: were gathered from secondary data based on geographic information systems (GIS). There are 2 sets of data which consists of building characteristics (type of building: commercial, institutions, mixed use, recreations, industrial, residential) and transportation (local road, main road, public transportation, etc.).

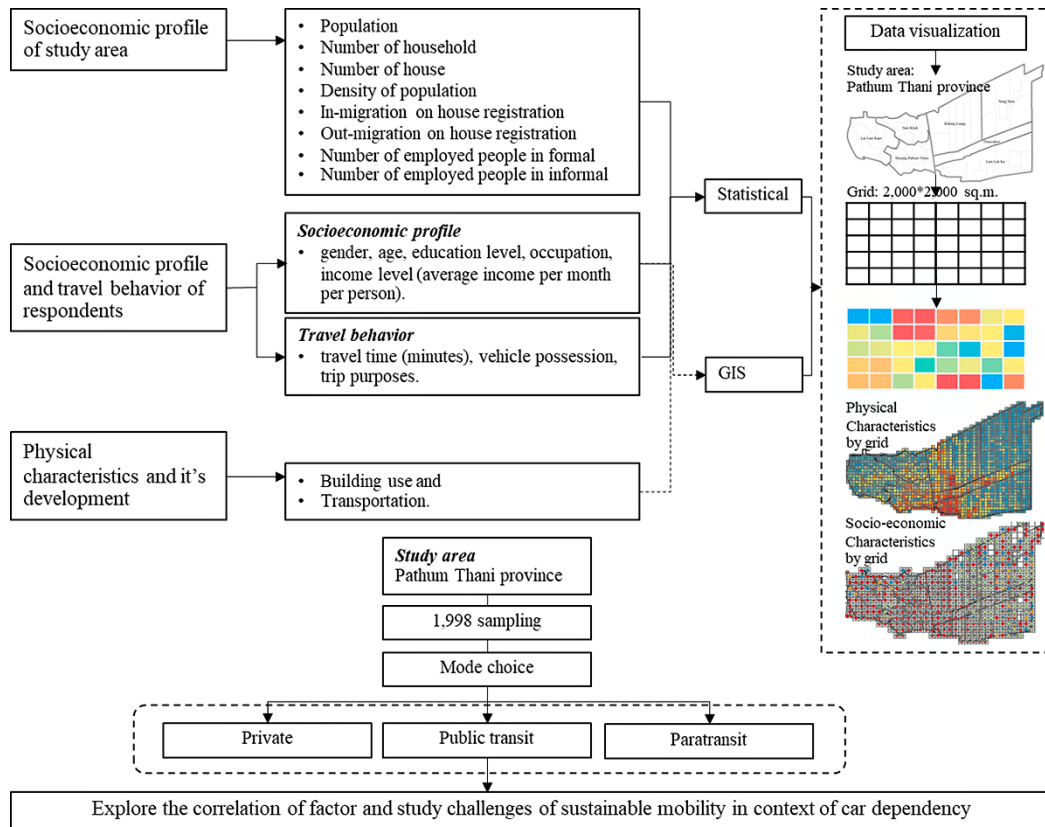


Figure 1. The framework of the study

This research was primarily conducted by using a questionnaire with 2,000 samplings. The sampling size was determined, and the sets of sample sizes were at the confidence level of 95%. The total sample size in this study was distributed to cover entire districts of the study area. Therefore, with the screening data, the final number is 1,998 sets based on the method for collecting the data on the basis of face-to-face randomization.

The survey was also dispersed by using an area of distribution at 2,000*2,000 square meter grid by considering the building density representing the population density within the grid. This was conducted to confirm the distribution of the sample data within the study area. After collecting data, the screening was performed with a focusing on eliminating missing data. Furthermore, this questionnaire was approved by the Human Re-

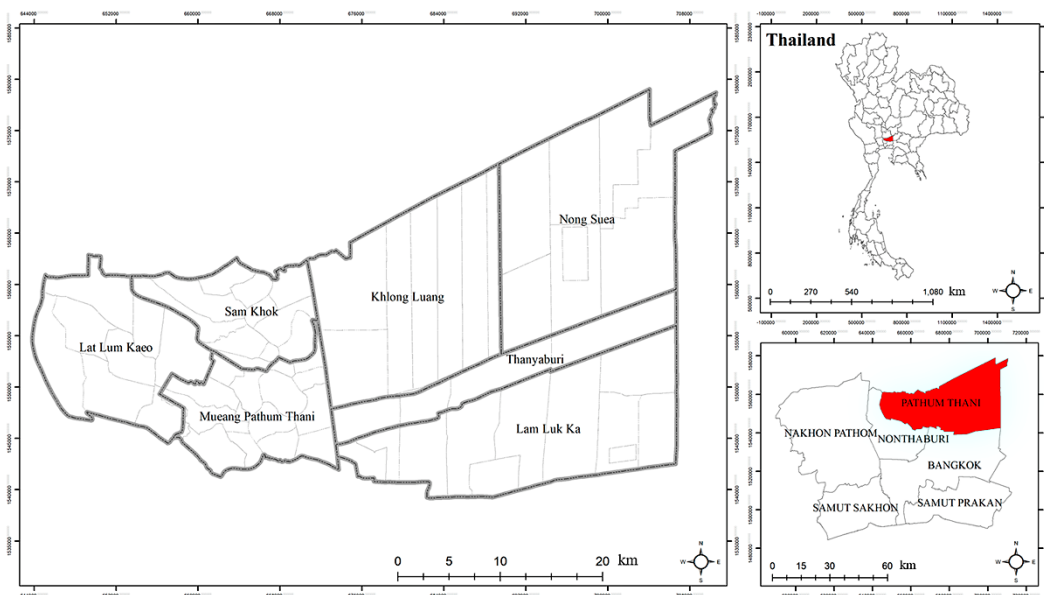


Figure 2. Study area

search Ethics Committee of Thammasat University Social Sciences (certificate of approval number 107/2022) with approval on August 15, 2022.

Method of Analysis

This study applies statistical analysis and geographic information systems (GIS), furthermore Chi-Square was adopted to explore the correlation between soci-

oeconomic, travel behavior, and mode choice, which provides an understanding of the factors associated with car dependency in the study area. By comparing different mode choices in the analysis, the consideration was targeted to the main three types which include private categories, public transit, and para-transit. The analysis of the results is explained in the next section, as illustrated in Figure 3.

Results

Socioeconomic Profile of Study Area

Pathum Thani Province is considered a local expansion from the nation's capital with a suburban context where activity density is concentrated in the main corridor of highway network passing through the study area. In addition to the activity density of the study area, a wide variety of activity nodes was also discovered, attracting numerous commuters to the provincial area. Figure 3 demonstrates the statistical information on the social and economic characteristics of the study area at the provincial level. It also can be confirmed that the population growth rate is on the increase trend. However, the tendency of an increase is lower than in the capital city, going by the annual comparison result over the past ten years. Considering the number of migrations in and out of the housing registration, it was found that the move-in rate declined during 2013-2017. However, the trend increased during 2018-2019, after that, the number of moving in rate has declined until now which presents a consistent trend with the number of relocations. However, considering the annual data, the number of moving-in rates is greater than that of moving-out, indicating increased travelling and settlement in the area. Furthermore, this aligns with the increasing number of employees in the formal and informal sectors, especially in 2020-2021. Therefore, the increasing number of populations reflects the number of residents, as concentration of users of urban infrastructure increase accordingly.

Physical Characteristics with car despondency

The study area has intensified and expanded with urbanization from central or capital areas to remote areas. Urban areas covered by buildings are replacing agricultural or vacant areas which represent the expansion of Pathum Thani Province and its transition of buildings and road intersections from 2007 to 2017, as shown in Figure 4. It presents the allocation of the economic centres of the province, described as a dense area of mixed residential and commercial buildings. Furthermore, several shopping malls are located nearby the main highway to attract huge demand of trip generations. In addition, there are several multi-modal connectivity transfer points or terminal areas to connect for travelling abroad by air transport. As well as, it is also provided a service for the regional connection of northern and northeastern trips, passing through the area to the capital city.

However, looking at the activity nodes and intersections in 2017, it reveals the city's growth over the past ten years. The centre of the city or economic agglomeration areas presents the same area located at the main highway junctions. Moreover, within the urban growth process, it can be observed that the building settlement has spread from the city centre with no direction as a scattering pattern. It demonstrated that rather than expanding to the area near the boundary with the Bangkok area, the direction of expansion was far away from Bangkok to the area of Pathum Thani province. Regarding the development of transpor-

Year	Population	No. of Household	Population density	In-migration	Out-migration	No. of employment (Formal)	No. of employment (Informal)	Year	Growth rate							
2012	1,093,837	489,783	677.55	93,342	73,620	322,014	145,773	2012	-	-	-	-	-	-	-	-
2013	1,053,158	506,671	690.21	83,407	70,688	306,302	152,481	2013	1.87	3.45	1.87	-10.64	-3.98	-4.88	4.60	
2014	1,074,058	521,360	703.91	84,176	70,121	614,590	275,187	2014	1.98	2.90	1.98	0.92	-0.80	100.65	80.47	
2015	1,094,249	551,271	717.14	81,024	68,255	608,816	291,124	2015	1.88	5.74	1.88	-3.74	-2.66	-0.94	5.79	
2016	1,111,376	567,974	728.36	80,360	68,189	647,332	272,910	2016	1.57	3.03	1.57	-0.82	-0.10	6.33	-6.26	
2017	1,129,115	585,814	739.99	78,314	66,614	623,490	273,294	2017	1.60	3.14	1.60	-2.55	-2.31	-3.68	0.14	
2018	1,146,092	603,834	751.11	81,170	69,346	610,587	304,508	2018	1.50	3.08	1.50	3.65	4.10	-2.07	11.42	
2019	1,163,604	624,930	762.59	86,883	72,689	608,673	308,130	2019	1.53	3.49	1.53	7.04	4.82	-0.31	1.19	
2020	1,176,412	642,474	770.98	85,338	70,053	670,986	275,399	2020	1.10	2.81	1.10	-1.76	-3.63	10.24	-10.62	
2021	1,190,060	660,020	779.99	76,097	64,846	755,565	187,811	2021	1.16	2.73	1.16	-10.85	-7.43	12.61	-31.80	

Figure 3. Socioeconomic profile of study area

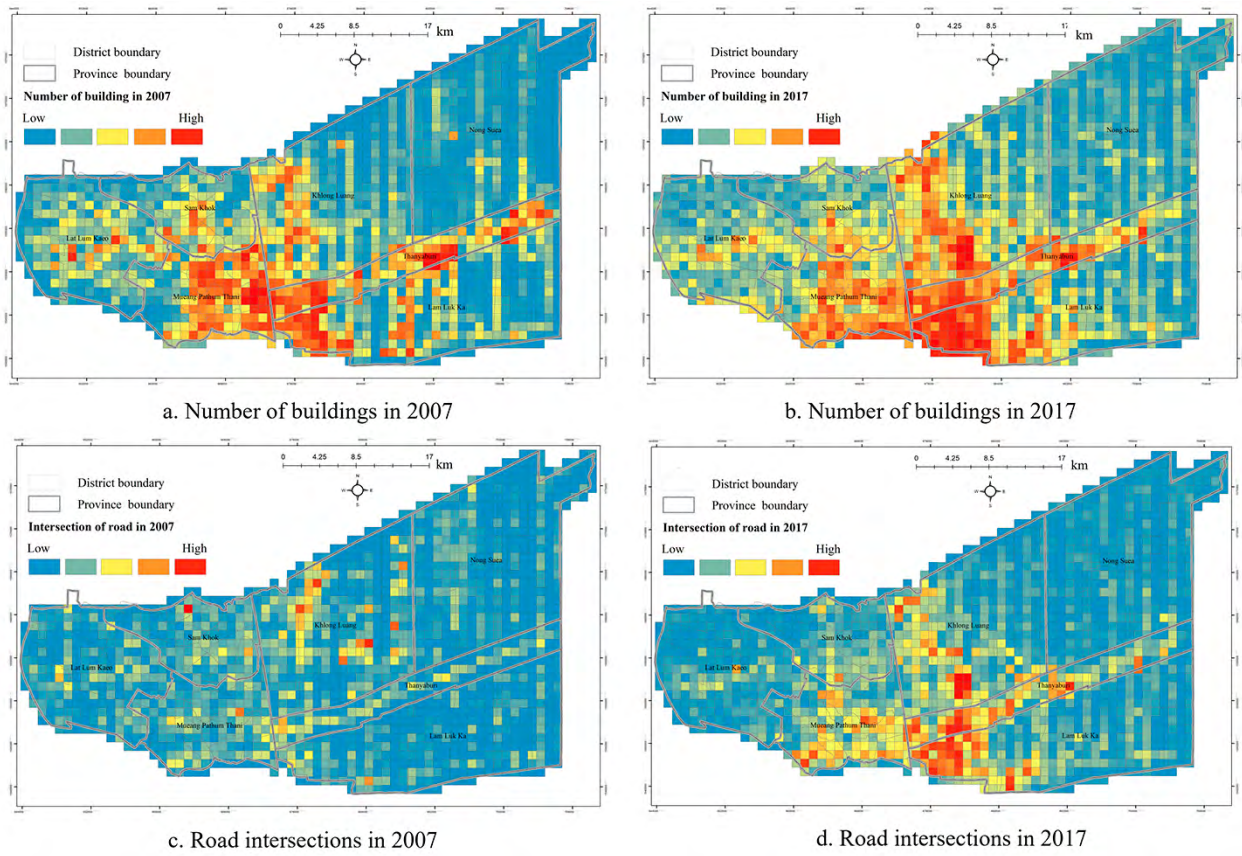


Figure 4. Changes of buildings and road intersection between 2007 and 2017

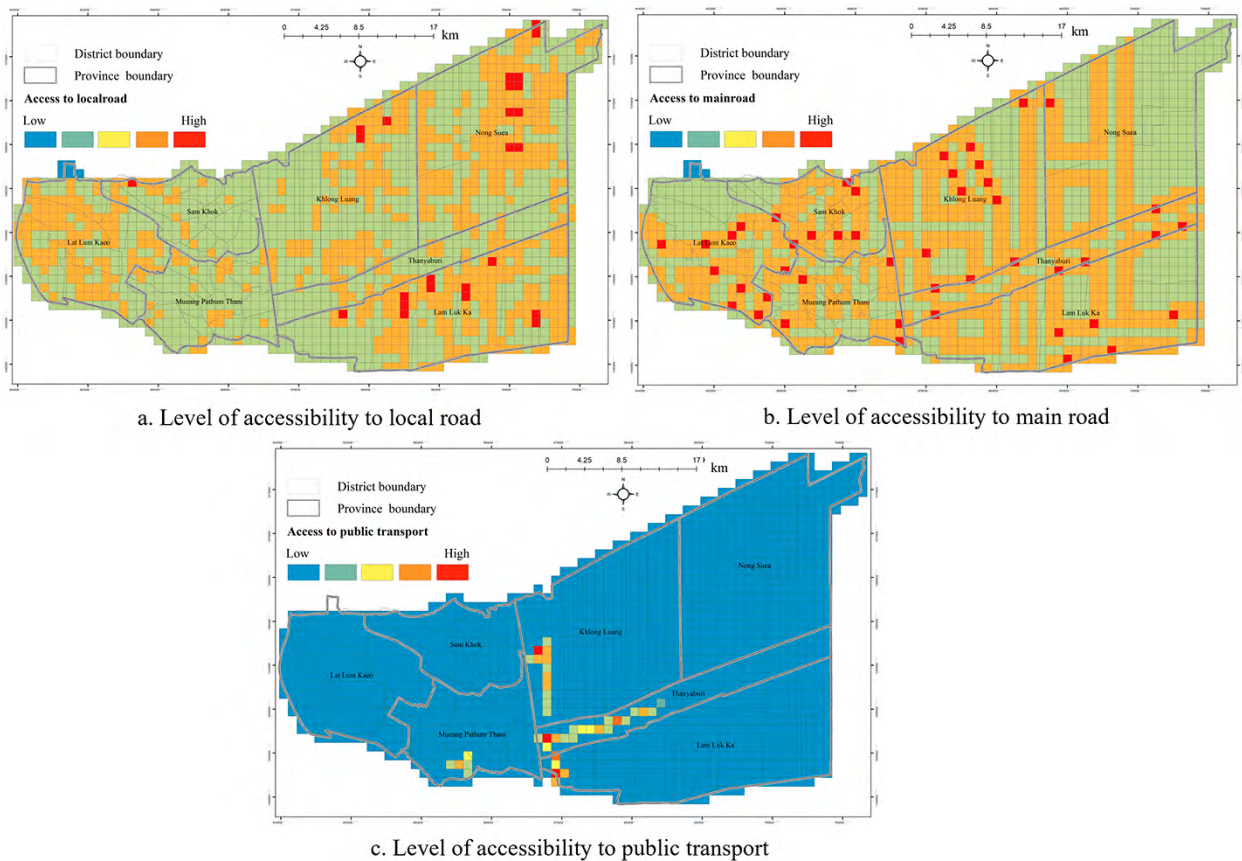


Figure 5. Level of public transportation accessibility

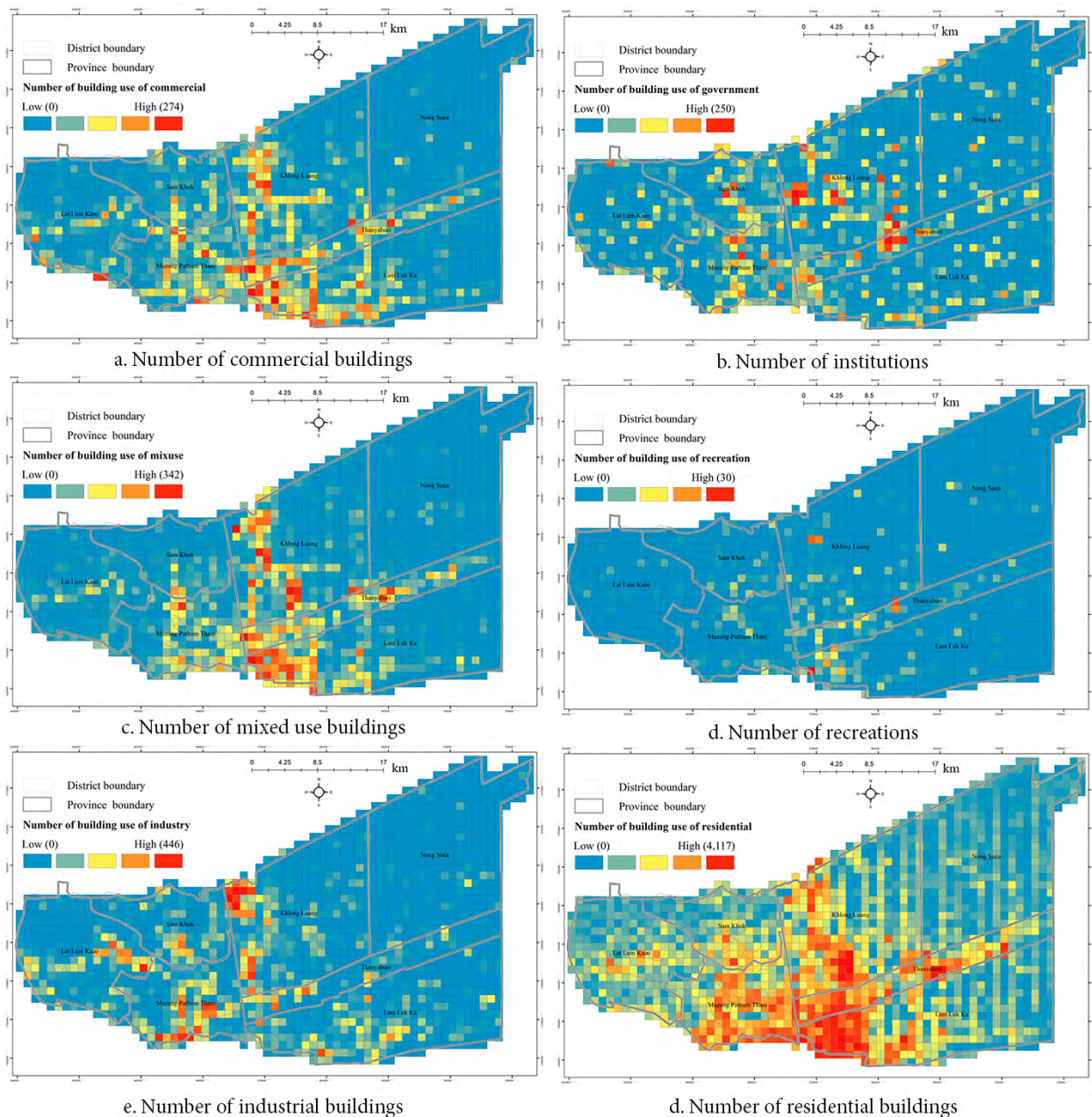


Figure 6. Characteristics of building activities

tation networks and transportation systems, it demonstrates that the substantial expansion of highway networks to support the travelling demand of the population, while public transport development was found its constrain and the availability in terms of service area is mainly limit only within the city center area (as shown in Figure 5). Thus, the urbanization process could be triggered by the restriction of public transport development which is slower than the city's expansion rate. This certainly leads to car dependency in this suburbanized area, making private cars the primary mode of transportation.

Socioeconomic profile and commuters' behavior with car dependency

Based on the results of the questionnaire analysis which was conducted in this part, this research attempts to explore the correlation between socioeconomic, travel behaviour, and mode choice to provide better understanding among the factors associated with car dependency in areas. Table 1 shows a correlation between the respondent profile and travel behaviours. The analysis of the sample data of 1,998 people showed that most of respondents were male (50.8%) with the age category of 26-30 years old (26.8%), followed by 31-35 years old (25.0%) and 36-40 years (15.7%). Most of the educational levels were

a bachelor's degree (60.0%), followed by a high school degree/vocational certificate (17.6%) and a vocational certificate (15.5%). For the average income of the respondents, it was found that the average personal income per month per person of the sample group falls within 20,000-25,000 baht (30.5%), followed by an income level of 25,001-30,000 baht (28.4%), and income level 30,001–35,000 baht (13.0%). When socioeconomic factors were considered, it was found that

all factors were statistically significant at the 0.05 level of significance. It exhibited that different socioeconomic characteristics were significant for using the different travel modes. Regarding travel behaviour, the respondents had a vehicle in possession of more than 89.1% of which most of which were personal cars, followed by motorcycles. The car ownership of preliminary data presents their travelling patterns of Pathum Thani as dependent on a personal vehicle by

Table 1. Respondent profile

Variables	Private		Public transit		Paratransit		Total		P-value
	n	%	n	%	n	%	n	%	
Gender									
Male	939	93.5	41	4.1	24	2.4	1,014	50.8	0.018*
Female	851	89.7	51	5.4	47	5.0	978	48.9	
Others	6	100.0	0	0.0	0	0.0	6	.3	
Age (years)									
Lower than 20	20	62.5	6	18.8	6	18.8	35	1.8	0.000*
21 to 25	121	90.3	7	5.2	6	4.5	140	7.0	
26 to 30	471	89.5	25	4.8	30	5.7	536	26.8	
31 to 35	458	93.7	20	4.1	11	2.2	499	25.0	
36 to 40	279	90.6	22	7.1	7	2.3	314	15.7	
41 to 45	227	92.7	9	3.7	9	3.7	245	12.3	
46 to 50	146	98.0	1	0.7	2	1.3	153	7.7	
Older than 50	74	97.4	2	2.6	0	0.0	76	3.8	
Education level									
Junior high school level	8	80.0	1	10.0	1	10.0	10	.5	0.000*
High school or vocational school level	272	89.5	19	6.3	13	4.3	309	15.5	
Diploma or occupational school level	342	97.4	5	1.4	4	1.1	351	17.6	
Bachelor's degree	1,049	90.0	67	5.8	49	4.2	1,199	60.0	
Higher than a bachelor's degree	125	96.9	0	0.0	4	3.1	129	6.5	
Occupation									
Student/university students	30	63.8	9	19.1	8	17.0	52	2.6	0.000*
University staff	2	100.0	0	0.0	0	0.0	2	0.1	
Workers in a private company	842	89.0	58	6.1	46	4.9	975	48.8	
Shopkeeper or shop owner	480	97.2	5	1.0	9	1.8	495	24.8	
General employed	412	93.8	20	4.6	7	1.6	443	22.2	
Housekeeper	0	0.0	0	0.0	1	100.0	1	0.1	
Others	30	100.0	0	0.0	0	0.0	30	1.5	
Income level (average income per month per person, THB)									
5,001 - 10,000	43	97.7	1	2.3	0	0.0	45	2.3	0.000*
10,001 - 15,000	139	90.3	9	5.8	6	3.9	158	7.9	
15,001 - 20,000	187	88.6	2	0.9	22	10.4	211	10.6	
20,001 - 25,000	517	88.1	52	8.9	18	3.1	610	30.5	
25,001 - 30,000	528	94.6	21	3.8	9	1.6	568	28.4	
30,001 - 35,000	240	92.7	6	2.3	13	5.0	260	13.0	
More than 35,000	142	97.3	1	0.7	3	2.1	146	7.3	

one person owning more than one vehicle either car or motorcycle. However, when the modes of transportation that commuters choose to use were considered, the results were focused on three types of mode utilization (private cars and public transport, and paratransit).

According to the data, most commuters adopt their personal vehicles (personal cars, motorcycles, bicycles, etc.) as their main mode of travel, representing more than 89.9 percent. It is consistent with the number of personal vehicle possessions by more than three-fourths of all travellers. Travelling by bus is followed by 4.6%, and paratransit accounts for 3.6%. In terms of traveling time, it was found that over 41.6% of travel times are less than 15 minutes, indicating that such travels are short trips within the area. When travel

behaviour factors were considered, it was found that all factors were statistically significant at the 0.05 level of significance. Therefore, it can be confirmed that different travel behaviour characteristics were significant in terms of the differences in travel mode selection. The respondents' profiles and travel behaviour are presented in graphic visualization for a clear understanding, as illustrated in Figure 7.

Furthermore, this study also analysed the explanatory variables in different travel behaviours of suburban commuters. The result of Table 2 presents the significant finding of the socioeconomics of commuters leading to the selection of transportation mode choices which the decision makers must comprehend for the appropriate policy options and sustaining the transportation problem of the study area.

Table 2. Respondents' travel behaviors

Variables	Private		Public transit		Paratransit		Total		P-value
	N	%	N	%	N	%	N	%	
Travel time (minutes)									
< 15	715	89.4	45	5.6	40	5.0	832	41.6	0.000*
15-30	631	92.4	24	3.5	28	4.1	690	34.5	
31-60	446	94.7	23	4.9	2	0.4	471	23.6	
> 60	4	80.0	0	0.0	1	20.0	5	0.3	
Vehicle possession									
Yes	1,670	95.8	51	2.9	23	1.3	1,781	89.1	0.000*
No	126	58.6	41	19.1	48	22.3	217	10.9	
Trip purposes									
Studying	29	61.7	10	21.3	8	17.0	52	2.6	0.000*
Working	1,030	91.0	65	5.7	37	3.3	1,154	57.8	
Dining and eating	254	94.4	12	4.5	3	1.1	276	13.8	
Shopping	232	89.9	4	1.6	22	8.5	260	13.0	
Leisure and recreation	251	99.2	1	0.4	1	0.4	256	12.8	
Total	1,796	89.9	92	4.6	71	3.6	1,998	100.0	

*The level of significance was set at $p < 0.05$ for the analyses.

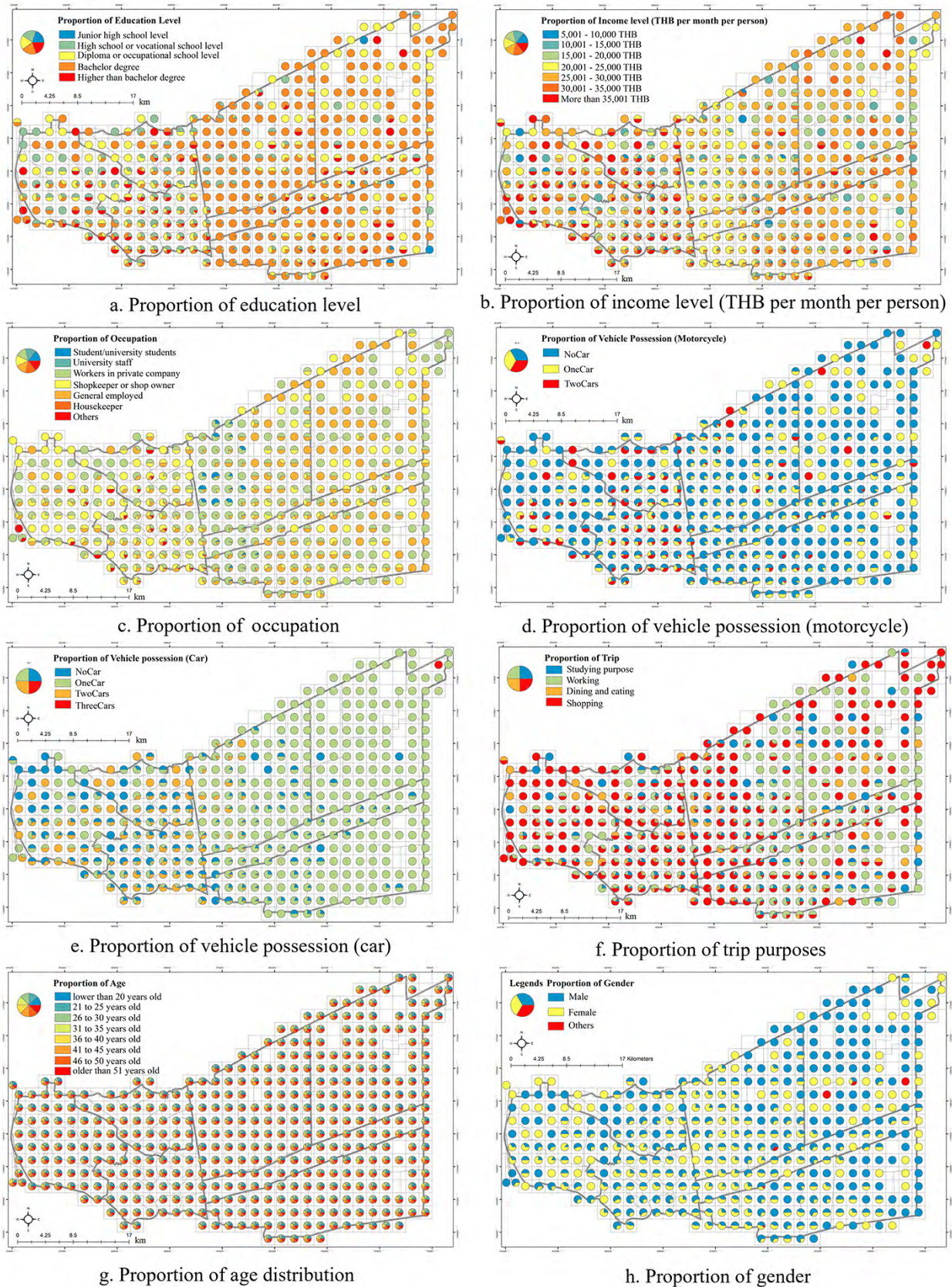


Figure 7. Respondent profiles and their travel behaviors

Discussion

Car dependency is one of the significant problems and challenges among urban and transportation planners. Several studies have indicated that numerous factors contributed to the support of travelling by private vehicles instead of public transport or other forms of active transportation modes. Although there are more alternative forms of traveling within the city, private vehicles are the most needed. Therefore, passenger cars have been dominant on most street networks. This result of study indicated that car dependency for travelling is not only related to the nature of the travel behaviour of commuter in suburban area, but the social and economic characteristics also influenced due to the pattern of urban development (e.g., efficiency and accessibility of public transport, road development pattern, etc.). The socio-economic factors were primary factor in choosing a mode of travel at the individual level, where the sample group with a high education level and income often used a personal car. Furthermore, travel time and trip purposes were also significant for choosing the mode of travel as the subjects of choosing private cars due to saving time and convenience in travelling, especially for longer network trips.

When considering on the physical characteristics of urban and transportation characteristics, the direction of urban development in Pathum Thani Province is noticeable different in terms of intensity and variety of land use activities and transportation systems within their spatial aspect. The center area is full of intense density and there is a variety of activities in terms of nodal of activities and urban services, e.g., large shopping centers, hospitals, clusters of small shopping centers, as well as the concentration of housing. Regarding the transportation system in the city center, it is also available to serve both public and para-public transport systems, transshipment points for freight and passengers among various modes of travel within the area. On the other hand, the peri-urban area is significantly less dense and diverse in terms of concentration of activities than other urban centers. Most scattered developed areas are in the form of agricultural and low density housing, including small commercial activities. As for the transportation systems supported in this area, most travelling patterns are by private vehicles and para-public transport due to the available network of public transport is inaccessible.

However, Pathum Thani Province play a role as an area that supports expansion of urbanization of capital of Thailand. As a result, most of the areas are full of prime residences that support suburbanization. These residential areas are located next to the business cent-

ers or between several sub centers and its periphery. Therefore, at the location of diversity and concentration of activities, the connectivity supported by public transport systems are available only at the urban core or main urban function or centers which causes a large amount of travel volumes to create trip pattern of private vehicles. Given that commuting pattern, car dependency has become the main problematic of mobilization among suburbanization area of urban development which is also confirmed by Litman (2002) about the influencing factors from transport and land use associations. In addition, among a variety urban problems and issues, a sustainable development approach is taken as the core of strategic planning and development by focusing on balanced development in social, economic, and environmental dimensions (Hassan & Lee, 2015). The situation of relying on private vehicle must be tackle to balance with the dimension of social and environmental due to causing the adverse effects of climate change, negative health issues, and social inequalities (Li & Zhao, 2017; Frederick et al., 2018; Al-Hinti et al., 2007). Therefore, efforts to create sustainability in transportation systems must be considered by creating alternative solutions to alleviate traffic congestion while diminishing the need for private cars. Several approaches are adopted, such as developing public transport systems prioritizing, improving safety, connectivity and accessibility, and promoting affordability and non-motorized travel development through appropriate infrastructures and facilities allocation with friendly urban design to promote daily non-motorized travel. Based on this research approach, it can provide valuable message to help reduce the dependence on private cars by capturing commuters' behavior in associated with urban spatial configuration which can help to lead for recommending the development policy to be consistency with the national goals. Such an approach, it would particularly helpful at planning and policy due to the country 20-year strategic plan for transport and transportation development (2018-2037), target for transport and transportation development in the issue of creating equitable and equitable access to transport systems through design and implementation services for all. In order to pay attention to the development of public transportation with the aim on reducing the dependence on private vehicles, the target should lead to the transport behaviors changes to effectively reduce the traffic on the roads from the origin trips at the vicinity of Bangkok.

Findings arising from this study appeal to the impact of association between urban and transporta-

tion systems development that consequent ty car dependency in sub-urbanized area of Pathum Thani Province. However, there were also study limitations related to the factors within the consideration of research framework. Due to the dependency on personal vehicles, many studies in the past have deliberated several factors to provide multi-dimensional reflections among land use patterns among several context of road network in different specific requirements within diverse group of individuals and communities. In addition, further studies should improve the format of the input data based on rigorous verification and validation. Currently, several research in land use and transportation has been applied information techniques related to technology and innovations, e.g., Augmented Reality (AR), Virtual Reality (VR), GPS, mobile applications, etc., which helps to make precise and real-time informed decisions with large databases. However, considering the large amount of data requirement to produce more realistic reflections of diverse commuters' behavior, lack of data availability together with traditional data col-

lecting process could not be sufficient in capturing the real performance of urban structures while restrain the significant reflection based on commuters' socioeconomic characteristics, opinions and needs of representations among diverse group of travelers in the area. Therefore, the study results are more or less in extraction the current problematics in driving the development of a sustainable transport system policy and planning. Finally, the development of urban and transportation systems must be focused on more than just infrastructures or physical considerations. Moreover, the needs and compatibility of the commuters' behavior must be contemplated due to the reason that trip making decision in terms of modal usage are influenced by several factors involved in any particular traveling context within different capacity of urban configuration. Notably, a plan for reducing the number of private vehicles and enhancing sustainable development must be realistic while the considering among the multi-dimensional of social, cultural, and economic including tangible and intangible must be comprehended.

Conclusion

This paper aims to study the challenges of sustainable mobility in the context of car dependency in suburban areas in Thailand. This study leverage information relating to the socioeconomic and physical profile of the study area, like physical characteristics, socioeconomic profile, and travel behaviour of respondents, to consider the challenges of sustainable mobility in car dependency. The findings of the analysis pinpoint car dependency are not a single aspect; that includes numerous factors that are affected. Importantly, it highlighted the challenges of sustainable urban and transport development due to the results pointing to a developmental asymmetry; the development of public transport in the study area is slower than the city's expansion rate. This leads to car dependency in this suburbanized area, making private cars the primary mode of transportation.

Thus, city planners, urban designers, and policy decision-makers should have to look at the comprehensive view of maintaining the pace of transport infrastructure development with the support of inclusive commuting behaviours in their city. Recommendations for reducing dependence on personal vehicles should focus on public transport and personal mobility, including putting in place significant feeder investments to support the implementation of main public transport and active mobility, etc. Though this study has some limitations in input factors needing to be more comprehensive in all relevant factors, these findings can be extended, leading to sustainability in developing transportation and transportation systems in the future for suburban areas.

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References

- Al-Hinti, I., Al-Ghandoor, A., Akash, B., & Abu-Nada, E. (2007). Energy saving and CO2 mitigation through restructuring Jordan's transportation sector: The diesel passenger cars scenario. *Energy Policy*, 35(10), 5003-5011.
- Ammapa, J., Visuttiporn, P., Klaylee, J., Chayphong, S., & Iamtrakul, P. (2022). Using GIS-Based Spatial Analysis: Comparing Pattern of Urbanization and Transportation Networks, *10th International Conference on Traffic and Logistic Engineering, Macau, China*, 17-21.
- Banister, D. (1995). *Transport and Urban Development*, London: E & FN Spon.
- Chen, M., Liu, W., & Lu, D. (2016). Challenges and the way forward in China's new-type urbanization. *Land Use Policy* 55, 334–339.
- Ponce de Leon Barido, D., & Marshall, J. D. (2014). Relationship between urbanization and CO2 emissions depends on income level and policy. *Environmental science & technology*, 48(7), 3632-3639.
- Ergas, C., Clement, M., & McGee, J. (2016). Urban density and the metabolic reach of metropolitan areas: A panel analysis of per capita transportation emissions at the county-level. *Social Science Research*, 58, 243-253.
- European Parliament. (2006). *Policy Department for Structural and Cohesion Policies*. Brussels, Belgium: European Parliament.
- Frederick, C., Riggs, W., & Gilderbloom, J. H. (2018). Commute mode diversity and public health: A multivariate analysis of 148 US cities. *International Journal of Sustainable Transportation*, 12(1), 1-11.
- Godfrey, R., & Julien, M. (2005). Urbanisation and health. *Clinical Medicine*, 5(2), 137.
- Ha, N. M., Le, N. D., & Trung-Kien, P. (2019). The impact of urbanization on income inequality: A study in Vietnam. *Journal of Risk and Financial Management*, 12(3), 146.
- Haider, M. A., & Iamtrakul, P. (2022). Analyzing Street Crime Hotspots and Their Associated Factors in Chittagong City, Bangladesh. *Sustainability*, 14(15), 9322. <https://doi.org/10.3390/su14159322>
- Hassan, A. M., & Lee, H. (2015). Toward the sustainable development of urban areas: An overview of global trends in trials and policies. *Land use policy*, 48, 199-212.
- Iamtrakul, P., Padon, A., & Klaylee, J. (2022). Analysis of urban sprawl and growth pattern using geospatial technologies in Megacity, Bangkok, Thailand. In *Geoinformatics and Data Analysis: Selected Proceedings of ICGDA 2022* (pp. 109-123). Cham: Springer International Publishing. <https://doi.org/10.1007/978-3-031-08017-3>
- Iamtrakul, P., Padon, A., & Klaylee, J. (2022). Measuring Spatializing Inequalities of Transport Accessibility and Urban Development Patterns: Focus on Megacity Urbanization, Thailand. *Journal of Regional and City Planning*, 33(4), 345-366. <https://doi.org/10.5614/jpwk.2022.33.3.4>
- Iamtrakul, P. and Chayphong, S. (2023). Factors affecting the development of a healthy city in Suburban areas, Thailand. *Journal of Urban Management*, In Press. DOI: 10.1016/j.jum.2023.04.002.
- Iamtrakul, P., & Chayphong, S. (2021). The perception of Pathumthani residents toward its environmental quality, suburban area of Thailand. *Geographica Pannonica*, 25(2), 136-148. DOI: 10.5937/gp25-30436
- Iamtrakul, P., & Hokao, K. (2012). The study of urbanization patterns and their impacts on road safety. *Lowland Technology International*, 14(2), 60-69.
- Iamtrakul, P., Chayphong, S., & Lo, A. Y. W. (2022). Exploring the Contribution of Social and Economic Status Factors (SES) to the Development of Learning Cities (LC). *Sustainability*, 14(19), 12685.
- Iamtrakul, P., Chayphong, S., Makó, E., & Phetoudom, S. (2023). Analysis of Road Users' Risk Behaviors in Different Travel Modes: The Bangkok Metropolitan Region, Thailand. *Infrastructures*, 8(4), 79. DOI: 10.3390/infrastructures8040079
- Iamtrakul, P., Chayphong, S., Kantavat, P., Hayashi, Y., Kijisirikul, B., & Iwahori, Y. (2023). Exploring the Spatial Effects of Built Environment on Quality of Life Related Transportation by Integrating GIS and Deep Learning Approaches. *Sustainability*, 15(3), 2785. DOI: 10.3390/su15032785
- Kanbur, R., & Zhuang, J. (2013). Urbanization and Inequality in Asia. *Asian Development Review*, Vol. 30 (1), pp. 131-147.
- Li, S., & Zhao, P. (2017). Exploring car ownership and car use in neighborhoods near metro stations in Beijing: Does the neighborhood built environment matter?. *Transportation research part D: transport and environment*, 56, 1-17.
- Litman, T. (2002). *The Costs of Automobile Dependence and the Benefits of Balanced Transportation*. Canada: Victoria Transport Policy Institute.
- Liu, M., Liu, X., Huang, Y., Ma, Z., & Bi, J. (2017). Epidemic transition of environmental health risk during China's urbanization. *Science bulletin*, 62(2), 92-98.
- OECD Environmental Performance Reviews: Lithuania 2021 <https://www.oecd-ilibrary.org/sites/0921490f-en/>

- [index.html?itemId=/content/component/0921490fen](#) (28.09.2022)
- Official statistics registration systems <https://stat.boradopa.go.th/stat/statnew/statMenu/newStat/home.php> (2.10.2022)
- Poumanyvong, P., Kaneko, S., & Dhakal, S. (2012). Impacts of urbanization on national transport and road energy use: Evidence from low, middle and high income countries. *Energy policy*, 46, 268-277.
- Rodrigue, J.-P. (2020). *The Geography of Transport Systems*. Fifty edition, New York: Routledge.
- Rodrigue, J.-P., Comtois, C., & Slack, B. (2006). *The Geography of Transport Systems*. New York: Routledge.
- Statista Research Department, Share of urban population worldwide in 2022, by continent <https://www.statista.com/statistics/270860/urbanization-by-continent/> (1.10.2022)
- Thairoads, Thailand road safety observatory <http://trso.thairoads.org/> (2.10.2022)
- Wang, P., Luo, M., Liao, W., Xu, Y., Wu, S., Tong, X., Tian, H., Xu, F., & Han, Y. (2021). Urbanization contribution to human perceived temperature changes in major urban agglomerations of China. *Urban Climate*, 38, 100910.
- Wu, X., Wang, L., Yao, R., Luo, M., Wang, S., & Wang, L. (2020). Quantitatively evaluating the effect of urbanization on heat waves in China. *Science of the Total Environment*, 731, 138857.