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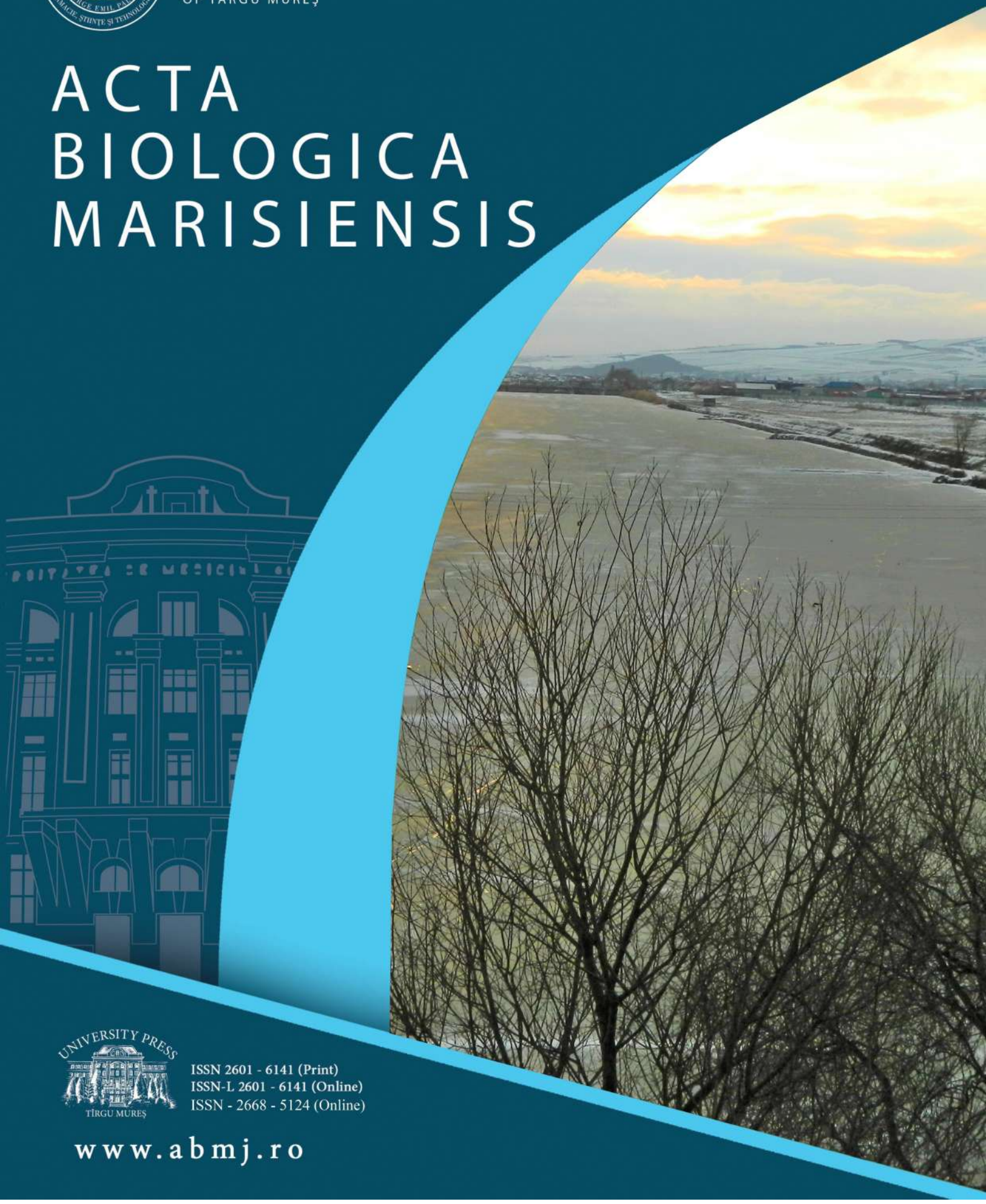

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CONTENTS

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AN OVERVIEW OF URBAN PARK DEVELOPMENT IN ZHENGZHOU, CHINA

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Abstract: As essential elements of green spaces and social spaces in cities, urban parks significantly improve the quality of life and promote urban sustainability. Research on the development process of urban parks can be meaningful for coping with the current issues and future opportunities facing cities. This study takes Zhengzhou as the case aiming to outline the development process and characteristics of urban parks within the city. We adopted the empirical analysis to review the evolution processes and trends of Zhengzhou's urban parks from the perspective of implementation approaches, spatial layout, and functions and uses. Results reveal four subsequent phases: the emergence phase (1949-1977), the growth phase (1978-1996), the acceleration phase (1997-2012), and the promotion phase (after 2012), according to the periods of urban development and the opportunities for green space development. The discussion includes development issues and strategies regarding land use approaches, user group needs, and public participation. The findings may help formulate adaptive and effective policies and planning tools for urban parks and provide a basis for further research on urban parks and Zhengzhou's road to the ideal "Park City".

Keywords: development phases, evolution trends, implementation approaches, spatial layout, functions and uses.

1. Introduction

Urban parks are green spaces for the public to recreate, relax and communicate (Chiesura, 2004; Smith et al., 2013). It has been shown that urban parks can help improve the quality of life in cities, enhancing human well-being (Chiesura, 2004; Sherer, 2003), facilitating social cohesion (Kaźmierczak, 2013; Völker et al., 2007), contributing to the general education of the citizens (Fekete et al., 2020), and providing ecosystem services within cities (Forsyth and Musacchio, 2005; Haase et al., 2014). Thus, urban parks can promote the sustainable development of urban society and environment (Harnik, 2012; Maas et al., 2006). The term 'public park' implies the park that is fully and freely open to the public (Conway, 1996), which refers to a crucial type of urban parks. Since Birkenhead Park, the first real public park, was established in the UK in 1843 (Crompton, 2007), urban parks have gradually developed into an integral part of the urban landscape with the development of cities.

In the broader context of global urbanization, more and more cities today are

increasingly exposed to a series of environmental and social issues. With urban sustainable development gaining increased recognition, ecology, unique urban character and preserved historic value have growing importance regarding the European settlements. Characteristic streetscapes and appearance make cities more attractive for both visitors and investors, strengthening also their economic position. An urban environment with increasing green infrastructure is a source of inspiration for the citizens, strengthening recreation, health and local identity.

Regarding China's rapid urbanization process, in order to optimize the urban human living environment, a series of urban development models have been explored and promoted by the country according to different urban development stages and goals. Among them, "Landscape Garden City", "Ecological Garden City", and "Park City" are progressive urban development models with various standard levels, which put an emphasis on urban greening, especially with urban park construction as an essential instrument. "Landscape Garden City" is guided by the aesthetics of urban landscape and focuses on green space construction (Chen et al., 2013). The primary indicators for evaluation include public green area per capita, green area ratio, and green coverage ratio. "Ecological Garden City" aims to build a livable city with a good ecological environment (Cheng and Cheng, 2018; Zhang et al., 2017). It has a relatively comprehensive evaluation system, in which the park-related indicators mainly include the park area per capita, the coverage ratio of park catchment area, and the minimum park area per capita in each urban district. Currently, "Park City" is a proposed vision, emphasizing people-centered city and ecological civilization within cities (Wu et al., 2018; Li and Zhang, 2018; Wang, 2018; Zhu and Gao, 2018). The evaluation indicators have not yet been determined, but a higher standard is undoubtedly expected. Like many other cities, Zhengzhou was successively guided by the concepts of "Landscape Garden City", "Ecological Garden City", and "Park City" in the development process, which has greatly fostered the planning and construction of urban parks (**Table 1**).

Table 1. Comparison of "Landscape Garden City", "Ecological Garden City" and "Park City"

Urban development model	Year proposed	Core purpose & Focus of Construction	Park-related metrics	Year Zhengzhou reached
Landscape Garden City	1992	• Aesthetics of urban landscape • Green space construction	Public green area per capita	2006
Ecological Garden City	2007	• A livable city with a good ecological environment • Urban ecological environment; urban living environment; urban infrastructure	Park area per capita; coverage ratio of park catchment area; minimum park area per capita	2020
Park City	2018	• A harmonious coexistence between man and nature • People-centered city; ecological civilization; integration of urban park system and urban spatial pattern	Undetermined	-

Despite considerable studies about urban parks from multiple perspectives, there is little empirical evidence on the analysis and evaluation of urban park development itself from a historical and local point of view, which should be the basis for a better urban park system. Therefore, research on the development process of urban parks can be of significance for dealing with the current problems and future opportunities of cities. This study takes Zhengzhou as the empirical case aiming to outline the development process and characteristics of urban parks within the city. The research questions are threefold: 1) What phases have urban parks in Zhengzhou gone through? 2) What are the evolution trends? 3) What development strategies can be formulated? We started by examining four progressive phases designated according to the city's development stages and green space development opportunities. Then we reviewed the evolution trends from the perspective of implementation approaches, spatial layout, and functions and uses. The last part discussed the development issues and strategies regarding land use approaches, user group needs, and public participation. The overview of urban park development in Zhengzhou may help formulate adaptive and effective policies and planning tools for urban parks and provide a basis for further research on urban parks and Zhengzhou's road to the ideal "Park City".

2. Study Area and Methods

2.1. Study area

Zhengzhou is one of the eight ancient capitals of China and became the capital city of Henan Province in 1954. Located on the North China Plain and the south bank of the Yellow River, the city has made full use of its critical central location to develop into a significant integrated transportation hub in central China.

Zhengzhou has a multi-layered natural and built heritage originating from various historical periods, strongly related to the unique topography of the city. Historic parks and open spaces are also scenes of the life of the city today. Development-oriented heritage conservation and green infrastructure development therefore makes an integral part of the renovation projects.

The paper takes the central urban area of Zhengzhou region as the study area (**Fig. 1**). It covers approximately 1010.3 km^2 and 5.22 million inhabitants according to the 2019 census (Bureau ZS, 2019), with several rivers passing through (e.g., Jinshui River, Dongfeng Canal, and Xiong'er River). There are five districts in the central urban area: Zhongyuan, Erqi, Guancheng, Jinshui, and Huiji, with the new east urban zone involved in.

The history of Zhengzhou dates back to about 3,600 years ago when it was the capital of the Shang Dynasty. The 7-kilometer-long rammed-earth Shang Dynasty city wall still exists in the city center. A series of historical parks have been developed around it. However, in the later troubled history of Zhengzhou, due to factors such as wars and floods, very few historical features were preserved in the urban area. After the start of the 20th century, it is worth mentioning that several major green spaces were developed by the local government. Pingmin Garden, with an area of 8 acres, was first constructed for residents to visit, but it was eventually abandoned. Then Bishagang Cemetery was established in 1928 to commemorate the martyrs, later converted into the urban park with the longest history in Zhengzhou. And there was a green space centered around Penggong Temple, where the first real urban park was established later. Besides, Longhai Garden covering an area of 75 acres, was built in a nursery in 1934 for citizens to relax and enjoy, which was later changed. By the time of liberation in 1948,

Zhengzhou was a dilapidated small county after the war with only a few green spaces, including Longhai Garden, Bishagang Cemetery, the green space of Penggong Temple, and several private gardens. And there were few street trees in the urban area. Furthermore, due to the accumulation of sand caused by floods, Zhengzhou suffered from frequent sand storms and was known as the "Sandy City" (Committee ZLHC, 1997). After the founding of New China in 1949, Zhengzhou entered a development era and started urban construction. Notably, to improve the urban environment and change the city's image, a large number of trees were planted continuously in the urban area at the call of the municipal government. By 1985, the green coverage rate had reached 35.25%, which earned Zhengzhou a reputation as a "Green City" (**Fig. 2**).

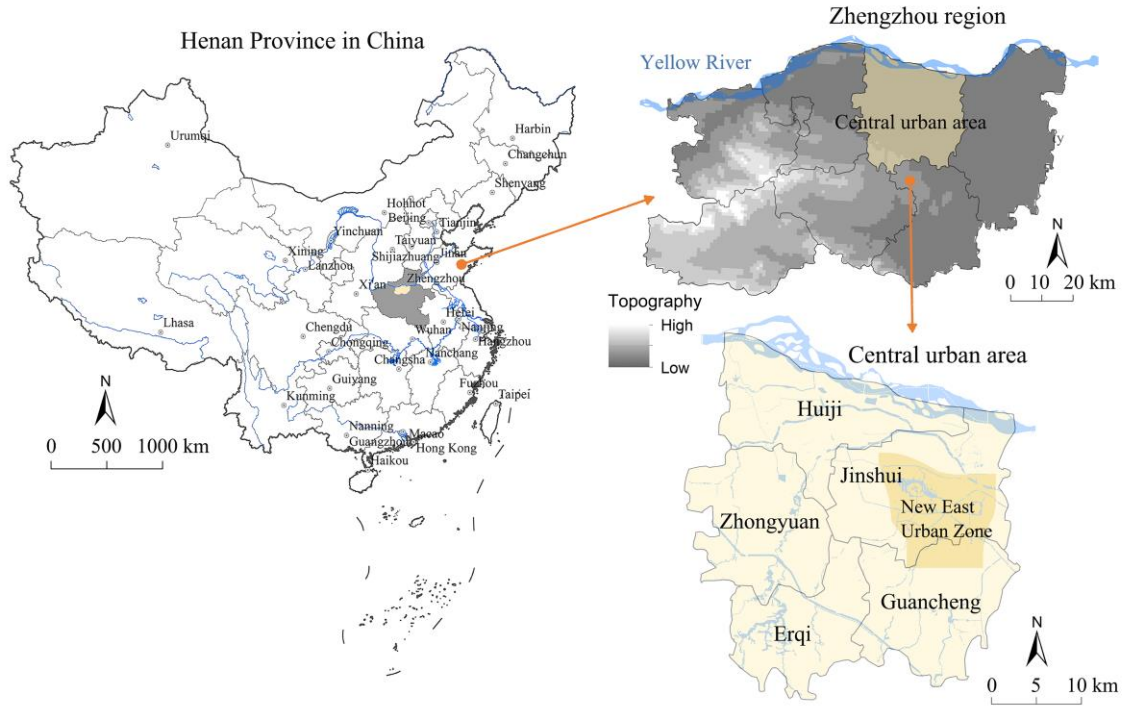

Fig. 1. Geography, topography and administrative units of Zhengzhou, Henan Province (Source: Prepared by the Author)

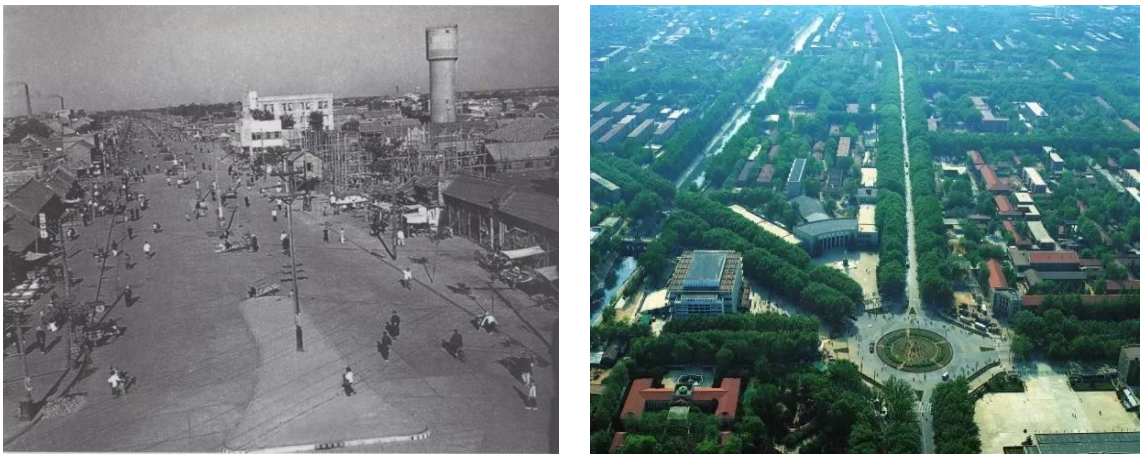

Fig. 2. Comparison of "Sandy City" image from the 1950s and "Green City" image from the 1980s (Source: mt.sohu.com; sh.dahe.cn)

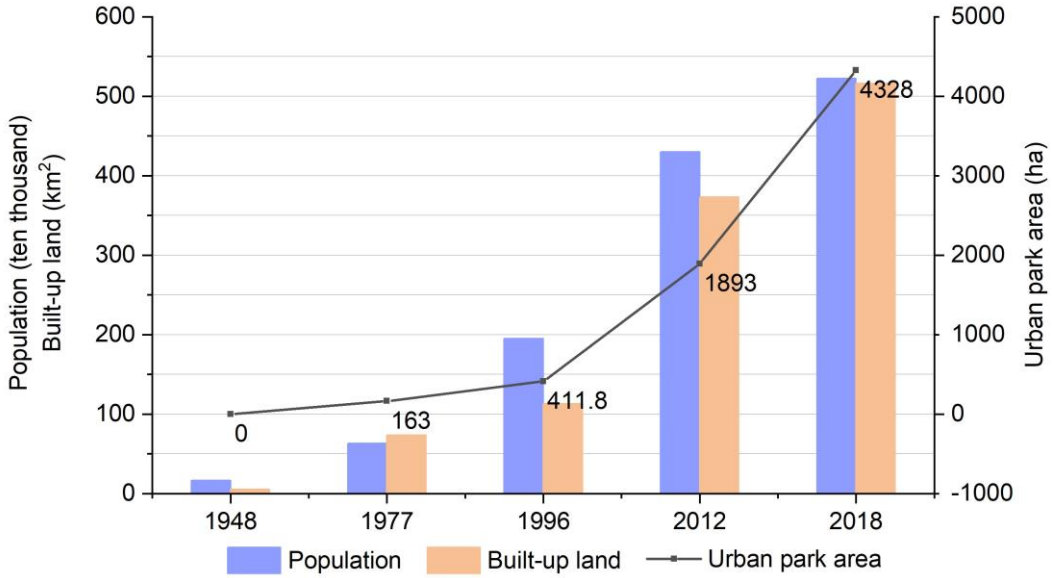

Fig. 3. Changes over the years in population, built-up land, and urban park area in the central urban area (Source: Municipal Bureau of Statistics and Zhengzhou Statistical Yearbook)

Over the past decades, Zhengzhou has undergone rapid urbanization with tremendous changes in population and built-up land in the central urban area. This has brought great development to urban green spaces, especially urban parks. According to statistics, the area of urban parks has grown substantially and rapidly (**Fig. 3**). The time frame of this study is from 1949 to the present.

2.2. Methods

This study was conducted using qualitative and inductive methods. We first applied empirical analysis based on text and illustrations to outline the development of Zhengzhou's urban parks from the perspective of implementation approaches, spatial layout, and functions and uses. It was followed by an evaluation of the main evolution trends. After that, a theoretical analysis on existing issues was conducted to discuss the development strategies for urban parks in Zhengzhou, referring to related research results.

3. Results and discussion

Zhengzhou's urban park development phases

1) The emergence phase (1949-1977)

- Zhengzhou was transformed into the capital city of Henan Province in 1954, which brought unprecedented opportunities for urban development.
- After the founding of New China in 1949, the country began to attach importance to people's leisure and recreation activities. Therefore, the construction of urban parks received support from the municipal government.

For Zhengzhou, the urban park was just an unfamiliar concept until 1952 when People's Park was established near the first planned city center with historical temples preserved. Subsequently, in 1957, Bishagang Park was converted from the original martyr's cemetery to be a landmark of another newly established city center. Then in 1964 Zijingshan Park emerged based on an ancient urban district from the Shang Dynasty (**Fig. 4**).

Fig. 4. Zijingshan Park (Source: blog.sina.com.cn)

Fig. 5. The first three parks in the urban pattern of the 1960s (Source: Prepared by the author)

The implementation of the original urban parks mainly relied on municipal government investment, including the transformation of special green spaces and historic open spaces. The three urban parks were all built as municipal-level parks to attract citizens from the whole city. That is why they were located at the critical nodes of the urban layout (**Fig. 5**). They were all multifunctional parks, combining culture with leisure and social activities. Moreover, under the guidance of policies, urban parks usually also played a role in agricultural production.

Urban parks of Zhengzhou can be traced back to the first three park initiatives. All of them have played a vital role in urban life and enjoyed a high reputation among citizens.

2) The growth phase (1978-1996)

- Driven by economic reform and opening-up policies proposed in 1978, the national economy progressively underwent a historic transformation from a centrally planned to a market economy, which significantly promoted urbanization.
- With a fundamental change in land development, land prices became a key factor in determining the urban spatial layout (Xu, 2007).

Since urban parks do not have an obvious role in generating economic benefits, it is difficult to reserve land for them through a purely market competition mechanism (Wolch et al., 2014). The "Management Regulations for the Construction of Urban Green Spaces in Zhengzhou" was promulgated by the municipal government to ensure development opportunities for green spaces, including guaranteeing required land and funds, supervising illegal occupation, etc. The area of urban parks increased by nearly 250 ha from 1977 to 1996. A few new urban parks were provided at essential locations, such as Shang City Park along ancient city wall and Xintongqiao Park beside the main road overpass.

Fig. 6. The belt-shaped park along Jinshui River (Source: Henan Business Daily)

Fig. 7. Amusement facilities in Bishagang Park in the 80s (Source: forums.nphoto.net)

Moreover, running through the central urban area, Jinshui River was an important but long-term polluted river. As part of an improvement project, the first belt-shaped riverside park was planned and developed here to enhance the urban environment and create leisure space for citizens (**Fig. 6**). On the whole, some critical scattered spots and linear areas were given priority to develop into urban parks.

In order to create leisure landscapes, plant design in urban parks was in focus. And, for exploiting economic benefits, urban parks increasingly accommodated diverse commercial facilities for amusement (**Fig. 7**). It can be said that leisure and amusement played a major role in urban parks.

3) The acceleration phase (1997-2012)

- The municipal government made a major strategic decision in 2000 to build a "Regional Central City", which greatly accelerated the urbanization of Zhengzhou.
- As the construction of green spaces lagged behind the urbanization process for a long time (Zhao et al., 2003), Zhengzhou finally lost its reputation as a "Green City". This largely urged the municipal government to initiate a greening campaign in 1997 and then set the goal of creating a "Landscape Garden City" to improve the city's appearance.

Urban parks were increased through innovative development approaches led by the municipal government, including changing other types of green land into and renting land owned by farmers for urban parks. Subsequently, as part of a comprehensive renewal of the old city, multiple tools, such as regeneration of run-down areas, replacement of industrial land, and conversion of illegal construction land, were applied to develop urban parks. Furthermore, through the overall urban planning, a large area of parks at multiple levels was developed in the new east urban zone to create an ecological and livable environment (**Fig. 9**). In addition, "Management Measures for Zhengzhou Urban Green Space Boundary" was published by the municipal government to ensure designated existing and future urban green spaces. From 1996 to 2012, the area of urban parks grew rapidly, up to about 4.5 times.

The local authority approved the "Green Space System Plan for Zhengzhou City (2003-2010)" (**Fig. 8**) and the "Green Space Plan for Local Recreation in Zhengzhou Old City". As a result, a large number of residential-level parks were constructed with the consideration of spatial balance.

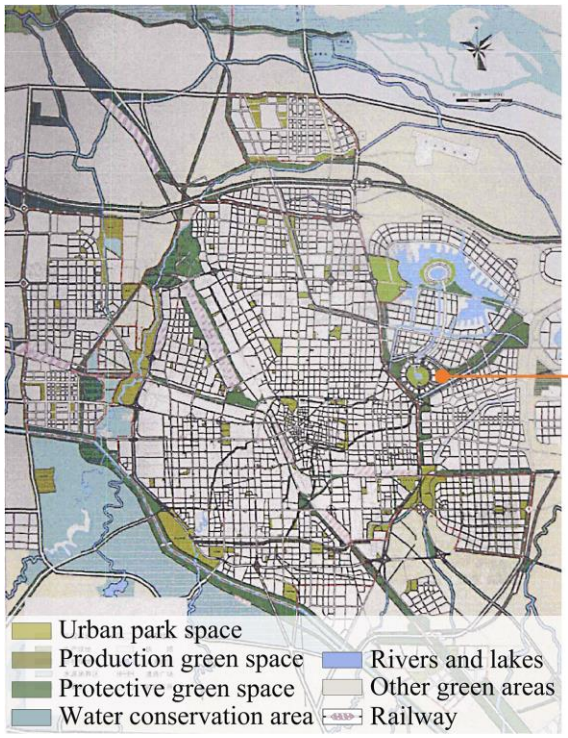

Fig. 8. Green Space System Plan for Zhengzhou City (2003-2010) (Source: news.zynews.cn)

Fig. 9. The parks in the new east urban zone (Source: news.zynews.cn)

The belt-shaped parks along Xiong'er River, Dongfeng Canal, and Jinshui River were built and open to the public, creating more convenient leisure opportunities. It was the first time that urban green spaces were defined as a system, and catchment areas of the parks were considered.

Under the call of the greening campaign, remarkably, most urban parks gradually changed into free-access public parks and gained more visibility from the outside by demolishing park fences. Various functional zones were added to the large parks, such as fitness areas for seniors and children's playgrounds. Due to the broad introduction of flowering plants, flower viewing in urban parks became popular. And urban parks had gradually played a role in attracting visitors during major festivals and events. In general, the uses of urban parks were significantly improved, and the parks' recreational functions were enhanced.

4) The promotion phase (after 2012)

- Zhengzhou was designated as "National Central City" in 2016 and is at the highest level in the national urban system planning with eight other cities, including Beijing, Tianjin, and Shanghai, which required a higher standard for urban development of Zhengzhou.
- After realizing the "Landscape Garden City", Zhengzhou took the "Ecological Garden City" as its new development goal and then "Park City" in order to improve the urban living environment.

To strengthen the construction and management of urban greening, the new version of regulations on urban green spaces in Zhengzhou took effect in 2012. In response to the rapid expansion of urban built-up areas, it emphasized reserving essential land for urban parks in the newly planned urban zones. In addition, the updated regulation clarified that

the municipal government was responsible for allocating land for the parks. In order to optimize the distribution of urban parks, along with the continuous comprehensive regeneration of the old city and run-down areas, appropriate plots freed up were encouraged to be used for developing urban parks. Compared with 2012, the area of urban parks more than doubled in 2018.

The local authority accepted the "Green Space System Plan for Zhengzhou City (2013-2030)". And the goal of developing an urban park system was put forward. Moreover, the planning and construction of green and ecological corridors along significant circular and radial roads were widely implemented, which has enhanced the link between green spaces. Furthermore, the "Three-Year Development Plan for Providing Public Green Spaces within 300m and Parks within 500m Ranges" was issued by the local authority in 2018, aiming to achieve full coverage of park catchment areas (**Fig. 10**). Thus, many parks at the municipal, district and residential levels were planned and constructed step by step to mitigate the uneven distribution. On the whole, the connectivity and spatial balance of urban parks were much emphasized and improved.

In order to enrich the experience of park users, multiple types of parks were developed, including wetland parks and theme parks. Besides, through ecological approaches, such as urban rainwater collection and ecological revetment design, urban parks have been expected to provide ecosystem services. Furthermore, historical and cultural characteristics are valued, aiming to use urban parks to display and transfer urban culture. It can be said that urban parks are not only increasingly improved to meet diverse leisure and recreation demands but also play an essential role in promoting urban ecology and culture.

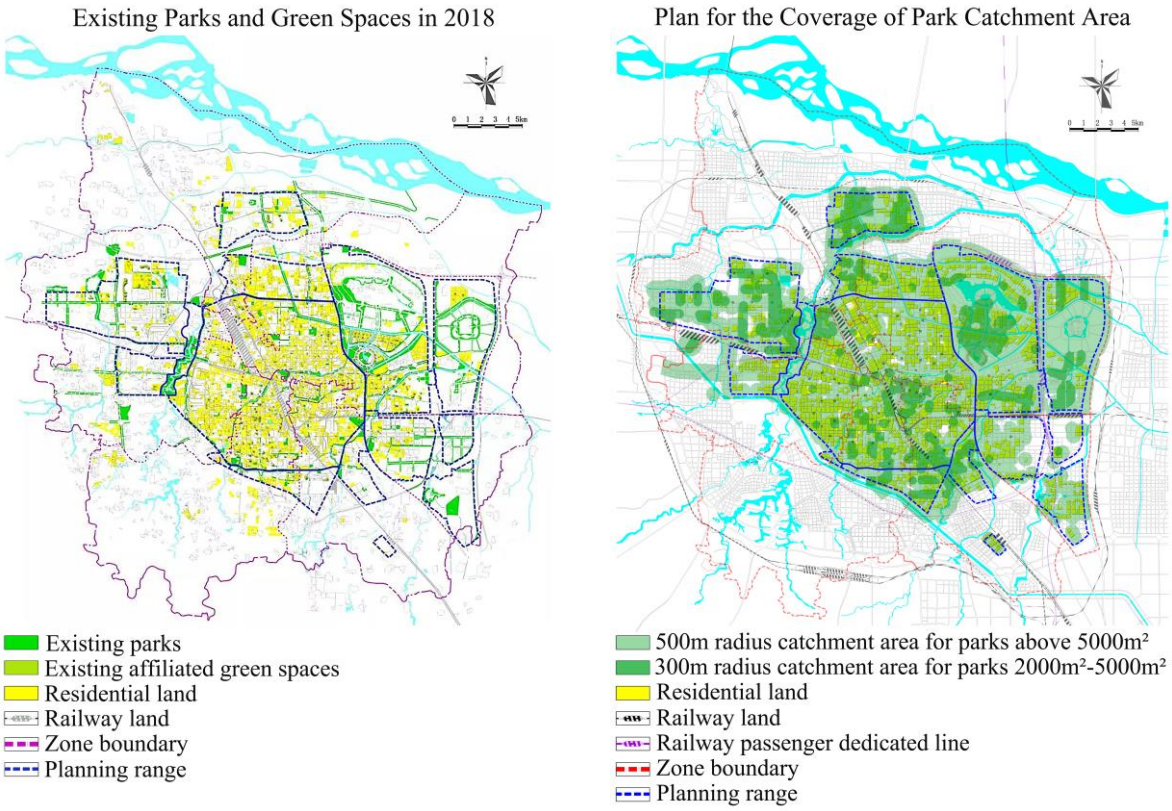

Fig. 10. Plan for the Coverage of Park Catchment Area (Source: www.sohu.com)

Zhengzhou's urban park evolution trends

1) Multiple implementation approaches

To cope with the weak position of urban park development regarding land availability under the market mechanism, a method combining centralized allocation and legislative control is formed. With the acceleration of urbanization, urban park development has been gradually integrated into the urban regeneration process, relying on land-use change. Besides, other available fragmented land is also encouraged to be flexibly converted to parkland. For newly expanding urban zones, urban parks are highly considered from the initial planning.

2) Systematic and balanced spatial layout

Urban parks have been gradually considered as a whole system with a distinct hierarchy. The connectivity of urban parks is strengthened through belt-shaped parks along rivers and roads, which significantly improves accessibility. The spatial distribution of urban parks has undergone a transition from relatively random to balanced. Moreover, the indicators for urban park allocation have evolved from controlling baseline (e.g., park area per capita) to assessing accessibility (e.g., park catchment area).

3) Humanized functions and uses

With the development of the city, special functions (e.g., agricultural production) caused by historical reasons are gradually abandoned. Leisure and recreation have become the main functions of urban parks to meet the needs of citizens. Meanwhile, as urban parks tend to be diversified, urban parks have taken cultural promotion and ecological improvement roles. Moreover, from closed to open, from payment to free, the service scope of urban parks has been dramatically expanded.

Discussion of development strategies

1) Innovating land use approaches

As Zhengzhou continues to undergo accelerated urbanization, the availability of land resources in the central urban area tends to decrease. Hence, the solution of simply planning more new land for urban parks will no longer be appropriate for the crowded urban environment. At the same time, the long-term relatively rapid and extensive urban expansion has resulted in unreasonable urban land use patterns. Thus, in order to change the insufficient and unbalanced supply of urban parks, comprehensive and efficient utilization of underutilized land and neglected space can be a promising approach (Ren, 2003; Wang et al., 2019). For example, Singapore reserves land for green space by rezoning and integrating low-efficiency land. In addition, for certain types of open spaces (e.g., schoolyards, rooftops, parking, roads, and markets), the application of double-use parks and temporary parks can be realistic solutions to increase park space (Harnik, 2012).

2) Responding to user group needs in a social context

With the development of modern cities, the connotation of public service equity has evolved from spatial equality to social equity (Jiang et al., 2011). Specifically, the concept and measurement standards of urban park equity have shown a more refined trend with the evolution of city level, social demand, and public awareness (He et al., 2019). It can be said that urban parks are expected to have higher adaptability, changing from place-based to people-based measures and from large-unit to small-unit measures. However, the allocation of urban parks in Zhengzhou has been limited to promoting spatial balance, and it is insufficient to deal with diverse user needs and uneven social context. Considering the development phase of urban parks, it is necessary to pay attention to diversified needs

of user groups within the complex social context in order to balance the supply and demand of urban parks.

3) Improving public participation mechanism

Various findings have proven that public participation is an integral part of sustainable urban park planning and management (Speller and Ravenscroft, 2006; Saruwono and Mohamed Anuar, 2018; Huang, 2010). On the one hand, public participation helps to understand park users' demands and integrate their ideas to improve the projects. On the other hand, involving local inhabitants in different stages of park development can significantly enhance their sense of responsibility for the active maintenance of urban parks (Yan, 2019). However, top-down planning and management have long been in operation for urban parks in Zhengzhou, which gives local citizens few opportunities to influence decision-making. Therefore, to achieve more effective development, the authorities should support and ensure public participation, including providing diversified channels for communication and ensuring the transparency of the decision-making process.

4. Conclusions

The sequential views, the place and its spirit, and the content altogether define urban parks, open spaces and streetscapes, as an integral part of urban design, is the art of relationship (Cullen, 1971). The duty is therefore to explore new, hidden relationships or strengthen existing ones, which provide both healthy recreation and leisure, and visual urban experience, unveiling the values and characteristics of the specific place to the spectator.

We selected Zhengzhou as the empirical case in urban China and reviewed its urban park development. The results show that the urban park development in Zhengzhou is a continuous and changing process. It has gone through four progressive phases: the emergence phase (1949-1977), the growth phase (1978-1996), the acceleration phase (1997-2012), and the promotion phase (after 2012). On the whole, we can see an evolution in Zhengzhou's urban parks in terms of diversification of implementation approaches, systematization and balance of spatial layout, and humanization of functions and uses. The future development strategies to tackle existing problems mainly lie in innovative land-use approaches, response to user group needs in a social context, and improvement of public participation mechanisms. The research findings may help formulate adaptive and effective policies and planning tools for urban parks and provide a basis for further research on urban parks and Zhengzhou's road to the ideal "Park City".

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Bureau ZS. (2019) Communiqué on Main Data of Zhengzhou's Permanent Resident Population in 2019 [Online]. http://tjj.zhengzhou.gov.cn/tjgb/4430813.jhtml [Accessed 17 May 2021].
2. Chen D, Gong B, She X (2013) Issues Related to the Designing and Construction of Garden City—A Case Study of

Hangzhou. Journal of Northwest Forestry University 28: 221-226.
3. Cheng S, Cheng Y (2018) Form Garden City to Park City Design — The Dialectic Relationship between Urban Ecology and Morphology. Chinese Landscape Architecture 34: 41-45.
4. Chiesura A (2004) The role of urban parks for the sustainable city. Landscape and urban planning 68: 129-138.
5. Committee ZLHC (1997) Zhengzhou Annals (3). Zhongzhou Ancient Books Publishing House, Zhengzhou, pp. 3-8, 11-21.
6. Conway H (1996) Public parks. Shire Publications Princes Risborough, pp. 4.
7. Crompton JL (2007) The role of the proximate principle in the emergence of urban parks in the United Kingdom and in the United States. Leisure Studies 26: 213-234.
8. Cullen, G. (1971) The Concise Townscape, The Architectural Press, London.
9. Fekete A, Gecséné Tar I, Sárospataki M, Győri P (2020) Educational role of public parks. Windows to past, to future and to exotic worlds. 4D Journal of landscape Architecture and Garden Art 55-56: 38-53.
10. Forsyth A, Musacchio L (2005) Designing small parks: a manual for addressing social and ecological concerns. John Wiley & Sons.
11. Haase D, Frantzeskaki N, Elmqvist T (2014) Ecosystem services in urban landscapes: practical applications and governance implications. Ambio 43: 407-412.
12. Harnik P (2012) Urban green: Innovative parks for resurgent cities. Island Press.
13. He P, Chen W, Cheng Q, Zhao L (2019) Research Progress of Chinese and International Spatial Justice in Urban Green Space. Chinese Landscape Architecture 35: 28-33.
14. Huang S-CL (2010) The Impact of Public Participation on the Effectiveness of, and Users' Attachment to, Urban Neighbourhood Parks. Landscape Research 35: 551-562.
15. Jiang H, Zhou C, Gao J (2011) Advance in The Equity of Spatial Distribution of Urban Public Service In Western Countries. City Planning Review 35: 72-77.
16. Kaźmierczak A (2013) The contribution of local parks to neighbourhood social ties. Landscape and urban planning 109: 31-44.
17. Li X, Zhang Y (2018) A New Approach in Urban Green Development for the New Era - Strategies for Building Park Cities. Chinese Landscape Architecture 34: 38-43.
18. Maas J, Verheij RA, Groenewegen PP, De Vries S, Spreeuwenberg P (2006) Green space, urbanity, and health: how strong is the relation? Journal of Epidemiology & Community Health 60: 587-592.
19. Ren J (2003) Development Strategies of Urban Parks and Open Space in America and its Reference for China. Chinese Landscape Architecture 11: 47-50.
20. Saruwono M, Mohamed Anuar MIN (2018) Obstacles of Public Participation in the Design Process of Public Parks. Journal of ASIAN Behavioural Studies 3.
21. Sherer PM (2003) The benefits of parks: Why America needs more city parks and open space. CA: Trust for Public Land, San Francisco.
22. Smith LM, Case JL, Smith HM, Harwell LC, Summers J (2013) Relating ecosystem services to domains of human well-being: Foundation for a US index. Ecological Indicators 28: 79-90.
23. Speller G, Ravenscroft N (2006) Facilitating and evaluating public participation in urban parks management. Local Environment 10: 41-56.
24. Völker B, Flap H, Lindenberg S (2007) When are neighbourhoods communities?

Community in Dutch neighbourhoods. European sociological review 23: 99-114.
25. Wang G, Li H, Yang Y, Jombach S, Tian G. " City in the park," Greenway Network Concept of High-Density Cities: Adaptation of Singapore Park Connector Network in Chinese Cities. Proceedings of the Fábos Conference on Landscape and Greenway Planning, 2019. 13.
26. Wang H (2018) "Natural Landscape Locates Cities in Parks, Artificial Landscape Builds Parks in Cities" - Discussion on the Planning and Construction of Park City. Chinese Landscape Architecture 34: 16-21.
27. Wolch JR, Byrne J, Newell JP (2014) Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. Landscape and urban planning 125: 234-244.
28. Wu Y, Wang Z, Shu C, Liu D, Hao Y (2018) Discussion on the Concept & Practice Approach of "Park City". Chinese Landscape Architecture 34: 30-33.
29. Xu J (2007) Evolvement and Characteristic of Urban Spatial Structure in Zhengzhou. Huazhong Architecture 25: 131-133.
30. Yan M (2019) Taking Zhengzhou as an example to discuss the development of future urban parks. Modern Horticulture: 146-150.
31. Zhang Y, Guan H, Li X (2017) Response of Urban Green Space System Planning from Garden City to Ecological Garden City. Chinese Landscape Architecture 33: 71-77.
32. Zhao T, Liu J, Yuan G (2003) Analysis on the Status Quo of Urban Greening in Zhengzhou. Journal of Henan Forestry Science and Technology 23: 42-43.
33. Zhu Z, Gao M (2018) The Scene-making Pattern of Old Town Community in the City Park Context: A Case Study of Chengdu Old Town. Shanghai Urban Planning Review: 43-49.

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EVALUATING THE PERFORMANCE OF PALMER DROUGHT SEVERITY INDEX (PDSI) IN VARIOUS VEGETATION REGIONS OF THE ETHIOPIAN HIGHLANDS

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Abstract: This paper focuses on the environment of Ethiopia, a country highly sensitive to droughts severely affecting vegetation. Vegetation monitoring of Ethiopian Highlands requires visualization of environmental parameters to assess droughts negatively influencing agricultural sustainable management of crops. Therefore, this study presented mapping of several climate and environmental variables including Palmer Drought Severity Index (PDSI). The data were visualized and interpreted alongside the topographic data to evaluate the environmental conditions for vegetation. The datasets included WorldClim and GEBCO and Digital Chart of the World (DCW). Research has threefold objectives: i) environmental mapping; ii) technical cartographic scripting; iii) data processing. Following variables were visualized on seven new maps: 1) topography; 2) soil moisture; 3) T °C minimum; 4) T °C maximum; 5) Wind speed; 6) Precipitation; 7) Palmer Drought Severity Index (PDSI). New high-resolution thematic environmental maps are presented and the utility of GMT for mapping multi-source datasets is described. With varying degrees of soil moisture (mean value of 15.0), min T°C (-1.8°C to 24°C), max T°C (14.4°C to 40.2°C) and wind speed (0.1 to 6.1 m/s), the maps demonstrate the variability of the PDSI fields over the country area (from -11.7 to 2.3) induced by the complex sum of these variables and intensified by the topographic effects notable over the Ethiopian Highlands which can be used for vegetation analysis. The paper presents seven new maps and contributes to the environmental studies of Ethiopia.

Keywords: cartography; vegetation; drought; PDSI; precipitation; soil moisture; temperature.

1. Introduction

Drought, severely affecting vegetation, is caused by the shortage in water supply. It has twofold factors: atmospheric origin (precipitation), and soil moisture (surface water). There are many controlling factors which determine the distribution of drought, including atmospheric (precipitation, temperature, intensity and direction of winds), geological (soil moisture, permeability of subsoils), and hydrological (dense of river network and intensity of streams). Visualizing spatial patterns of droughts is crucial for the environmental monitoring of the region with such contrasting climate setting as Ethiopia. Although the duration drought may vary from several days to months or years, its environmental, agricultural and social consequences may have a substantial impact on both nature ecosystems and human existence through the affected agricultural regional

economy. Ethiopia is a country with sensitive climate environmental setting, contrasting topography, unique geologic parameters (location of the Afar Triple Junction and distribution of the part of the East African Rift System and Great Rift Valley), **Fig. 1**. The complicated combination of the climatic and topographic factors results in notable drought disasters, recorded in the Somali, the Afar Depression (geological region of the Afar Triple Junction), deserts and lowland regions as the area most affected by droughts. With a focus on visualizing the drivers of drought in Ethiopia, this paper presents a series of maps on current environmental-climate setting of Ethiopia with aim to demonstrate why drought is distributed in a certain correlation with topographic relief, a question which is of interest to the environmental monitoring in Ethiopia. Since humans are dependent upon climate setting, environmental conditions and ecosystems for agricultural production and services, regular updated climate monitoring is essential not only for the physical geographic but also for the social studies, which explains and justifies the actuality of the undertaken research.

Agricultural problems caused by drought include a variety of processes. The most significant agricultural consequences include crop failure (Edossa et al., 2010; Suryabhagavan, 2017), soil and pasture losses (Tora et al., 2021; Mihretie et al., 2021) in vulnerable regions of Ethiopia. The direct economic and social issues include famine and diseases (Gebre et al., 2021), physical and mental health strain and children's health (Bahru et al., 2019; Dimitrova, 2021).

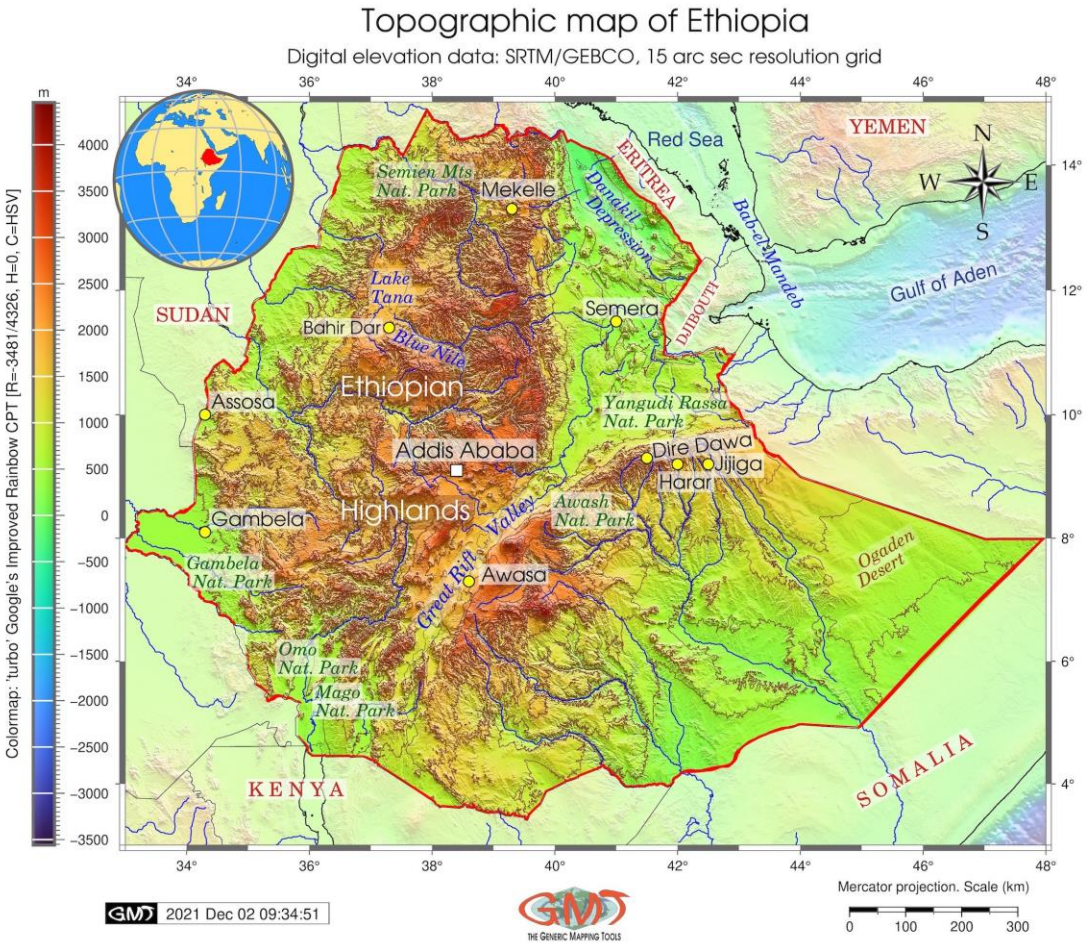

Fig. 1. Map of the study area. Mapping: GMT. Data: GEBCO, DCW. Source: author

Furthermore, drought leads to the increased costs of food for consumers in economic sector and decrease in cattle population (Aragie and Thurlow, 2022). The indirect yet important consequence of drought includes broken supply chains in industry and production: reduced supplies to food processors, demand for fertilizer and farm labor.

The environmental consequences of drought include direct affect on the vulnerable species, such as fruits, flowers, vegetables, tree nuts, and medicinal herbs that are more sensitive to droughts compared to the field crops (Di Falco et al., 2010). Biodiversity consequences include a high risk for losses in species diversity of rare species if the water demand exceeds water supply (Legesse and Negash, 2021). The depletion of water in soils causes significant declines in vegetation productivity and growth of roots (Demelash et al., 2021) that finally affects biodiversity and ecosystems. This is caused by the deficit of water in surface and groundwater that declines during drought period, affecting water availability necessary for normal functionality of plants.

The aim of the present study is to plot a series of maps showing visualized computed index of droughts (Palmer Drought Severity Index, PDSI), and several supporting meteorological, topographic, climate and environmental data of Ethiopia using high-resolution datasets by technical tools of Generic Mapping Tools (GMT) cartographic scripting toolset. Besides environmental assessment and visualization, this paper discusses a GMT-based approach to prepare a series of meteorological maps of Ethiopia using a scripting approach. The presented maps visualize the following environmental variables in Ethiopia in 2018: 1) topography; 2) soil moisture; 3) T °C minimum; 4) T °C maximum; 5) Wind speed; 6) Precipitation; 7) Palmer Drought Severity Index (PDSI). The presented paper serves the threefold research objectives:

i. Contributing to the environmental and climatic studies of Ethiopia through the visualized new seven thematic maps;

ii. Presenting new approaches of scripting tools for technical developing of the contemporary cartography;

iii. Utilizing multi-source datasets from the open repositories showing the application of the multi-source data in the environmental-climate research. The actuality of present study consists in the presented maps visualizing meteorological and climate parameters. Those are necessary for environmental monitoring of the country and assessment of climate change and its possible effects. Among other variables, this paper demonstrates the visualized map of the Palmer Drought Severity Index (PDSI), an index developed by Palmer in 1965 and widely used in various aspects of the environmental monitoring, e.g. as follows:

(a) to assess climate and environmental changes;

(b) to perform ecological monitoring;

(c) to complete climatic divisions for measurements of the hydrologic drought and to indicate severe or extreme drought using PDSI values (Alley, 1985).

The PDSI is the most widely used in climatology regional index of drought which enables to quantify intensity and period of droughts (start/end time) for the global long-term drought analysis (Alley, 1985). In computations of PDSI, we need to estimate the precipitation and temperature for the measurement of dryness (Dai et al., 2004).

Theoretically, the drought should be estimated based on the 'supply-and-demand' properties of soil moisture of the study area which includes such complex parameters as evapotranspiration reflecting the 'demand' of

soil, i.e. the need for water (Ficklin et al., 2015).

The PDSI presents an approximated and straightforward model of the drought calculation based only on precipitation and temperature. The PDSI is a standardized measure, ranging from about -10 (extreme drought) to +10 (extreme moisture) and 0 as neutral conditions, of surface moisture setting (Dai et al., 2004).

Practically, the comparative analysis of these values allows to perform spatial analysis of the variability of droughts over the study area. The approaches to asses and calculate drought in climate and environmental studies, are diverse (Tesfamariam et al., 2019). More sophisticated cases of the PDSI calculations include the prognosis of possible drought based on the existing data processed as time series analysis using numerical modelling and visualized graphs (Beyaztas et al., 2018).

Values, nature and spatial distribution of the environmental parameters can be analyzed using various techniques and approaches through data processing, analysis, modelling and visualization (Suetova et al., 2005; Schenke and Lemenkova, 2008; Klaučo et al., 2013; Jain et al., 2015; Lemenkov and Lemenkova, 2021a, 2021b; Lemenkova2019c). Climate data assessment methods use fieldwork records from the local meteorological stations where, for examples, the values of temperature and their statistical extremes, wind speed and direction, frequency and intensity of precipitations are recorded directly. The determined datasets are then stored as data massifs in Climate Centers and Research Units for further data processing (Asfaw et al., 2018). On the other hand, the datasets in tabular formats require detailed and effective mapping for interpretation of the environmental parameters.

Probably the most common approach of cartographic visualization is based on the ArcGIS (Gohl, 2006a, 2006b; Gauger et al., 2007; Lemenkova, 2011; Klaučo et al., 2017; Ghiglieri et al., 2020; Koroso et al., 2020; Kebede et al., 2021), which enables to perform various types of spatial data processing, modelling and visualization. Besides the commercial ArcGIS, the examples of the free open source GIS used for environmental mapping include ILWIS GIS, SAGA GIS and QGIS (Alemayehu et al., 2009; Lemenkova, 2020a, 2020c). While there have been cartographic attempts to present climate mapping of Ethiopia by the traditional GIS approaches, a scripting GMT-based approach enabling rapid data processing of Ethiopian ecosystems using machine learning methods has heretofore been lacking. Compared to the GIS applications, the GMT cartographic data processing obtained using scripting. Due to its console-based approach, the GMT is, to a certain extent, similar to the programming languages applied in geosciences (Lemenkova, 2019a, 2019b).

Retrieval of climate data from available repositories for data processing is very common. These may include government records on climate and meteorological data, field observations and questionnaire surveys (Adgo et al., 2013), census data, crop yield data from surveys (Eze et al., 2020), multi-temporal images (Gebrehiwot et al., 2011). Mapping meteorological variables provides a great importance to analysis of climate change, mitigation its environmental and social impacts and local adaptation (Mera, 2018; Matewos, 2020).

Environmental monitoring, in turn, is useful for evaluating global ecological and social conditions within Ethiopia, a country with extreme climate setting and sensitive ecosystems (Haile et al., 2020). Therefore, the application of the thematic GMT based mapping method for monitoring droughts in Ethiopia, a region with extreme temperatures, prone to

droughts, presents cartographic visualization of the high-resolution data provided as a series of

The actuality of this study consists in the added value on environmental data analysis through advanced visualization which may have direct benefits for policy makers and studies on environmental risk assessment using produced maps. Moreover, current research in sustainable agriculture and food systems in Ethiopia has a notable gap between the environmental applications in farming and technical methodologies of mapping and cartographic visualization. At the same time, these are necessary to process geospatial data for possibilities of agricultural activities in various regions of Ethiopia and crop vegetation mapping.

The presented research aims to minimize this gap by presenting a series of thematic maps of Ethiopia prepared using advanced methodologies of GMT for data processing in a semi-automated regime for high-resolution mapping. Environmental mapping of Ethiopia using GMT presented observations of climate variables including PDSI drought index to detect and visualize variability in of climate setting to assess their possible effects on agriculture of Ethiopia. Using scripting methods of GMT and TerraClimate data for environmental mapping is ensured by the large amounts of automation in GMT. The series of the environmental maps may support data analysis in sustainable farming of Ethiopia. Therefore, this research can bring new data to the environmental analysis and support agriculture and public sectors on relevant topics of environment and agriculture of Ethiopia.

2. Materials and methods

Datasets

Data-driven mapping includes visualization of the georeferenced datasets which may vary in reliability, resolution and base maps for developing further environmental analysis using cartographic techniques. source of origin. This necessarily rises a question of the data quality control and assessment. Publicly reknown open data reputable repositories, such as GEBCO, NOAA, USGS, GloVis (well-known sources for the Landsat/Sentinel imagery), or TerraClimate present the reliable source for the input data suitable for mapping. This study captures data from the GEBCO and TerraClimate sources. Specifically, the datasets used in this study utilize on the GEBCO (GEBCO Compilation Group, 2020) used for topographic mapping in **Fig. 1.** and TerraClimate (Abatzoglou et al., 2018) used for **Fig. 2–7**.

High-resolution (4 km) climate data from the TerraClimate WorldClim (Fick and Hijmans, 2017) CRUTS 4.0. sources have been used to visualize and map series of climatic parameters in Ethiopia on 2018: soil moisture; extreme temperatures (T °C min and T °C max), wind speed and precipitation and PDSI. Data processing included five types of actions:

i. data search, selection and capture;

ii. data modeling and numerical processing;

iii. data visualization, elimination and symbolization using cartographic design tools;

iv. data behavior analysis: estimating coherency and finding correlations in datasets (min/max temperatures, soil moisture, topographic elevations, wind speed, PDSI);

v. data interpretation and assessment: explaining trends in spatial distribution of categorical parameters and continuous fields.

Correct, up-to-date georeferenced data about environmental and climate parameters are essential for environmental monitoring of such disasters as droughts, for supporting real-time environmental hazards mapping and climate control, and for performing correlation analyses between geographic variables (for

instance, agricultural monitoring, crop mapping, assessment of wildlife habitat distribution). To aid in these efforts, TerraClimate published the set of climate data service to its online portal. The TerraClimate is a global repository of the climate variables, where each data in the NetCDF format contains an estimate of the climate measurements for various years. This study utilities the most recently available, that is 2018, as a case study.

The data from the TerraClimate repository present a useful resource as an input data source to terrestrial environmental mapping of Ethiopia. Clipped from the global original data for Ethiopia using the coordinates of the country borders, TerraClimate data produced a set of robust data layers on Ethiopia that has been adopted as the conceptual and input data for the thematic series in the presented research: temperatures (min/max), soil moisture, wind speed and PDSI. The series of six climate grid from the TerraClimate source and a topographic grid based on GEBCO were handled by the GMT for mapping selected meteorological parameters over the country for 2018 and visualizing the drought-prone areas in Ethiopia. The presented georeferenced data of the climate variables in Ethiopia are visualized, with aim to highlight and compare patterns of data distribution over Ethiopia (temperature extremes, soil moisture, topography, wind speed and PDSI). Thus comparison of the thematic data present new information about the role of topographic location in climate, meteorological and environmental processes driving drought disasters.

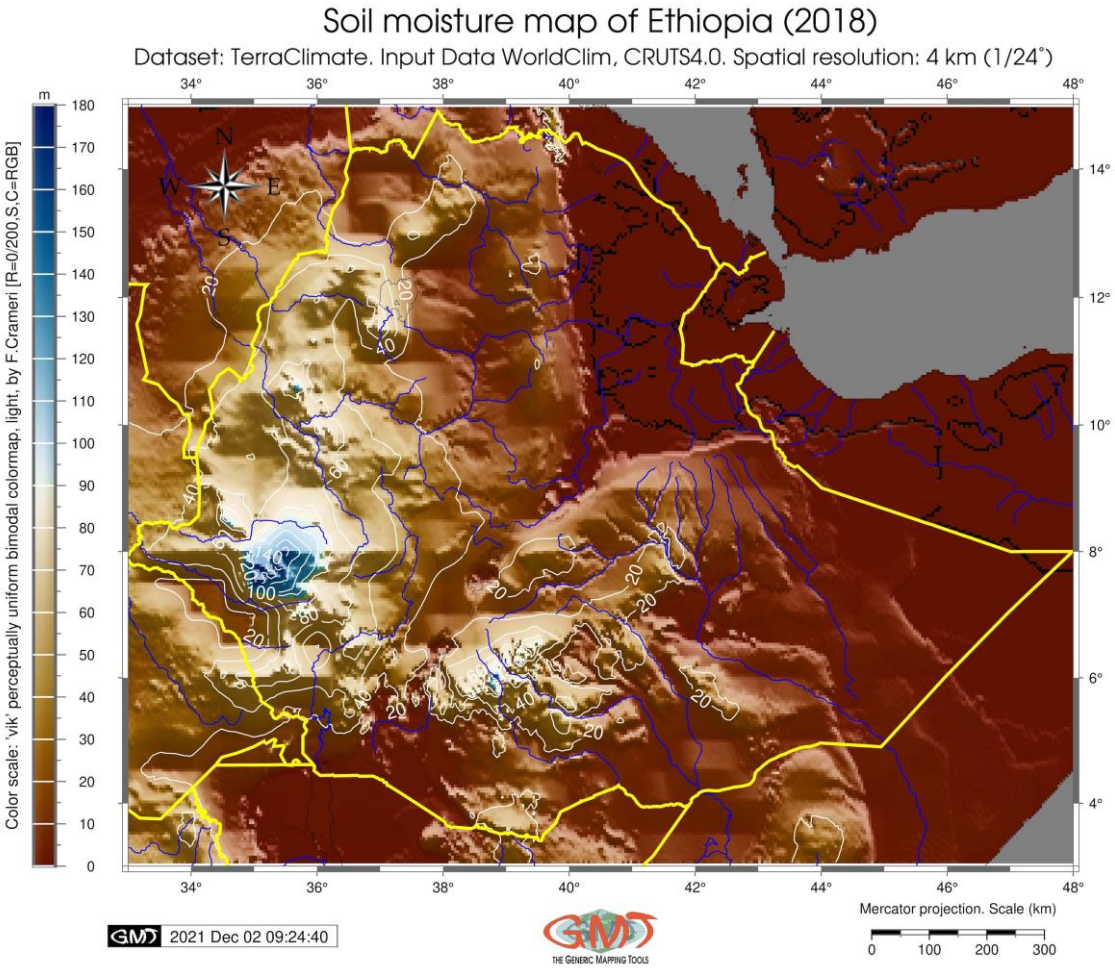

Fig. 2. Soil moisture map in Ethiopia in 2018. Mapping: GMT. Source: author

Research tools

Mapping for all illustrations (**Fig. 1–7**) has been done in Generic Mapping Tools (GMT) cartographic scripting toolset. The GMT based scripting approach applies the principle of programming in terms of console-based generating maps as an efficient cartographic workflow that supports both numerical modelling of the spatial datasets from the tabular formats and aesthetic graphical drawing of maps created for the environmental monitoring of Ethiopia. The regional extent of the study area was applied for Ethiopia, i.e., 33°E to 48°E and 3°N and 15°N.

The data were modelled and interpolated by raster grids using GMT. The datasets were captured from the WorldClim and GEBCO repositories with raster data and Digital Chart of the World (DCW) with vector data for clipping the country to highlight the study area. The mapping process of the GMT based scripting differs from designing a map using Graphical User Interface (GUI) based traditional GIS, such as ArcGIS or QGIS, because the data processing is being performed using script from a console. The mapping includes technically comprehensive and detailed visualization of the distribution of continuous fields of data and categorical environmental parameters in various vegetation regions of Ethiopia.

The input raster images for each of the maps (**Fig. 2–7**) was processed by a set of the GMT modules where each one defines certain map characteristics as described in existing technical papers (Lemenkova, 2020b, 2021a, 2021b).

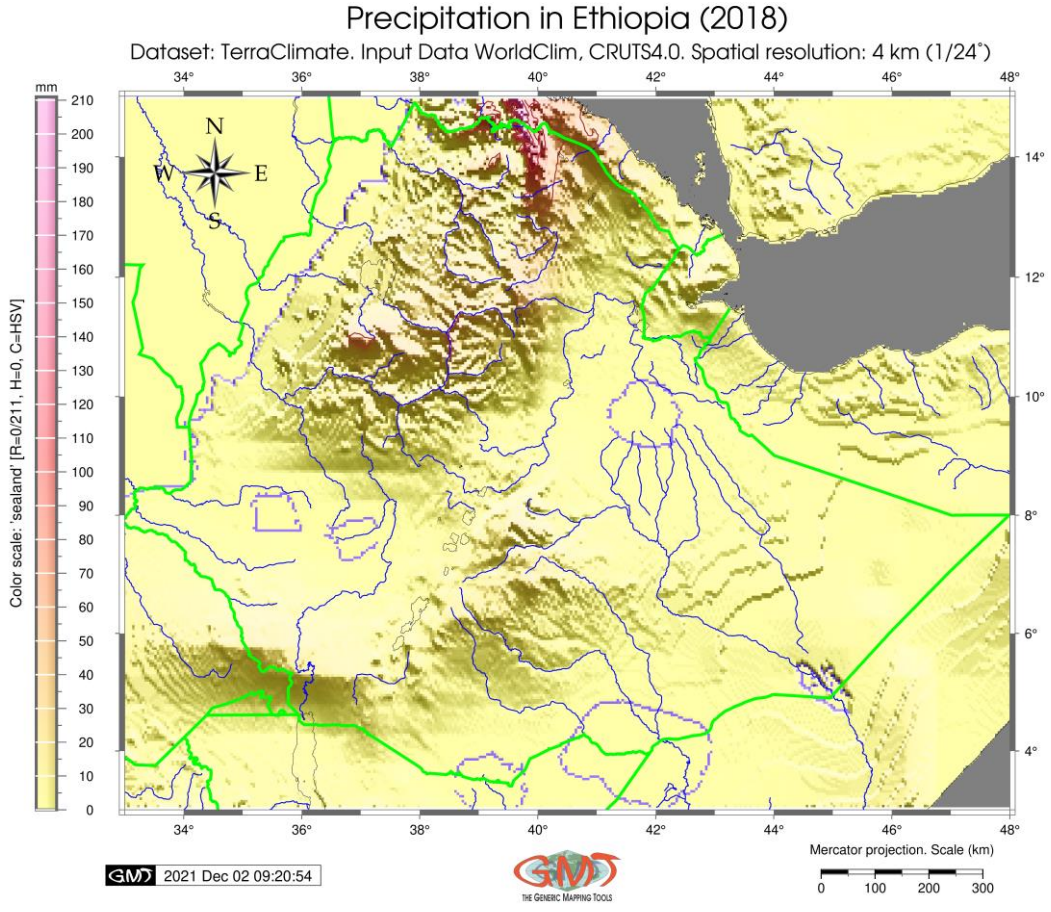

Fig. 3. Precipitation in Ethiopia in 2018. Mapping: GMT. Source: author

The GMT 'pscoast' modules was used for adding general cartographic elements (rivers and country borders) and 'psscale' was used to plot color explanation legend. The 'psbasemap' module was used to plot a title and a cartographic grid with graticule annotations (here the flag '-Bpxg2f0.5a2 -Bpyg2f2a2 -Bsxg1 -Bsyg1' for each map which shows primary and secondary grid annotations and intervals for the ticks).

To facilitate spatial comparison and cartographic visualization, the maps of the presented series (**Fig. 1-7**) were reconciled to the Mercator projection and the same spatial extent covering the country of Ethiopia (33°E–48°E, 3°N–15°N). The output environmental raster grids (**Fig. 2-7**) were recomputed by GMT and the output graphics converted from the PostScript (ps) format to the standard graphical output (jpg) using the fine resolution (720 dpi) as follows: 'gmt psconvert ET_PDSI.ps -A0.5c -E720 -Tj -Z', keeping the same criteria and layout sizes (5.5. inches) used in the implementation of the topographic map (**Fig. 1.**).

Cartographic coherency

The template draft of the GMT script designed for all the seven maps of the thematic series enabled visual cartographic coherency for the overall compatibility of the maps. This facilitated the comparative analysis of the continuous fields represented on the maps. Using identical coordinate extent, projection and orientation enabled to compare how differently the variability of the climate parameters behaved with respect to the topographic features of Ethiopia. The emphasis of the cartographic visualization was on the two steps in a technical mapping workflow:

i. how each flag within a GMT script controls the appearance of the cartographic elements (scale bar, grid image, rivers, DEM hillshade of Ethiopia) and how color palettes on all the maps within a map series;

ii. how sensitive the colour palettes are to climate variability parameters (temperatures, soil moisture, precipitation, PDSI values) demonstrated on the maps.

Therefore, all seven maps were examined how the symbolized environmental variables TerraClimat datasets in one map worked together with other maps of the presented series to enable visual correlation, compatibility and comparability of the maps. The template script of GMT with identical coordinates and map extent was applied for the 7 maps to ensure the iterative technical process of mapping.

3. Results and discussion

The paper presented modelled, visualized and mapped climate and topographic data across the Ethiopia ranges. The data were processed by the GMT methods to display visual cartographic quality through the selected colour palettes and vector properties (graticule, text annotations, legend) and meet the map purpose of modelling drought distribution, while maintaining the environmental goals of the research. The presented study had both theoretical environmental and practical cartographic goals. The environmental goal was to develop a conceptual GMT-based environmental analysis for visualization methods to depict data on a series of climate maps in general and the PDSI map in particular. The practical cartographic goal was to develop and present the cartographic functionality of the GMT scripting tool as a geoinformation visualization device and a scripting framework used for climate datasets.

The geoinformatics and data science approach has been taken to both goals using technical functionality from cartographic semantics and data processing, data visualization and aesthetic design.

In the study presented here, twofold methods of data visualization were presented for comparison of the topography and climate variables of Ethiopia, mapped using GMT: i) separable display of environmental variables achieved through series of the separate seven maps; ii) PDSI mapping demonstrating the integral display of the drought parameters, achieved through visualization of the complex PDSI index of drought over Ethiopia.

The results present a series of seven new maps based on the climatic data on Ethiopia, visualized and interpreted alongside the topography: 1) topography; 2) soil moisture; 3) T °C minimum; 4) T °C maximum; 5) Wind speed; 6) Precipitation; 7) Palmer Drought Severity Index (PDSI). The maps visualize meteorological and climate parameters for ecological monitoring, assessment of climate change, distribution and intensity of droughts.

The precipitation values (**Fig. 3.**) vary from 0 to 211 mm according to the TerraClim dataset checked up by GDAL. Although the maximal values reach higher values, the mean values dominating over the country are 5.167 (mainly light yellow color in **Fig. 3.**) and a standards deviation (StdDev) is 11.294.

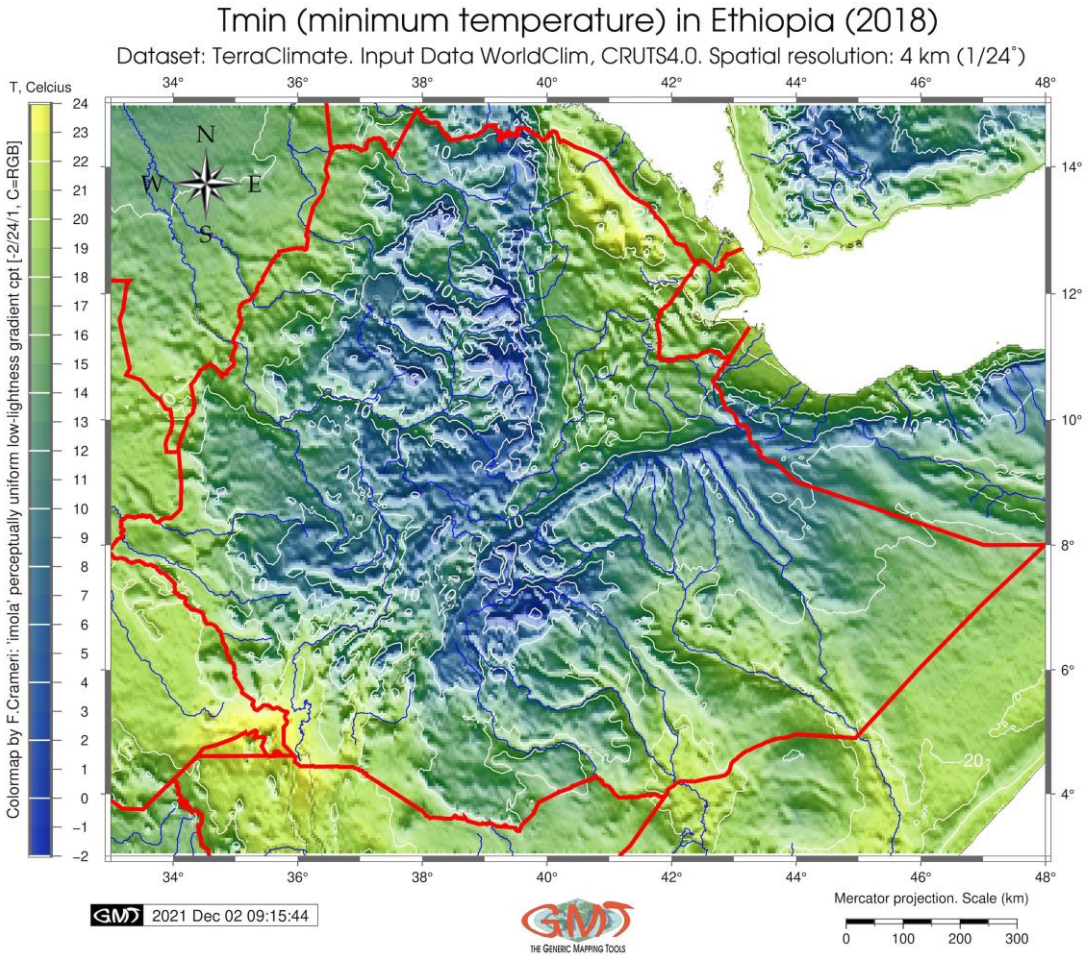

Fig. 4. T °C minimum (tmin) in Ethiopia in 2018. Mapping: GMT. Source: author

According to the data inspection by GDAL, there are three peaks of the higher precipitation in Ethiopia, which location is roughly corresponding to the topographic heights: 1) the Ethopian Highlands; 2) Omo and Mago National Parks; 3) Semien Mts National Park where mean values of the predominant precipitation values exceed 20 mm. Comparison of the presented figures enables to see the variations of climate and meteorological characteristics of the country with main topographic features of Ethiopia.

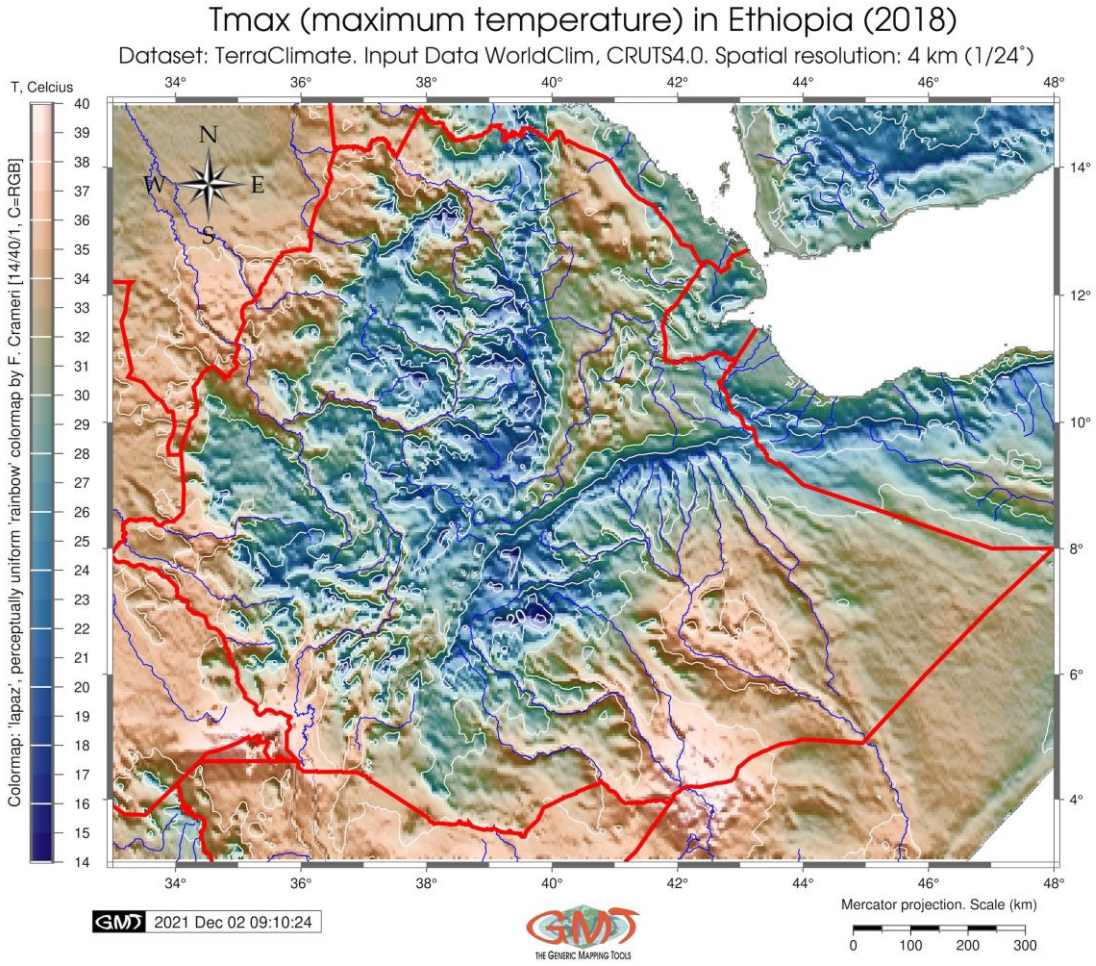

Fig. 5. T °C maximum (tmax) in Ethiopia in 2018. Mapping: GMT. Source: author

The Tmin has values ranging from -1.8 °C to 24 °C, while the Tmax has values ranging from 14.4 °C to 40.2 °C with the maximal areas clearly visible in the SE region of the country and the minimal values primarily concentrated along the Great Rift Valley. The selected color palette is 'lapaz' from the available choice of GMT. A similar pattern of the values distribution can be seen in Figure 4 (Tmin colored by the color palette 'imola' of GMT) showing the lowest values in the Great Rift Valley and over the Ethiopian Highlands (dark blue colors in Figure 4) and highest (up to 24 °C) in the NE region of the country.

It has been observed that the wind speed (**Fig. 6.**) well reflects the surface topography very well with distribution of lower values (0 to 1 m/s, yellow color in **Fig. 6.**) being directed almost in meridian direction which corresponds to the general extent of the Ethiopian

In general, the wind speed has lower values (0.5 to 2.0, which corresponds to the yellow to light aquamarine colors in **Fig. 6.**) in the depressions and topographic lowlands while the lower speed is notable for the higher elevations in the topographic landforms (2.0 to 4.5, which corresponds to the green colors and hues in **Fig. 6.**). The highest values of the wind speed (above 5.0 m/s) are notable along the coasts of Somali (44.0°E–47.0°E).

Along the Ethiopian Highlands higher values are demonstrated by the soil moisture (**Fig. 2.**) which has the highest value of 180 (checked by 'gdalinfo -stats et_soil.nc') Highlands (compare to **Fig. 1.**). According to the data inspection (gdalinfo -stats et_ws.nc), the minimum recorded is 0.100m/s, maximum is 6.1 m/s. The wind speed increases strongly in the depression area which forms a 'delta'-shaped form eastwards of the longitude 39.5°E. decreasing towards the desert areas (Ogaden Desert) representing the rocky and sandy nature of the Triassic deposits. The mean value is about 14.990, standard deviation (StdDev) is 20.056, according to the gdalinfo, which is changing abruptly toward the eastern direction along with the topography of the Ethiopian Highlands (compare **Fig. 1. to 2.**). Another region of higher values in soil moisture is notable around the Awasa city on the right flank off the Great Rift Valley (**Fig. 1.**) with values in the interval 40–60 (blue colors in **Fig. 2.**).

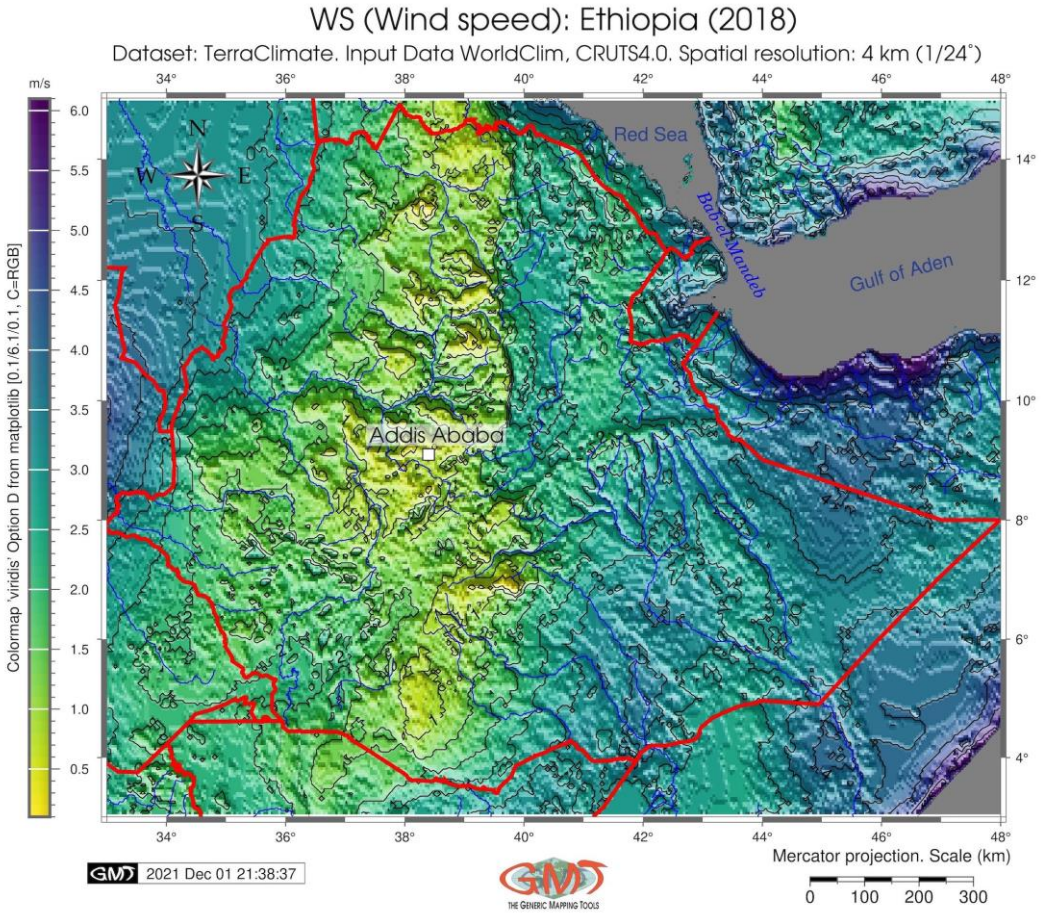

Fig. 6. Wind speed in Ethiopia (2018). Data: TerraClimate. Mapping: GMT. Source: author

The lowest values are notable in the lowlands of the Yangudi Rassa National Park and Semera. A comparison of the presented maps – topographic elevation (**Fig. 1.**), soil moisture (**Fig. 2.**), precipitation (**Fig. 3.**), extremal temperature as minimal (**Fig. 4.**) and maximal (**Fig. 5.**), wind speed (**Fig. 6.**) and the PDSI (**Fig. 7.**)– at the area surface of Ethiopia, shows a great agreement of the datasets proving the dependence of the PDSI on temperature, precipitation, soil-relief parameters and geomorphology of the study area.

The results show the lowest values of the PDSI (-11.7, a moderately moist area) are found in the NW region of Ethiopian Highlands, while the highest values (2.3, an extreme drought: orange to red colors in **Fig. 7.**), are recorded in the south-east off the Ethiopian Highlands (compare **Fig. 7. to 1.**). **Fig. 4.** and **Fig. 5.** are showing the extremal values of the temperature (**Fig. 4.** for the minimal and **Fig. 5.** for the maximal temperature in 2018) have isolines remarkably correlating to the topographic map (**Fig. 1.**) with clearly visible 'delta'-shaped depression area NE to the Greate Rift Valley and the Danakil Depression, where the temperature patterns change accordingly following the topographic relief patterns.

The application of GMT enabled to produce multiple cartographic representations of Ethiopia using several climate grids from a single detailed repository of TerraClimate by scripting approach from a GMT console.

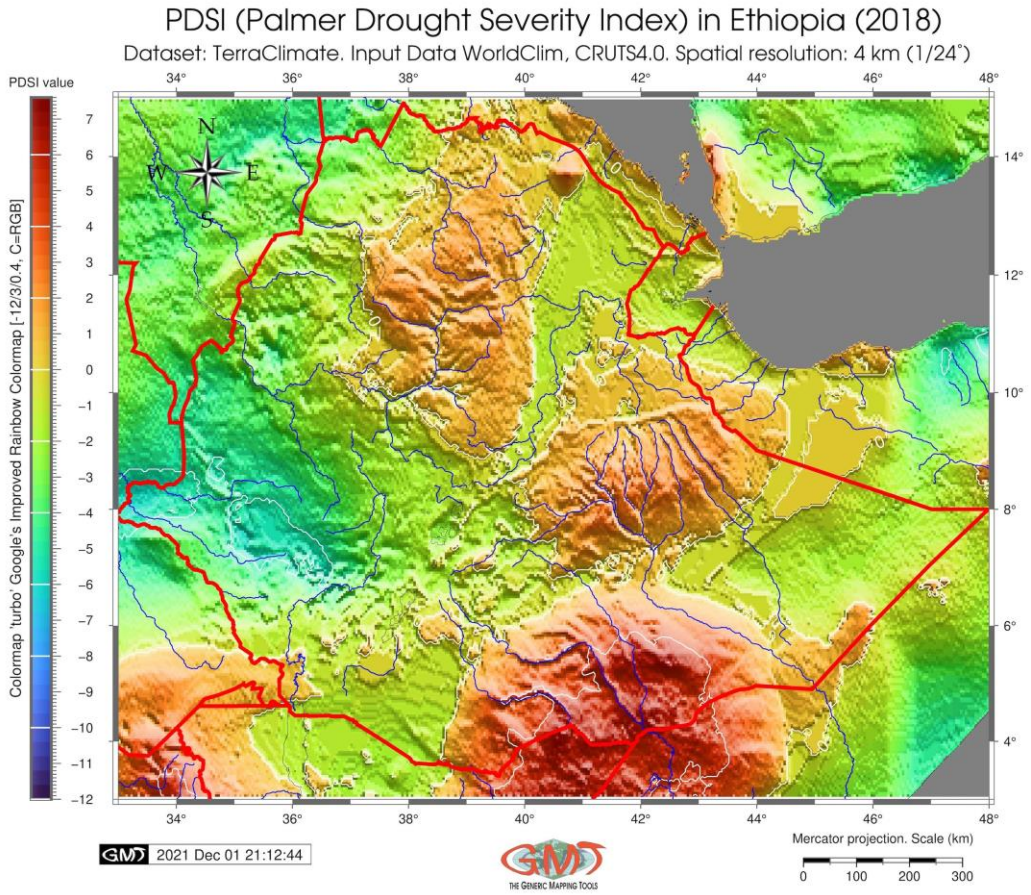

Fig. 7. Palmer Drought Severity Index (PDSI) in Ethiopia. Mapping: GMT. Source: author

Using GMT enables to produce a variety of maps with different purposes, such as geological, geomorphological, climate or environmental maps as scripting method rapidly processes multi-format raw data (IMG, GRD, NetCDF) to high-quality finished mapping outputs. The paper contrasts the existing approaches of the traditional GIS by using more sophisticated approach of GMT based scripting and customized mapping goals to visualization of the environmental parameters of Ethiopia: temperature (minima and maximal), soil moisture, wind speed, topography and the PDSI values.

The presented results explicitly demonstrate the influence of the console-based mapping on the cartographic output by presenting high-quality aesthetic map layouts. The paper shown the cartographic GMT based scripting as an influencing technology that amends cartographic workflow and affects analytical visualization of maps for environmental analysis derived from a multi-source datasets of TerraClimate aimed for multi-purpose environmental and climate assessment of Ethiopia. Comprehensive and detailed maps of the environmental parameters, climate elements and visualization of PDSI are a valuable resource for researchers to assess possible droughts in Ethiopia, a country with a highly contrasting clime and topographic setting.

Discussion

Mapping spatial data has been a subject of longstanding interest in environmental and climate studies, judging by relevant publications. Data visualization through application of various GIS and methods of cartographic data processing can effect changes in visual understanding of the mapped parameters, finding correlations between the phenomena (precipitation, soil moisture, temperature, PDSI) through analysis of their logical topology, geometry and distribution of the fields analyzed along with categorical variables, thus most approaches of mapping are designed to highlight depicted objects and better visualize their characteristics. In the presented multi-source data processing that resulted in a series of maps, projection was pre-established and agreed as the same for all the maps from the series, based on the principle of the best look reflecting the extent and topographic features of Ethiopia.

The guiding principle driving the presented research is to produce a series of the seven new thematic maps on climate settings of Ethiopia with a special accent on PDSI. While preserving identity and logical consistency of maps (projections, spatial extent, location) the maps demonstrate different meteorological and environmental variables over Ethiopia: temperature, soil moisture, precipitation and wind speed. This paper introduced a scripting approach which largely contrasts with the existing GIS-based mapping. Hence, the literature review of the existing publications on climate mapping of Ethiopia shown that the solutions offered to visualize environmental settings and map climate data (PDSI, temperatures, soils moisture etc) have been largely based on the traditional GIS approaches (for instance, ArcGIS) while ignored other cartographic approaches (scripting GMT tools).

The synchronized adjustment of cartographic symbols and elements has been applied for standardization of the maps (**Fig. 1. to 7.**) and achieving cartographic consistency. Pairwise variation in visual categories of the continuous fields using variability on color palettes of temperatures (**Fig. 4. and 5.**), environment (**Fig. 1. and 2.**), meteorology (**Fig. 3. and 7**.) and climate (**Fig. 4. and 6.**) resulted in multiple representations of their elements as a conceptual approach of semantic mapping applying geometric and graphical multiplicities. The presented series of maps

focused on the interaction between various environmental, climate and topographic features of Ethiopia aimed to demonstrate and highlight strong correlation between the topographic, climate and meteorological processes, soil moisture and temperature distribution over the area which is finally reflected in PDSI. The map of PDSI, generalizing and summarizing the environmental properties of the country through the computed and visualized index, effectively highlights the regions of Ethiopia prone to drought.

Conclusions

The presented thematic maps of Ethiopia are based on the visualization of the high-resolution datasets used for interpretation of the spatial distribution of droughts (PDSI) and related auxiliary parameters (extreme temperatures (min/max), speed intensity, precipitation, soil moisture, topography) in Ethiopia. The links between the demonstrated environmental and climatic components based on visual comparison and overlay of the cartographic imprints demonstrate interrelations between these factors. The correlations between the soil moisture, precipitation, relief and temperatures point at their environmental associations affecting meteorological variables and drought that can be useful in possible prognosis and modelling of droughts. The cartographic series of the thematic climatic and topographic maps produced using identical spatial extent, projection and view yet using a variety of color palettes for each environmental variable can be successfully used as a reliable source for ecological monitoring in Ethiopia. In this way, this paper contributes to the environmental research of Ethiopia with a special focus and detailed visualization of PDSI map for drought modelling.

The demonstrated results show the predominant distribution of the PDSI values over the Ethiopia Highlands and mountainous areas. The spatial distribution of the PDSI and other climatic datasets covering Ethiopia (as on 2018) obtained as a result of the GMT based mapping reflects the correlation with topography as well as the effects of temperature and precipitation on the variations of the PDSI values. For instance, higher values of the PDSI correlates well with distribution of the areas of the prevailing winds with higher speed. On the contrary, the lower values of the PDSI (severe drought) are found on the sites with low-speed winds. For climate and environmental research, cartographic visualization is a primary technical tool of data processing used to identify geospatial clusters and regular patterns of meteorological continuous fields and to compare these features with patterns of both topographic relief and potential droughts based on PDSI map. Similar situation can be seen on the comparison of maps showing precipitation, temperature and topography with the PDSI values over the country. Thus, regions of higher precipitation coincide with the areas of higher PDSI values (that is, relatively moist regions), while low-level precipitation regions correlate with the PDSI regions showing lower values (that is, extreme drought). The relationship between the occurrence of higher/lower temperature values (min/max as for 2018) in Ethiopia and the PDSI values has also been noticed by the comparison of the respecting maps.

The generated maps are required by the drought assessment and environmental monitoring studies. These maps are proposed for the first time on a GMT-based approach based on scripting techniques and contribute to the existing studies on environment and ecological monitoring of Ethiopia with special focus on climate change, problems of drought and crop harvest (Ntale and Gan, 2003). A series of the climatic variables (soil

moisture, extremal temperatures (T °C min; and T °C max), wind speed, precipitation; PDSI) have been visualized based on the existing datasets of WorldClim using scripting approach of GMT to show the reference of the climate to the topographic setting in Ethiopia. The assumption made is that the relief elevation, orientation and steepness should be affecting these parameters and which has been visualized on the series of maps and discussed as interpretation of the map values. A presented series of the GMT-based climate and environmental maps associated with the PDSI index of Ethiopia is useful as the base illustrations in future similar research on the environmental assessment and monitoring of the country.

Scripting cartographic concept implemented in GMT enabled to find out optimal cartographic solutions for data visualization that support effective map production workloads through minimizing human-made routine and increasing automatization. Incorporating various multi-source datasets into the map series, as presented in this research, extends the range of variables for a regional extent of Ethiopia, which in turn increases the volume of information to maintain analysis of correlation between the climate and topographic parameters for the environmental monitoring of Ethiopia.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Abatzoglou J, Dobrowski S, Parks S, Hegewisch KC (2018) TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. Sci Data 5:170191.
2. Adgo E, Teshome A, Mati B (2013) Impacts of long-term soil and water conservation on agricultural productivity: the case of Anjenie watershed, Ethiopia. Agric Water Manag 117:55–61.
3. Aragie EA, J Thurlow EA (2022) Modeling the recovery dynamics of Ethiopia cattle population. Journal of Arid Environments 197: 104664
4. Alemayehu F, Taha N, Nyssen J, Girma A, Zenebe A, Behailu M, Deckers S, Poesen J (2009) The impacts of watershed management on land use and land cover dynamics in Eastern Tigray (Ethiopia). Resources, Conservation and Recycling 53(4):192–198.
5. Alley, W.M. 1985. The Palmer Drought Severity Index as a Measure of Hydrologic Drought. JAWRA J Am Water Resour Assoc 21: 105–114.
6. 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.
7. Bahru BA, Bosch C, Birner R, Zeller M (2019) Drought and child undernutrition in Ethiopia: A longitudinal path analysis. PLOS ONE 14(6): e0217821.
8. Beyaztas U, Arikan BB, Beyaztas BH, Kahya E (2018) Construction of prediction intervals for Palmer Drought Severity Index using bootstrap. J Hydrol 559: 461–470.
9. Dai A, Trenberth KE, Qian T (2004) A Global Dataset of Palmer Drought Severity Index for 1870–2002: Relationship with

Soil Moisture and Effects of Surface Warming. J Hydrometeorol 5(6): 1117–1130.
10. Demelash H, Tadesse T, Menamo T, Menzir, A (2021) Determination of root system architecture variation of drought adapted sorghum genotypes using high throughput root phenotyping. Rhizosphere 19: 100370
11. Di Falco S, Bezabih M, Yesuf M (2010) Seeds for livelihood: Crop biodiversity and food production in Ethiopia. Ecological Economics 69(8): 1695-1702.
12. Dimitrova A (2021) Seasonal droughts and the risk of childhood undernutrition in Ethiopia. World Development 141: 105417.
13. Domonkos P, Szalai S, Zoboki J (2001) Analysis of drought severity using PDSI and SPI indices. Idoejaras 105: 93–107.
14. Edossa DC, Babel MS, Gupta AD (2010) Drought analysis in the Awash river basin, Ethiopia. Water resources management 24(7): 1441–1460.
15. Eze E, Girma A, Zenebe A, Zenebe G (2020) Feasible crop insurance indexes for drought risk management in Northern Ethiopia. Int. J. Disaster Risk Reduct 47: 101544.
16. Fick SE, Hijmans RJ (2017) WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. Int J Climatol 37:4302–4315.
17. Ficklin DL, Letsinger SL, Gholizadeh H, Maxwell JT (2015) Incorporation of the Penman–Monteith potential evapotranspiration method into a Palmer Drought Severity Index Tool. Comput Geosci 85 Part A:136–141.
18. Gauger S, Kuhn G, Gohl K, Feigl T, Lemenkova P, Hillenbrand C (2007) Swath-bathymetric mapping. Reports on Polar and Marine Research 557:38–45.
19. Ghiglieri G, Pistis M, Abebe B, Azagegn T, Engidasew TA, Pittalis D, Soler A, Barbieri M, Navarro-Ciurana D, Carrey R, Puig R, Carletti A, Balia R, Haile T (2020) Three-dimensional hydrostratigraphical modelling supporting the evaluation of fluoride enrichment in groundwater: Lakes basin (Central Ethiopia). J. Hydrol. Reg. Stud. 32:100756.
20. GEBCO Compilation Group, 2020. GEBCO 2020 Grid. https://doi.org/10.5285/a29c5465-b138-234d-e053-6c86abc040b9
21. Gebre B, Ayenew H Y, Biadgilign S (2021) Drought, hunger and coping mechanisms among rural household in Southeast Ethiopia. Heliyon 7(3): e06355.
22. Gebrehiwot T, van der Veen A, Maathuis B (2011) Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. Int J Appl Earth Obs Geoinf 13(3): 309–321.
23. Gohl K, Eagles G, Udintsev G, Larter RD, Uenzelmann-Neben G Schenke HW, Lemenkova P, Grobys J, Parsiegla N, Schlueter P, Deen T, Kuhn G, Hillenbrand CD (2006) Tectonic and sedimentary processes of the West Antarctic margin of the Amundsen Sea embayment and PineIsland Bay. Proc 2nd SCAR Open Science Meeting 12–14 July, Hobart, Australia.
24. Gohl K, Uenzelmann-Neben G, Eagles G, Fahl A, Feigl T, Grobys J, Just J, Leinweber V, Lensch N, Mayr C, Parsiegla N, Rackebrandt N, Schlüter P, Suckro S, Zimmermann K, Gauger S, Bohlmann H, Netzeband G, Lemenkova P (2006b) Crustal and Sedimentary Structures and Geodynamic Evolution of the West Antarctic Continental Margin and Pine Island Bay. Expeditionsprogramm Nr. 75 ANT XXIII/4 ANT XXIII/5, 11–12.
25. Haile GG, Tang Q, Leng G, Jia G, Wang J, et al. (2020) Long-term spatiotemporal variation of drought patterns over the

Greater Horn of Africa. Sci. Total Environ 704: 135299.
26. Jain VK, Pandey RP, Jain MK, Byun H-R (2015) Comparison of drought indices for appraisal of drought characteristicsin the Ken River Basin. Weather Clim Extremes 8: 1–11.
27. Kebede YS, Endalamaw NT, Sinshaw BG, Atinkut HB (2021) Modeling soil erosion using RUSLE and GIS at watershed level in the upper beles, Ethiopia. Environmental Challenges, 2: 100009.
28. Klaučo M, Gregorová B, Stankov U, Marković V, Lemenkova P (2013) Determination of ecological significance based on geostatistical assessment: a case study from the Slovak Natura 2000 protected area. Open Geosci 5(1):28–42.
29. Klaučo M, Gregorová B, Koleda P, Stankov U, Marković V et al. (2017) Land planning as a support for sustainable development based on tourism: A case study of Slovak Rural Region. Environ Eng Manag J 2(16):449–458.
30. Koroso NH, Zevenbergen JA, Lengoiboni M (2020) Urban land use efficiency in Ethiopia: An assessment of urban land use sustainability in Addis Ababa. Land Use Policy, 99: 105081.
31. Legesse A, Negash, M (2021) Species diversity, composition, structure and management in agroforestry systems: the case of Kachabira district, Southern Ethiopia 7(3): e06477.
32. Lemenkov V, Lemenkova P (2021a) Using TeX Markup Language for 3D and 2D Geological Plotting. Found Comput Decis Sci 46(3): 43–69.
33. Lemenkov V, Lemenkova P (2021b) Measuring Equivalent Cohesion Ceq of the Frozen Soils by Compression Strength Using Kriolab Equipment. Civ Environ Eng Rep 31(2): 63–84.
34. Lemenkova P (2011) Seagrass Mapping and Monitoring Along the Coasts of Crete, Greece. M.Sc. Thesis. University of Twente, Netherlands. Pp. 158.
35. Lemenkova, P (2019a) Statistical Analysis of the Mariana Trench Geomorphology Using R Programming Language. Geod Cartogr 45(2):57–84.
36. Lemenkova P (2019b) Topographic surface modelling using raster grid datasets by GMT: example of the Kuril-Kamchatka Trench, Pacific Ocean. Reports on Geodesy and Geoinformatics, 108, 9–22.
37. Lemenkova P (2019c) GMT Based Comparative Analysis and Geomorphological Mapping of the Kermadec and Tonga Trenches, Southwest Pacific Ocean. Geogr Tech 14(2):39–48.
38. Lemenkova P (2019d) Geomorphological modelling and mapping of the Peru-Chile Trench by GMT. Pol Cartogr Rev 51(4):181–194.
39. Lemenkova P (2020a) SAGA GIS for information extraction on presence and conditions of vegetation of northern coast of Iceland based on the Landsat TM. Acta Biol. Marisiensis 3(2):10–21.
40. Lemenkova P (2020b) GEBCO Gridded Bathymetric Datasets for Mapping Japan Trench Geomorphology by Means of GMT Scripting Toolset. Geod Cartogr 46(3):98–112.
41. Lemenkova P (2020c) Sentinel-2 for High Resolution Mapping of Slope-Based Vegetation Indices Using Machine Learning by SAGA GIS. Transylv Rev Syst Ecol Res 22(3):17–34.
42. Lemenkova P (2021a) Topography of the Aleutian Trench south-east off Bowers Ridge, Bering Sea, in the context of the geological development of North Pacific Ocean. Baltica 34 (1):27–46.
43. Lemenkova P (2021b) Geodynamic setting of Scotia Sea and its effects on

geomorphology of South Sandwich Trench, Southern Ocean. Pol Polar Res 42(1):1–23.
44. Matewos T (2020) The state of local adaptive capacity to climate change in drought-prone districts of rural Sidama, southern Ethiopia. Clim. Risk Manag 27:100209.
45. Mera GA (2018) Drought and its impacts in Ethiopia. Weather. Clim. Extremes 22: 24–35.
46. Mihretie FA, Tsunekawa A, Haregeweyn N, Adgo E, Tsubo M, Ebabu K, Masunaga T, Kebede B, Meshesha DT, Tsuji W, Bayable M, Berihun ML (2021) Tillage and crop management impacts on soil loss and crop yields in northwestern Ethiopia. International Soil and Water Conservation Research.
DOI: 10.1016/j.iswcr.2021.04.006
47. Ntale HK, Gan TY (2003) Drought indices and their application to East Africa. Int J Climatol 23:1335–1357.
48. Schenke HW, Lemenkova P (2008) Zur Frage der Meeresboden-Kartographie: Die Nutzung von AutoTrace Digitizer für die Vektorisierung der Bathymetrischen Daten in der Petschora-See. Hydrographische Nachrichten, 81: 16–21.
49. Suryabhagavan KV (2017) GIS-based climate variability and drought characterization in Ethiopia over three decades. Weather and Climate Extremes 15: 11–23.
50. Suetova IA, Ushakova LA, Lemenkova P (2005) Geoinformation mapping of the Barents and Pechora Seas. Geography and Natural Resources, 4:138–142.
51. Tesfamariam BG, Gessesse B, Melgani F (2019) Characterizing the spatiotemporal distribution of meteorological drought as a response to climate variability: The case of rift valley lakes basin of Ethiopia. Weather. Clim. Extremes 26:100237.
52. Tora TT, Degaga DT, Utallo AU (2021) Drought vulnerability perceptions and food security status of rural lowland communities: An insight from Southwest Ethiopia. Current Research in Environmental Sustainability 3: 100073

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EFFECTS OF PLANT GROWTH RETARDANTS ON DEVELOPMENT OF POINSETTIA "CHRISTMAS FEELING" CULTIVAR

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Abstract: The poinsettias were cultivated years ago as medicinal and ornamental plants, too; but in the recent time are in the light of world flower assortment surprising with new shapes and colors in the cold season. The ornamental values of these plants are given by bracts which can have the same size as foliage leaves or even larger. The tendency of floral industry consists in obtaining high quality ornamental plants with superior marketable price. In these regards, the role of plant growth retardants in regulating the growth of poinsettia is important to obtain healthy, compact bushes and extended decoration period. The aim of the paper is to evaluate the effects of plant growth retardants on poinsettia. Five treatments with different retardants were applied as drench or spray. In the experiment four replicates and a total of 144 poinsettias were used. Treatments with paclobutrazol (60 mg/l sprayed), daminozide (2500 mg/l sprayed) and chlormequat chloride (1000 mg/l sprayed), showed the best results in case of marketability.

Keywords: daminozide, drench, *Euphorbia pulcherrima*, paclobutrazol

1. Introduction

Poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) (sin. *Poinsettia pulcherrima* Willd. ex Klotzsch Graham, *Euphorbia erythrophylla* Bertol.) belongs to the Euphorbiaceae family. It is native in wet, tropical areas and temperate, sub-tropical and tropical climates (Carter, 2002; Niculescu, 2009).

Its ornamental value is given by the modified leaves (bracts) that have the same size as foliage leaves or sometimes even larger. The male and female flowers are forming the cyathia, which is surrounded by bracts. The color of more than 100 cultivars bracts varies between red, pink, white, cream, pale yellow, orange, pale green, and marbled/variegated bracts (Delavie et al., 2004; Schmidt, 2010; Deardorff and Wadsworth, 2016) dominating the red cultivars with 70-75% of world production.

The red color of poinsettia is due to anthocyanins, while the white varieties acquire their color by the anthocyanin content decreasement from vacuoles (Slatnar et al., 2013).

Since the spread of flowering timing, the role of plant growth retardants has increased. Controlling the growth of poinsettias can causes difficulties for growers because without the use of appropriate methods, these plants can grow too tall in greenhouses (Oszkóné et al., 1979; Faust et al., 2001). Influencing stem elongation is critical to successful commercial cultivation, because of the market demands (Lewis et al., 2004). The reduction of stem elongation can be achieved with plant growth retardants (PGR's) (Batelja et al., 2010).

Most growth retardants inhibit the biosynthesis of gibberellin (GA). A very popular growth retardant that inhibits the GA biosynthesis is daminozide (Batelja et al., 2010). Daminozide reduces the size of plant cells, thus shortening the length of the stem. It also inhibits the growth of the apical meristem, causing the plant to branch more and form more flowers on them (Bailey and Whipker, 1998). The treated plants grow strong roots, thus making better use of the soil's water supply and the nutrients. At the same time, daminozide increases chlorophyll production in the treated plant, causing the leaves to turn into a darker green color. Another useful growth retardant is chlormequat-chloride, which also blocks GA biosynthesis in the triazole process (Oszkóné et al., 1979). As a result of CCC treatment, the internode extensions are shortened, and the longitudinal growth of the plant is reduced. The agent accelerates flowering and intensifies the color of true leaves and bracts. By mixing these two materials (daminozide and chlormequat-chloride), the stem elongation was effectively reduced through the synergistic effect of the combination of the two (Oszkóné et al., 1979; Gibson et al., 2003). The biggest problem with using these materials is finding a method that has consistently effective results (Batelja et al., 2010). Another growth inhibitor (paclobutrazol) is also effective on stem elongation but can also reduce the size of bracts too much in case of excessive use (Niu et al., 2002). Paclobutrazol applied at the end of October has the least risk for affecting bract size according to an experiment made with "Freedom Red" poinsettia (Faust et al., 2001). Paclobutrazol (PBZ) has a strong growth inhibitory effect on a wide range of plants, inducing physiological changes including a decrease in gibberellin and sterol biosynthesis, increasing chlorophyll concentration and delaying aging due to increased endogenous cytokine levels (Niu et al., 2002). Maximum reduction in height and size of bracts was obtained when the paclobutrazol treatment was applied immediately after short days (Niu et al., 2002). The use of the agent, 3 weeks after the appearance of the colored bracts, did not affect the plant height and the bract area, regardless of the method or concentration used (Niu et al., 2002).

In the production of potted plants, a number of growth regulators can be used to adjust the size of the plant and this can be especially helpful after using excessive growth retardants (Runkle et al., 2005). Gibberellic acids have a growth-promoting effect and cytokinin's have a cell division-enhancing and branching-stimulating effect. By using growth regulators, leaf yellowing can be prevented, the size, number and lifespan of the flower can be increased (Runkle et al., 2005).

The aim of the experiment was to evaluate the effects of plant growth retardants on poinsettias. In addition, another desire of this research was to develop a cultivation technology that results in healthy and attractive plants which meets the market demands.

2. Materials and methods

The experiment was performed in a tunnel-based greenhouse with a double inflated foil cover in Transylvanian region. The height of the greenhouse was 5 meters, and the ventilation was provided by an automated roof ventilator. The cultivation tables were 2 m wide and 22 m long, on which the plants were irrigated constantly, the moisture and humidity was ensured (75% average air humidity, 20°C average temperature). The heating of the greenhouse was operated by a central heating system implemented through a pipe system under the tables. Monofactorial experiments were set with six different treatments applied with four replicates on six plants/treatment. In case of each replicates 6 plants did not receive any treatment and were kept as control (**Table 1.**). In the experiment a total of 144 cuttings were used belonging to the "*Christmas Feeling*" variety, purchased from the German company Elsner PAC Vertriebsgesellschaft mbH. The plants arrived on July 11. Potting up took place on July 12. To eliminate the possibility of infections various pesticides (Actara 25 WG, Dimilin 25 WP and Topsin 500 SC) were used. The method and time of application of the growth retardants are summarized in **Table 2.**

Table 1. Different treatments applied in the experiment

Experimental variants	Commercial name	Active ingredient (according to label)	Observations
V1 (control)	-	-	-
V2	Alar + Cycocel	daminozide and chlormequat (DAM + CCC)	used one time
V3	Bonzi	paclobutrazol (PBZ 10 mg/l)	used one time marked with D1
V4	Bonzi	paclobutrazol (PBZ 1 mg/l)	used two times marked with D2
V5	Bonzi	paclobutrazol (PBZ 60 mg/l)	used one time marked with S1
V6	Bonzi	paclobutrazol (PBZ 30 mg/l)	used two times marked with S2

Table 2. Growth retardants used in the experiment

Application time	**Method of application**	**Dosage**
17. Aug	Spray-first time	S1: 60 mg/l
17. Aug	Spray-first time	S2: 30 mg/l
29. Aug	Spray-second time	S2: 30 mg/l
17. Aug	Drench-first time	D1: 10 mg/l
17. Aug	Drench-first time	D2: 1 mg/l.
29. Aug	Drench-second time	D2: 1 mg/l
17. Aug	Spray-first time	DAM+CCC -2500 mg/l +1000 mg/l

Abbreviations: DAM + CCC - daminozide and chlormequat

Overall, the plants were examined at five different times (August, September, October and two times in December) and the following parameters were determined: plant height (cm), red bracts number, bracts length and width, total number of shoots, and the EC value. The recorded data concerning the influence of different growth regulators on development of *Poinsettia* "Christmas Feeling" cultivar was statistically interpreted with the Mann-Whitney test, worked out as average values per variant.

3. Results and discussion

The plant height and the bract area of poinsettias sprayed with paclobutrazol 60 mg/l (S1) were significantly different from the control plants, they were more marketable. Plants sprayed with DAM+CCC and PBZ 30 mg/l x 2 were near the same height with the plants treated with PBZ 60 mg/l treatment, no significant differences were found. The significantly lowest plant heights (**Fig. 1./ Fig. 3.**) were measured in case of paclobutrazol 10 mg/l and 1 mg/l drenched.

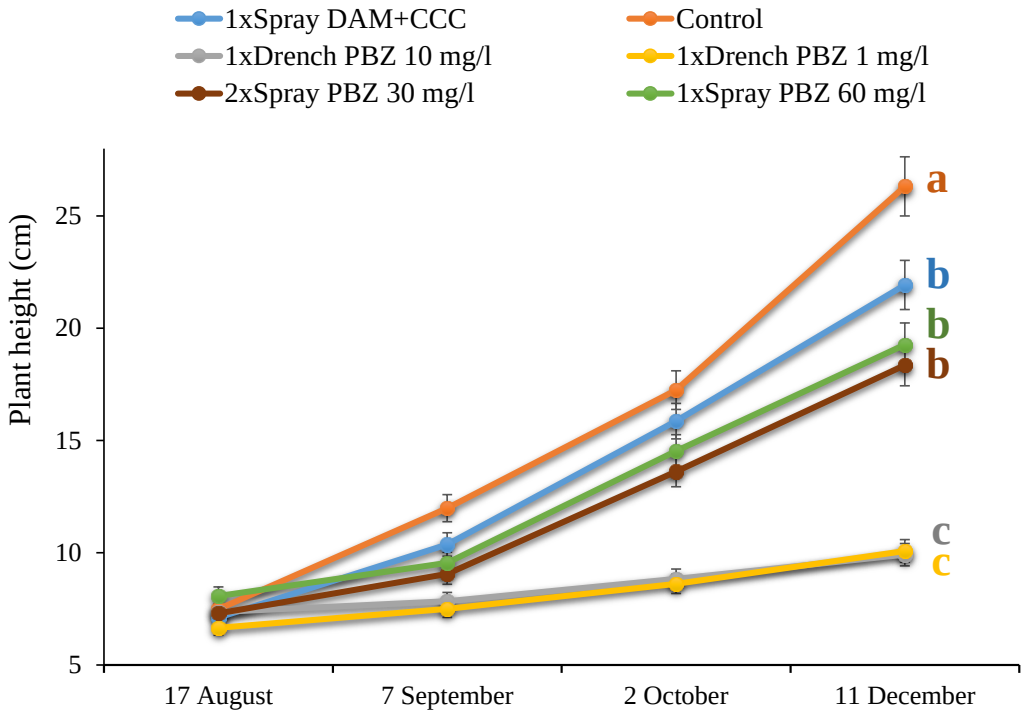

Fig. 1. Plant height at different measurement times and under different treatments. (Mann-Whitney test $p<0.05$). Different letters means statistical significant differences.

In case of the number of red bracts no significant differences were found between the control plants and the sprayed ones with PBZ (60 mg/l and 30 mg/l) and DAM+CCC. The lowest result was obtained with the PBZ 10 mg/l treatment which significantly differed from the other treatments. The poinsettias treated with PBZ 60 mg/l where the most marketable after visual examination because of the number of red bracts, the size of these bracts and the size of the plants (**Fig. 2. / Fig. 3. / Fig. 4.**).

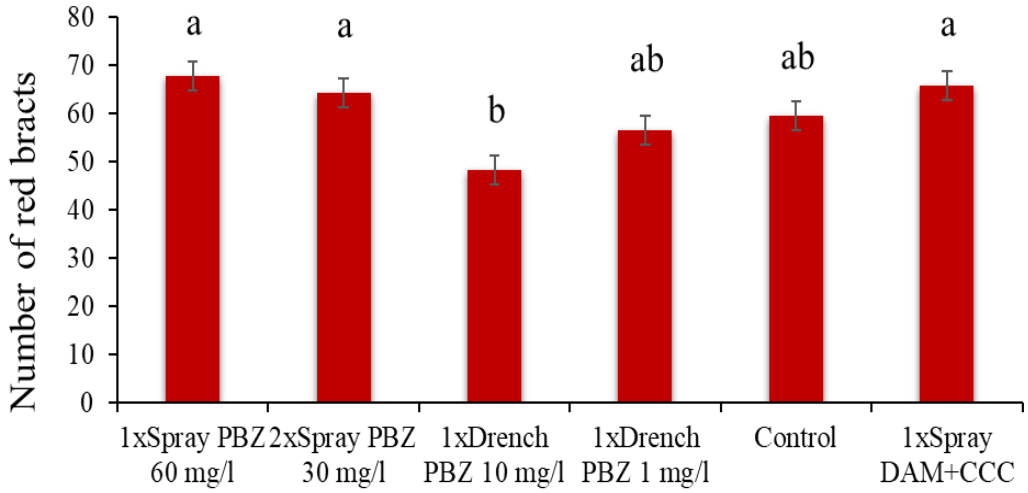

Fig. 2. Number of red bracts under different treatments (Mann-Whitney test $p<0.05$). Different letters means statistical significant differences.

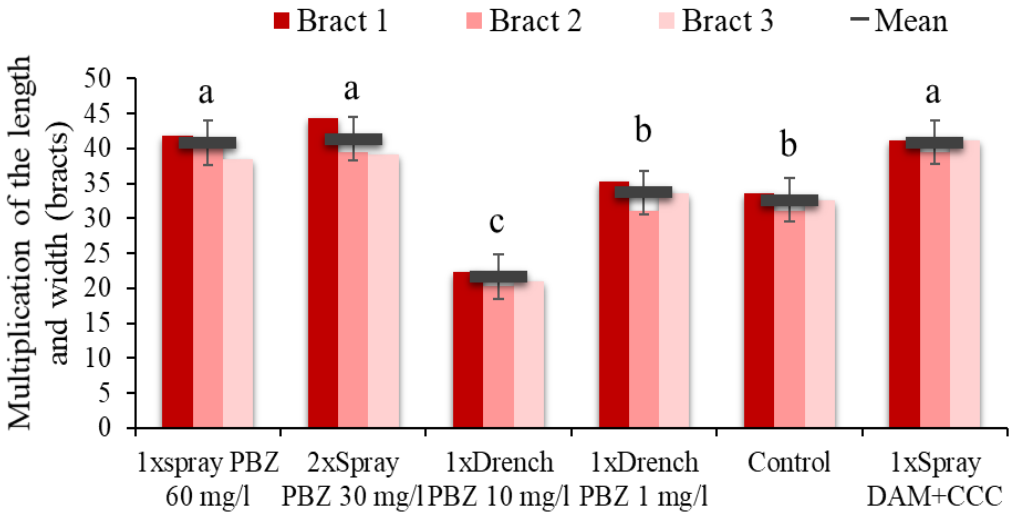

Fig. 3. Multiplication of the length and width of the three largest bract from each treatment (Mann-Whitney test $p<0.05$). Different letters means statistical significant differences.

The multiplication of the length and width of 3 selected bracts (the largest bracts) from each treatment were measured. Statistical differences were found between the sprayed plants with PBZ (60mg/l and 30mg/l) and the control plants. The lowest result was obtained with the drench of PBZ 10 mg/l which statistically differed from all treatments. The result of the DAM+CCC treatment was nearly the same as the PBZ treatment. The best result was obtained with the PBZ 60 mg/l treatment (**Fig. 2. / Fig. 3. / Fig. 4.**).

Treatments with PBZ 60 mg/l and daminozide and chlormequat chloride at concentration of 2500 mg/l: 1000 mg/l showed the best results in case of marketability. Same results were found in another two experiment made with poinsettia "Freedom Red" and "Freedom" (Faust et al., 2001; Niu et al., 2002).

All growth retardant treatments decreased the height of poinsettias and the anthesis was delayed by the daminozide and chlormequat chloride (DAM+CCC) treatment (Bailey and Miller, 1991).

The drenched plants with paclobutrazol 10 mg/l and paclobutrazol 1 mg/l excessively stopped the longitudinal growth of poinsettias and drastically reduced the height, bract size and internodes-length (Faust et al., 2001). These plants may have an increased rate of botrytis infection because of the reduction of height, bract area and compact size. The final plant height was around 5.5 cm shorter for DAM+CCC treatments, compared to the control, and varied between 7.5 and 15 cm in case of paclobutrazol treatments. According to Lewis et al., (2004) the obtained results were the same.

The combination of chlormequat chloride and daminozide treatment did not cause phytotoxic symptoms on poinsettias, neither when they were drenched or sprayed, which coincides with the results of the experiment made by Batelja et al. (2010).

Fig. 4. Poinsettias treated with different PGR's at the end of the experiment.

Conclusions

Altogether, it can be concluded that treatments with PBZ 60 mg/l and daminozide and chlormequat chloride at concentration of 2500 mg/l: 1000 mg/l showed the best results in case of marketability. The combination of chlormequat chloride and daminozide treatment did not cause phytotoxic symptoms on poinsettias, neither when they were drenched or sprayed. According to these it can be stated that the right cultivation technology and well-timed plant protection interventions, poinsettia can be successfully grown in the Transylvanian region in greenhouse conditions.

Conflict of interest

The authors declare that there are no conflicts of interest related to this article.

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References

1. Bailey D, Whipker B (1998) Best management practices for plant growth regulators used in floriculture. Hortic Inf Leafl 529: 1–16.
2. Bailey DA, Miller WB (1991) Poinsettia developmental and postproduction responses to growth retardants and irradiance. HortScience 26:1501–1503. https://doi.org/10.21273/HORTSCI.26.12.1501
3. Batelja Lodeta K, Goreta Ban S, Perica S, et al (2010) Response of poinsettia to drench application of growth regulators. J Food Agric Environ 8:297–301.

4. Carter A (2002) Euphorbia. In: Eggli U (ed) Illustrated handbook of succulent plants. Dicotyledons. Springer, Berlin: New York, p 102.
5. Deardorff DC, Wadsworth KB (2016) What's wrong with my houseplant? save your indoor plants with 100% organic solutions. Timber Press, Portland, Oregon.
6. Delavie A, Garnaud-d'Ersu V, Pienescu DE, Mioulane P (2004) Grădini şi plante de interior: enciclopedia Truffaut. Enciclopedia RAO, Bucureşti.
7. Faust JE, Korczynski PC, Klein R (2001) Effects of paclobutrazol drench application date on poinsettia height and flowering. HortTechnology 11:557–560. https://doi.org/10.21273/HORTTECH.11.4.557
8. Gibson JL, Cavins TJ, Greer L, et al (2003) Efficacy of plant growth regulators on the growth of Argyranthemum frutescens "Comet Pink." Acta Hortic 213–216. https://doi.org/10.17660/ActaHortic.2003.624.28
9. Lewis KP, Faust JE, Sparkman JD, Grimes LW (2004) The effect of daminozide and chlormequat on the growth and flowering of poinsettia and pansy. HortScience 39:1315–1318. https://doi.org/10.21273/HORTSCI.39.6.1315
10. Niculescu M (2009) Metode de cercetare şi prezentare a florei. Sitech, Craiova.
11. Niu G, Heins R, Carlson W (2002) Using paclobutrazol to control height of poinsettia `Freedom'. HortTechnology 12:232–236. https://doi.org/10.21273/HORTTECH.12.2.232
12. Oszkóné SE, Lammel K, Bodor J (1979) A mikulásvirág. Mezőgazda Kiadó, Budapest.
13. Runkle E, Blancard M, Olrich M (2005) Fascination on poinsettia. In: Floriculture Greenhouse Crop Production. https://www.canr.msu.edu/resources/fascination-on-poinsettia. Accessed 17 Nov 2020
14. Schmidt G (2010) Növényházi dísznövények termesztése, 2002 2nd edn. Mezőgazda Kiadó, Budapest.
15. Slatnar A, Mikulic-Petkovsek M, Veberic R, Stampar F, Schmitzer V (2013) Anthocyanin and chlorophyll content during poinsettia bract development. Sci Hortic 150:142–145. https://doi.org/10.1016/j.scienta.2012.10.014

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HORMONES CAN INFLUENCE ANTIBIOTIC SUSCEPTIBILITIES EVEN IN MONO- AND CO-CULTURE CONDITIONS

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Abstract: *Pseudomonas aeruginosa* and *Staphylococcus aureus* are known as important nosocomial infectious agents also their co-infections are commonly seen in some patient groups. It is well known that host factors such as hormones have roles in modulation of growth, pathogenesis and susceptibilities to antimicrobials. In our study, the influences of norepinephrine (NE) and melatonin (MEL) on antibiotic susceptibilities were examined in mono and co-culture conditions. Methicilin resistant *Staphylococcus aureus (*MRSA) ATCC 43300 and *Pseudomonas aeruginosa* ATCC 27853 were investigated to determine the minimum inhibitory concentrations (MIC) and minimum bactericidal concentrations (MBC) of ciprofloxacin and gentamicin in the absence/presence of NE (0.0017 and 0.04µg/mL) and MEL (6 and 60 pg/mL) by microdilution method in mono and co-culture. It was found that hormones decreased (among 2-64 fold) MIC and MBC values of both antibiotics for MRSA. However, it was shown that hormones had no effect on MIC values of both antibiotics for *P. aeruginosa*. MIC and MBC values of both antibiotics for co-culture were found to be reduced compared to monoculture of MRSA; were found to be increased compared to monoculture of *P. aeruginosa*. Whereas, hormones decreased MIC values of both antibiotics in co-culture conditions. Our results suggest that both hormones decreased MIC values and it seems that hormones could influence antibiotic susceptibilities in a strain-dependent manner.

Keywords: *Pseudomonas aeruginosa* and *Staphylococcus aureus* mono and co-culture, norepinephrine, melatonin, MIC, MBC, gentamicin, ciprofloxacin, antibiotic susceptibility

1. Introduction

It is well known that methicilin resistant *Staphylococcus aureus* (MRSA) and *Pseudomonas aeruginosa* are the most common hospital-acquired infectious agents; and their co-infections are very prevalent and harmful in some clinical outcomes such as cystic fibrosis, chronic wound infections, ulcers, surgical site infections (Dalton et al., 2011; DeLeon et al., 2014; Murray et al., 2014; Nguyen and Oglesby-Sherrouse, 2016; Briaud et al., 2020b). In recent years, there are many studies focusing on alterations of biological properties of *P. aeruginosa* and *S. aureus* when they are co-existed (Yang et al., 2011; Kim et al., 2015; Ping et al., 2017; Alves et al., 2018; Kahl, 2018; Wijesinghe et al., 2019; Briaud et al., 2020b; Yung et al., 2021); also for treatment of these complex infections, development of some alternative treatment

strategies are gained importance (Kahl, 2018; Yung et al., 2021).

On the other hand, many studies have shown the effects of host hormones, as environmental factors in the host body, on bacterial physiology during the infectious processes (Plotkin and Viselli, 2000; Plotkin et al., 2003; Lyte Mark, 2010; Lyte, Mark, Cryan, 2014; Gumus et al., 2017; Gümüş et al., 2019; Gonçalves et al., 2020; Boukerb et al., 2021; Engelsöy et al., 2021). These studies highlighted a new concept which is known as microbial endocrinology, a bi-directional interaction between host and microbe through interkingdom signaling based on neuroendocrine factors of human and sensor molecules of microorganisms (Lyte Mark, 2010; Lyte, Mark, Cryan, 2014). According to previous studies, microorganisms sense and respond to hormones and regulate their self-growth, virulence, antimicrobial susceptibilities (Freestone et al., 2007; Fteita et al., 2014; Sandrini et al., 2014; Yang et al., 2014; Gumus et al., 2017; Gümüş et al., 2019; Truccollo et al., 2020; Engelsöy et al., 2021; Lyte et al., 2021).

From past to present, most of these studies focused on the interactions between norepinephrine and microorganisms (Belay et al., 2003; Bansal et al., 2007; Freestone et al., 2007; Lyte Mark, 2010; Yang et al., 2014; Lyte, Mark, Cryan, 2014; Sandrini et al., 2014; Xu et al., 2015; Bearson, 2016; Boyanova, 2017; Gümüş et al., 2019; Truccollo et al., 2020; Lucca et al., 2020). It has been reported that norepinephrine affects the behaviors of microorganisms via regulating iron accessing and/or triggers of norepinephrine-induced auto-inducers production (Freestone et al., 2007; Li W, Lyte M, Freestone PP, Ajmal A, Colmer-Hamood J, 2009; Lyte Mark, 2010; Lyte, Mark, Cryan, 2014; Sandrini et al., 2014).

Another mammalian hormone melatonin, have a capacity of binding some metal molecules, such as iron, zinc and copper; it was hypothesized that in this way, melatonin influences microorganism' cytoplasmic regulation (Zhou et al., 2016; Liu et al., 2020; He et al., 2021).

In the present study, we aimed to investigate the roles of norepinephrine (NE) and melatonin (MEL) on antimicrobial susceptibilities of methicillin-resistant *Staphylococcus aureus* and *Pseudomonas aeruginosa* in single and co-culture conditions.

2. Materials and Methods

2.1 Bacteria

We investigated the susceptibilities of MRSA ATCC 43300 and *P. aeruginosa* ATCC 27853 to ciprofloxacin (CIP) and gentamicin (GN) in the presence/absence of NE and MEL using the microdilution method.

2.2 Hormones

We examined two concentrations of norepinephrine (**LNE:** 0.0017 and **HNE:** 0.04μg/mL)] and melatonin (**LMEL:** 6 and **HMEL:** 60 pg/mL) according to their physiological blood levels.

2.3 Antibiotics, Determination of Minimum Inhibition Concentrations (MIC)

MRSA and *P. aeruginosa* were grown in Mueller Hinton broth at 37 °C for 24 hours to provide overnight culture. The initial concentrations of bacteria were arranged to approximately 10^7 CFU/mL. Minimum inhibition concentrations were determined by microdilution method. To obtain a co-culture condition, MRSA and *P. aeruginosa* were added into the same well simultaneously.

Two-fold serial concentrations were prepared between 2.5- 1280 μg/mL for ciprofloxacin and gentamicin in 96-well plates. (CLSI, 2021) CIP and GN were selected

because they are broad-spectrum antibiotics and used widely.

Hormones (20 µL) and bacteria (as co-cultured or separately) (20 µL) were added to wells. The plates were incubated at 37 °C for 24 hours to examine whether the presence of hormones could influence the MIC values. MIC values were considered as the lowest concentration of the antimicrobial agent which inhibited the growth of the microorganism. The experiments were repeated three times independently and all conditions were analyzed twice.

2.4 The Determination of Minimum Bactericidal Concentrations (MBC)

After determining MIC values, 10µl of the contents was aspirated from the wells which showed no growth according to MIC results and inoculated on Mueller Hinton Agar. The plates were incubated at 37 °C for 24 hours. The plates were examined for the presence/absence of the growth of the bacteria. The MBC values were determined as the lowest concentration of the antimicrobial agent which inhibits the growth of bacteria.

3. Results

In our study, the effects of hormones on MIC values of ciprofloxacin and gentamicin for MRSA and *P. aeruginosa* were determined separately and together.

MIC and MBC values of ciprofloxacin and gentamicin for MRSA were 320 and 160 µg/ml, respectively without hormones. As shown in **Table 1**, hormones decreased the MIC values of both ciprofloxacin and gentamicin for MRSA strain. The alterations of MIC values were almost 2-64 fold. Although MBC values of gentamicin were found to be reduced in the presence of hormones, ciprofloxacin did not change except for high concentrations of melatonin.

Table 1. MIC and MBC values of ciprofloxacin and gentamicin (µg/ml) for MRSA with and without hormones

Antibiotics	without hormones	HNE	HMEL	LNE	LMEL
		MIC values			
Ciprofloxacin	320	160	80	160	80
Gentamicin	160	≤2.5	≤2.5	≤2.5	≤2.5
		MBC values			
Ciprofloxacin	320	320	160	320	320
Gentamicin	160	≤2.5	20	10	≤2.5

HNE: high norepinephrine, **LNE:** low norepinephrine, **HMEL:** high melatonin, **LMEL:** low melatonin

Table 2. MIC and MBC values of ciprofloxacin and gentamicin (µg/ml) for *P. aeruginosa* with and without hormones

Antibiotics	without hormones	HNE	HMEL	LNE	LMEL
		MIC values			
Ciprofloxacin	2.5	2.5	2.5	2.5	2.5
Gentamicin	2.5	2.5	2.5	2.5	2.5
		MBC values			
Ciprofloxacin	2.5	2.5	2.5	5	2.5
Gentamicin	2.5	2.5	2.5	5	2.5

HNE: high norepinephrine, **LNE:** low norepinephrine, **HMEL:** high melatonin, **LMEL:** low melatonin

Table 3. MIC and MBC values of ciprofloxacin and gentamicin (µg/ml) for MRSA+ *P. aeruginosa* in co-culture conditions with and without hormones

Antibiotics	without hormones	HNE	HMEL	LNE	LMEL
			MIC values		
Ciprofloxacin	20	10	2.5	5	2.5
Gentamicin	40	2.5	2.5	2.5	2.5
			MBC values		
Ciprofloxacin	40	160	2.5	40	40
Gentamicin	40	2.5	2.5	5	5

HNE: high norepinephrine, **LNE:** low norepinephrine, **HMEL:** high melatonin, **LMEL:** low melatonin

MIC and MBC values of ciprofloxacin and gentamicin for *P. aeruginosa* were determined as 2.5 µg/ml without hormones. No alterations were found in MIC and MBC values of ciprofloxacin and gentamicin. On the other hand, the presence of norepinephrine at low concentration was found to be 2-fold increased the MBC values of both antibiotics (**Table 2**).

In our study, we also examined MIC and MBC values of antibiotics in co-culture conditions with and without hormones. In the absence of hormones, MIC values of ciprofloxacin and gentamicin were determined as 20 and 40 µg/ml, respectively; MBC values of both antibiotics were determined as 40 µg/ml. Furthermore, it was found that hormones decreased (2-16 fold) MIC values of both antibiotics and MBC value of gentamicin was found to be reduced (8-16 fold) in the presence of hormones, in co-culture conditions. Whereas high melatonin decreased MIC value of ciprofloxacin, high norepinephrine increased it. There was no alteration of MIC values of ciprofloxacin in the presence of low hormone concentrations (**Table 3**).

As clearly seen in **Table 1** and **Table 2**, MIC and MBC values of antibiotics for monoculture were found to be changed compared to co-culture conditions. MIC values of ciprofloxacin and gentamicin (320 and 160 µg/ml, respectively) for *S. aureus*-monoculture were found to be reduced (ciprofloxacin and gentamicin were 20 and 40 µg/ml) compared to co-culture conditions. Similarly, MBC values of both antibiotics (ciprofloxacin and gentamicin were 320 and 160 µg/ml) decreased for *S. aureus* strain compared to co-cultures' MBC values (ciprofloxacin and gentamicin were 40 µg/ml) (**Table 1**). On the other hand, it was found that MIC and MBC values of ciprofloxacin and gentamicin (2.5 µg/ml) for monocultures of *P. aeruginosa* were found to be increased compared to co-culture conditions (**Table 2**).

4. Discussions

Lyte and Ernst introduced the concept of microbial endocrinology, a bi-directional interaction between host and microbe through interkingdom signaling based on neuroendocrine factors of human and sensor molecules of microorganisms which have coexisted and known each other for millions of years (Lyte M and Ernst S., 1992; Sharaff and Freestone, 2011). Since then, many studies have shown the effects of host hormones, as environmental factors in the host body, on bacterial physiology during the infectious processes (Kornman and Loesche, 1982; Plotkin and Viselli, 2000; Lyte Mark, 2010; Alves et al., 2014; Gumus et al., 2017; Gümüş et al., 2019; Truccollo et al., 2020; Vidaillac et al., 2020; Engelsöy et al., 2021).

Beyond many physiological features of bacteria, antibiotic susceptibility can also be modulated by hormones helping bacteria for

better growth recovery following antibiotic treatment. Freestone et al., 2012 have indicated that *P. aeruginosa* exposed to sub-inhibitory concentrations of tobramycin in serum-SAPI medium still growth when NE was added. This effect has also been observed in *S. epidermidis* (Freestone et al., 2016). Ambrose et al., 2018 concluded that NE in combination with levofloxacin increased the rate of *Escherichia coli* replication provides an opportunity to enhance the bactericidal effect. On the contrary, it was reported that NE markedly decreased antibacterial activity of tigecycline against multidrug-resistant *Acinetobacter baumanii* strain, but had only a slight effect on the activity of colistin (Inaba et al., 2016).

A mammalian hormone, melatonin (MEL) plays roles as antioxidant, anti-inflammatory, and immunomodulatory; there is a limited number of studies about the possible effects of MEL on microbial behaviors (Tekbas et al., 2008; Bishayi et al., 2016; Zhou et al., 2016; Lee et al., 2018, 2020; Chen et al., 2019; Ganganna et al., 2021). Wiid et al., 1999 suggested that for the treatment of tuberculosis, dosing isoniazid simultaneous with MEL provides at least a threefold increase in the efficacy of the drug *in-vitro*. Kilinçel et al., 2019 observed similar results for antifungals against Candida species; they have shown that MEL in combination with antifungals reduces the MIC values of antifungals. Liu et al., 2020 determined that MEL exhibits synergistic activity with colistin against resistant pathogens both *in-vitro* and *in-vivo*.

Consistent with earlier studies as mentioned above, in our study, we found that NE and MEL, each at two different concentrations, decreased MIC values of ciprofloxacin and gentamicin, and decreased MBC value of gentamicin for MRSA strain. However, MBC value of ciprofloxacin was found to be reduced in the presence of only MEL at high concentration.

For *P. aeruginosa,* there wasn't any difference in antibiotic's MICs. For MBC of both antibiotics, only an increasing was found to be detected in the presence of NE at low concentration. Considering these results, indicating possible effects of hormones on antimicrobial susceptibility depend on hormones' concentrations, antibiotics and bacterial species tested.

MRSA and *P. aeruginosa* are commonly identified as causative agents of polymicrobial infections. Antibacterial treatment of polymicrobial infections can be a challenge, thus there are many studies investigating microbial behaviors and interactions during the polymicrobial infectious processes of *S. aureus* and *P. aeruginosa* (Beaudoin et al., 2017; Orazi and O'Toole, 2017; Radlinski et al., 2017; Tognon et al., 2017; Alves et al., 2018; Kahl, 2018; Briaud et al., 2019, 2020a; Orazi G, Jean-Pierre F, 2020; Yung et al., 2021; Camus et al., 2021).

Although the pathogens are studied in pure culture, it is well known that microorganisms within diverse communities are actively responding to each other. These interactions between species can affect pathogenic behaviors such as virulence, biofilm formation and antibiotic tolerance (Korgaonkar et al., 2013; Vega et al., 2013; Briaud et al., 2019, 2020b). Therefore, our study was carried out to assess antibiotic susceptibilities of MRSA and *P. aeruginosa* against ciprofloxacin and gentamicin also in co-culture conditions. Whereas, MIC and MBC values of both antibiotics for co-culture were found to be reduced compared to monoculture of MRSA; were found to be increased compared to monoculture of *P. aeruginosa*.

There are many studies examining possible mechanisms of alterations in antibiotic susceptibilities in microbial co-existence (Michelsen et al., 2014; Beaudoin et al., 2017; Radlinski et al., 2017; Briaud et al., 2019;

Trizna et al., 2020; Dehbashi et al., 2021). In such a study, it was shown that antibiotic resistance increased via composing polymicrobial biofilm (Beaudoin et al., 2017). In another study, it was found that *S. aureus* co-cultured with *P. aeruginosa* in a wound-like medium, had higher tolerance to tetracycline and gentamicin compared to its single species culture but tolerance to ciprofloxacin was reported to be not changed. Besides, the antibiotic tolerance of *P. aeruginosa* was not changed (DeLeon et al., 2014). Although has not been clarified the specific mechanism, some authors suggested that excreted enzymes of *P. aeruginosa* could produce several aminoglycoside-modifying enzymes (Poole, 2005; DeLeon et al., 2014), which could have inactivated the gentamicin in the co-culture which protects both species.

All these kinds of studies suggest that today, to manage antibiotic resistance, a global health concern, inter-kingdom interactions can be used as a target for new antibacterial therapeutics.

It is still unclear whether NE and MEL have some effects on antibiotic susceptibilities of co-cultured microorganisms. To our knowledge, this is the first report aimed to investigate the effects of hormones on microbial behaviors in co-culture conditions. We found that hormones decreased MIC values when bacteria were grown together. While MBC values of both antibiotics were reduced in the presence of MEL at high concentrations, MBC value of ciprofloxacin was increased in the presence of a high level of NE. On the other hand, low levels of hormones did not affect MBC values of ciprofloxacin. All hormones also decreased MBC values of gentamicin.

Conclusions

In conclusion, our study clearly indicated that, NE and MEL affect antibiotic susceptibilities of MRSA and *P. aeruginosa* strains in mono and co-culture. These possible effects of hormones on bacterial susceptibilities are needed to be investigated furtherly, especially which could be useful for developing new approaches for the treatment of infectious diseases.

Conflict of interest

The authors declare that there are no conflicts of interest related to this article.

References

1. Alves CT, Silva S, Pereira L, Williams DW, Azeredo J, Henriques M (2014) Effect of progesterone on Candida albicans vaginal pathogenicity. Inter J Med Microbiol 304:1011–1017.
2. Alves PM, Al-Badi E, Withycombe C, Jones PM, Purdy KJ, Maddocks SE (2018) Interaction between Staphylococcus aureus and Pseudomonas aeruginosa is beneficial for colonisation and pathogenicity in a mixed biofilm. Pathog Dis 76:1–10.
3. Ambrose PG, VanScoy BD, Adams J, Fikes S, Bader JC, Bhavnani SM, Rubino CM (2018) Norepinephrine in combination with antibiotic therapy increases both the bacterial replication rate and bactericidal activity. Antimicrob Agents Chemother 62(4): e02257-17.
4. Bansal T, Englert D, Lee J, Hegde M, Wood TK, Jayaraman A (2007) Differential effects of epinephrine, norepinephrine, and indole on Escherichia coli O157:H7 chemotaxis, colonization, and gene expression. Infect Immun 75:4597–4607.
5. Bearson BL (2016) Molecular profiling: Catecholamine modulation of gene

expression in escherichia coli o157:H7 and salmonella enterica serovar typhimurium. Adv Experiment Med Biol 874:167–182.

6. Beaudoin T, Yau YCW, Stapleton PJ, Gong Y, Wang PW, Guttman DS, Waters V (2017) Staphylococcus aureus interaction with Pseudomonas aeruginosa biofilm enhances tobramycin resistance. npj Biofilms Microbiomes 3:1–8.
7. Belay T, Aviles H, Vance M, Fountain K, Sonnenfeld G (2003) Catecholamines and in vitro growth of pathogenic bacteria: Enhancement of growth varies greatly among bacterial species. Life Sci 73:1527–1535.
8. Bishayi B, Adhikary R, Nandi A, Sultana S (2016) Beneficial Effects of Exogenous Melatonin in Acute Staphylococcus aureus and Escherichia coli Infection-Induced Inflammation and Associated Behavioral Response in Mice After Exposure to Short Photoperiod. Inflammation 39:2072–2093.
9. Boukerb AM, Cambronel M, Rodrigues S, Mesguida O, Knowlton R, Feuilloley MGJ, Zommiti M, Connil N (2021) Inter-Kingdom Signaling of Stress Hormones: Sensing, Transport and Modulation of Bacterial Physiology. Frontiers in Microbiology 12:1–18.
10. Boyanova L (2017) Stress hormone epinephrine (adrenaline) and norepinephrine (noradrenaline) effects on the anaerobic bacteria. Anaerobe 44:13–19.
11. Briaud P, Bastien S, Camus L, Boyadjian M, Reix P, Mainguy C, Vandenesch F, Doléans-Jordheim A, Moreau K (2020a) P131 Most of Staphylococcus aureus and Pseudomonas aeruginosa coinfecting isolates coexist, a condition that may impact clinical outcomes in cystic fibrosis patients. Front Cell Infect Microbiol 3:10:266. doi: 10.3389/fcimb.2020.00266.
12. Briaud P, Bastien S, Camus L, Boyadjian M, Reix P, Mainguy C, Vandenesch F, Doléans-Jordheim A, Moreau K (2020b) Impact of Coexistence Phenotype Between Staphylococcus aureus and Pseudomonas aeruginosa Isolates on Clinical Outcomes Among Cystic Fibrosis Patients. Front in Cell Infect Microbiol 10:1–10.
13. Briaud P, Camus L, Bastien S, Doléans-Jordheim A, Vandenesch F, Moreau K (2019) Coexistence with Pseudomonas aeruginosa alters Staphylococcus aureus transcriptome, antibiotic resistance and internalization into epithelial cells. Sci Rep 9:1–14.
14. Camus L, Briaud P, Vandenesch F, Moreau K (2021) How Bacterial Adaptation to Cystic Fibrosis Environment Shapes Interactions Between Pseudomonas aeruginosa and Staphylococcus aureus. Front Microbiol 12:1–16.
15. Chen X, Sun C, Laborda P, He Y, Zhao Y, Li C, Liu F (2019) Melatonin treatments reduce the pathogenicity and inhibit the growth of Xanthomonas oryzae pv. oryzicola. Plant Pathol 68:288–296.
16. CLSI, Clinical and Laboratory Standards Institute, M07– A10: Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria That Grow Aerobically; Approved Standard, Vol. 35, CLSI, Wayne, PA, USA, 31th edition, 2021
17. Dalton T, Dowd SE, Wolcott RD, Sun Y, Watters C, Griswold JA, Rumbaugh KP (2011) An in vivo polymicrobial biofilm wound infection model to study interspecies interactions. PLoS ONE 2011;6(11):e27317. doi: 10.1371/journal.pone.0027317.
18. Dehbashi S, Alikhani MY, Tahmasebi H, Arabestani MR (2021) The inhibitory effects of Staphylococcus aureus on the antibiotic susceptibility and virulence factors of Pseudomonas aeruginosa: A549 cell line model. AMB Express 30;11(1):50. doi: 10.1186/s13568-021-01210-y.

19. DeLeon S, Clinton A, Fowler H, Everett J, Horswill AR, Rumbaugh KP (2014) Synergistic interactions of Pseudomonas aeruginosa and Staphylococcus aureus in an In vitro wound model. Infect Immun 82:4718–4728.
20. Engelsöy U, Svensson MA, Demirel I (2021) Estradiol Alters the Virulence Traits of Uropathogenic Escherichia coli. Front Microbiol 20;12:682626. doi: 10.3389/fmicb.2021.682626.
21. Freestone PP, Hirst RA, Sandrini SM, Sharaff F, Fry H, Hyman S, O'Callaghan C (2012) Pseudomonas aeruginosa-catecholamine inotrope interactions: A contributory factor in the development of ventilator-associated pneumonia? Chest 142:1200–1210.
22. Freestone PPE, Al-Dayan N, Lyte M (2016) Staphylococci, catecholamine inotropes and hospital-acquired infections. Adv Exp Med Biol 874:183–199.
23. Freestone PPE, Haigh RD, Lyte M (2007) Specificity of catecholamine-induced growth in Escherichia coli O157:H7, Salmonella enterica and Yersinia enterocolitica. FEMS Microbiol Lett 269:221–228.
24. Fteita D, Könönen E, Söderling E, Gürsoy UK (2014) Effect of estradiol on planktonic growth, coaggregation, and biofilm formation of the Prevotella intermedia group bacteria. Anaerobe 27:7–13.
25. Ganganna A, Rudariah CB, Rao R, Prakash VM (2021) Antibacterial activity of melatonin against prime periodontal pathogens: An in vitro study. J Intern Oral Health 13:164–168.
26. Gonçalves B, Bernardo R, Wang C, Schröder MS, Pedro NA, Butler G, Azeredo J, Henriques M, Pereira Mira N, Silva S (2020) Effect of progesterone on Candida albicans biofilm formation under acidic conditions: A transcriptomic analysis. Intern J Med Microbiol 310:151414.
27. Gümüş D, Kalaycı Yüksek F, Sefer Ö, Yörük E, Uz G, Anğ Küçüker M (2019) The roles of hormones in the modulation of growth and virulence genes' expressions in UPEC strains. Microb Pathog 132:319–324.
28. Gumus D, Yoruk E, Kalayci-Yuksek F, Uz G, Topal-Sarikaya A, Ang-Kucuker M (2017) The effects of insulin and glucose on different characteristics of a UPEC: Alterations in growth rate and expression levels of some virulence genes. Clin Lab 63:1589–1597.
29. He F, Wu X, Zhang Q, Li Y, Ye Y, Li P, Chen S, Peng Y, Hardeland R, Xia Y (2021) Bacteriostatic Potential of Melatonin: Therapeutic Standing and Mechanistic Insights. Front Immunol 12.
30. Inaba M, Matsuda N, Banno H, Jin W, Wachino J ichi, Yamada K, Kimura K, Arakawa Y (2016) In vitro reduction of antibacterial activity of tigecycline against multidrug-resistant Acinetobacter baumannii with host stress hormone norepinephrine. Intern J Antimicrob Agents 48:680–689.
31. Kahl BC (2018) Staphylococcus aureus and Pseudomonas aeruginosa Respiratory Tract Coinfection - What Can We Learn from Animal Models? J Infect Dis 217:854–856.
32. Kilinçel Ö, Çalişkan E, Şahin I, Öztürk CE, Kiliç N, Öksüz Ş (2019) The effect of melatonin on antifungal susceptibility in planktonic and biofilm forms of Candida strains isolated from clinical samples. Med Mycol 57:45–51.
33. Kim S, Yoon Y, Choi KH (2015) Pseudomonas aeruginosa DesB promotes staphylococcus aureus growth inhibition in coculture by controlling the synthesis of HAQs. PLoS ONE 10:1–16.

34. Korgaonkar A, Trivedi U, Rumbaugh KP, Whiteley M (2013) Community surveillance enhances Pseudomonas aeruginosa virulence during polymicrobial infection. Proc Natl Acad Sci U S A 110:1059–1064.
35. Kornman KS, Loesche WJ (1982) Effects of estradiol and progesterone on Bacteroides melaninogenicus and Bacteroides gingivalis. Infect Immun 35:256–263.
36. Lee SJ, Lee HJ, Jung YH, Kim JS, Choi SH, Han HJ (2018) Melatonin inhibits apoptotic cell death induced by Vibrio vulnificus VvhA via melatonin receptor 2 coupling with NCF-1 article. Cell Death Dis 19;9(2):48. doi: 10.1038/s41419-017-0083-7.
37. Lee YM, Park JP, Jung YH, Lee HJ, Kim JS, Choi GE, Han HJ, Lee SJ (2020) Melatonin restores Muc2 depletion induced by V. vulnificus VvpM via melatonin receptor 2 coupling with Gαq. J Biomed Sci 27:1–14.
38. Li W, Lyte M, Freestone PP, Ajmal A, Colmer-Hamood J HA (2009) Norepinephrine represses the expression of toxA and the siderophore genes in Pseudomonas aeruginosa. FEMS Microbiol Lett 299(1):100-9. doi: 10.1111/j.1574-6968.2009.01739.x
39. Liu Y, Jia Y, Yang K, Tong Z, Shi J, Li R, Xiao X, Ren W, Hardeland R, Reiter RJ, Wang Z, Wang Z, Ren W, Liu Y (2020) Melatonin overcomes MCR-mediated colistin resistance in Gram-negative pathogens. Theranostics 10:10697–10711.
40. Lucca V, Apellanis Borges K, Quedi Furian T, Borsoi A, Pippi Salle CT, de Souza Moraes HL, Pinheiro do Nascimento V (2020) Influence of the norepinephrine and medium acidification in the growth and adhesion of Salmonella Heidelberg isolated from poultry. Microb Pathog 138:103799.
41. Lyte JM, Shrestha S, Wagle BR, Liyanage R, Martinez DA, Donoghue AM, Daniels KM, Lyte M (2021) Serotonin modulates Campylobacter jejuni physiology and in vitro interaction with the gut epithelium. Poultry Sci 100(3):100944. doi: 10.1016/j.psj.2020.12.041.
42. Lyte M and Ernst S. (1992) Catecholamine induced growth of gram negative bacteria. Life Sci 50:203–212.
43. Lyte Mark FPPE (2010) Microbial Endocrinology. Springer, New York
44. Lyte, Mark, Cryan JF (eds) (2014) Microbial Endocrinology: The Microbiota-Gut-Brain Axis in Health and Disease, Springer, New York
45. Michelsen CF, Christensen AMJ, Bojer MS, Høiby N, Ingmer H, Jelsbak L (2014) Staphylococcus aureus alters growth activity, autolysis, and antibiotic tolerance in a human host-adapted Pseudomonas aeruginosa lineage. J Bacteriol 196:3903–3911.
46. Murray JL, Connell JL, Stacy A, Turner KH, Whiteley M (2014) Mechanisms of synergy in polymicrobial infections. J Microbiol 52:188–199.
47. Nguyen AT, Oglesby-Sherrouse AG (2016) Interactions between Pseudomonas aeruginosa and Staphylococcus aureus during co-cultivations and polymicrobial infections. Appl Microbiol Biotechnol 100:6141–6148.
48. Orazi G, Jean-Pierre F OG (2020) Pseudomonas aeruginosa PA14 Enhances the Efficacy of Norfloxacin against Staphylococcus aureus Newman Biofilms Giulia. J Bacteriol 25;202(18):e00159-20. doi: 10.1128/JB.00159-20.
49. Orazi G, O'Toole GA (2017) Pseudomonas aeruginosa alters Staphylococcus aureus sensitivity to vancomycin in a biofilm model of cystic fibrosis infection. mBio 8:1–17.

50. Ping O, Mao S, Xuewen H, Kaiyu W, Zhongqiong Y, Hualin F, Yinglun L, Yi G, Gang S, Changliang H, Xiaoxia L, Weiming L, Lixia L, Yunfeng Z, Xu S, Lizi Y (2017) Sclareol protects Staphylococcus aureus-induced lung cell injury via inhibiting alpha-hemolysin expression. J Microbiol Biotechnol 27:19–25.
51. Plotkin BJ, Roose RJ, Erikson Q, Viselli SM (2003) Effect of Androgens and Glucocorticoids on Microbial Growth and Antimicrobial Susceptibility. Curr Microbiol 47:514–520.
52. Plotkin BJ, Viselli SM (2000) Effect of insulin on microbial growth. Curr Microbiol 41:60–64.
53. Poole K (2005) Aminoglycoside resistance in Pseudomonas aeruginosa. Antimicrob Agents Chemother 49:479–487.
54. Radlinski L, Rowe SE, Kartchner LB, Maile R, Cairns BA, Vitko NP, Gode CJ, Lachiewicz AM, Wolfgang MC, Conlon BP (2017) Pseudomonas aeruginosa exoproducts determine antibiotic efficacy against Staphylococcus aureus. PLoS Biology 15:1–25.
55. Sandrini S, Alghofaili F, Freestone P, Yesilkaya H (2014) Host stress hormone norepinephrine stimulates pneumococcal growth, biofilm formation and virulence gene expression. BMC Microbiol 14:1–12.
56. Sharaff F, Freestone P (2011) Microbial Endocrinology. Cent Euro J Biol 6:685–694.
57. Tekbas OF, Ogur R, Korkmaz A, Kilic A, Reiter RJ (2008) Melatonin as an antibiotic: New insights into the actions of this ubiquitous molecule. J Pineal Res 44:222–226.
58. Tognon M, Köhler T, Gdaniec BG, Hao Y, Lam JS, Beaume M, Luscher A, Buckling A, Van Delden C (2017) Co-evolution with Staphylococcus aureus leads to lipopolysaccharide alterations in Pseudomonas aeruginosa. ISME J 11:2233–2243.
59. Trizna EY, Yarullina MN, Baidamshina DR, Mironova A V., Akhatova FS, Rozhina E V., Fakhrullin RF, Khabibrakhmanova AM, Kurbangalieva AR, Bogachev MI, Kayumov AR (2020) Bidirectional alterations in antibiotics susceptibility in Staphylococcus aureus—Pseudomonas aeruginosa dual-species biofilm. Sci Rep 10:1–18.
60. Truccollo B, Whyte P, Bolton DJ (2020) An investigation of the effect of catecholamines and glucocorticoids on the growth and pathogenicity of Campylobacter jejuni. Pathogens 9:1–15.
61. Vega NM, Allison KR, Samuels AN, Klempner MS, Collins JJ (2013) Salmonella typhimurium intercepts Escherichia coli signaling to enhance antibiotic tolerance. Proc Natl Acad Sci U S A. 110:14420–14425.
62. Vidaillac C, Yong VFL, Aschtgen MS, Qu J, Yang S, Xu G, Seng ZJ, Brown AC, Ali MK, Jaggi TK, Sankaran J, Foo YH, Righetti F, Nedumaran AM, Aogáin M Mac, Roizman D, Richard JA, Rogers TR, Toyofuku M, Luo D, Loh E, Wohland T, Czarny B, Horvat JC, Hansbro PM, Yang L, Li L, Normark S, Normark BH, Chotirmall SH (2020) Sex steroids induce membrane stress responses and virulence properties in Pseudomonas aeruginosa. mBio 11:1–19.
63. Wiid I, Hoal-Van Helden E, Hon D, Lombard C, Van Helden P (1999) Potentiation of isoniazid activity against Mycobacterium tuberculosis by melatonin. Antimicrob Agents Chemother 43:975–977.
64. Wijesinghe G, Dilhari A, Gayani B, Kottegoda N, Samaranayake L, Weerasekera M (2019) Influence of Laboratory Culture Media on in vitro

Growth, Adhesion, and Biofilm Formation of Pseudomonas aeruginosa and Staphylococcus aureus. Med Prin Pract 28:28–35.

65. Xu F, Wu C, Guo F, Cui G, Zeng X, Yang B, Lin J (2015) Transcriptomic analysis of Campylobacter jejuni NCTC 11168 in response to epinephrine and norepinephrine. Front Microbiol 6:1–11.
66. Yang L, Liu Y, Markussen T, Høiby N, Tolker-Nielsen T, Molin S (2011) Pattern differentiation in co-culture biofilms formed by Staphylococcus aureus and Pseudomonas aeruginosa. FEMS Immunol Med Microbiol 62:339–347.
67. Yang Q, Anh NDQ, Bossier P, Defoirdt T (2014) Norepinephrine and dopamine increase motility, biofilm formation, and virulence of Vibrio harveyi. Front Microbiol 5:1–12.
68. Yung DBY, Sircombe KJ, Pletzer D (2021) Friends or enemies? The complicated relationship between Pseudomonas aeruginosa and Staphylococcus aureus. Mol Microbiol 116:1–15.
69. Zhou W, Zhang X, Zhu CL, He ZY, Liang JP, Song ZC (2016) Melatonin receptor agonists as the “perioceutics” agents for periodontal disease through modulation of Porphyromonas gingivalis virulence and inflammatory response. PLoS ONE 10;11(11):e0166442.
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SPONTANEOUS CORMOPHYTES FROM THE ROMANIAN FLORA KNOWN AS MEDICINAL PLANTS IN OTHER COUNTRIES

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Abstract: Romania's medicinal flora is an important source of raw material for pharmacological research and drug production. By consulting the pharmacological literature on authenticated scientific sources such as Google Scholar, 15 species of medicinal plants existing in the Romanian flora, but not used in the traditional Romanian medicine, were identified. In accordance with the World Health Organization's call on all countries to use traditional medicine in primary care, we set out to help complete the list of medicinal plants in Romania using information from traditional medicine in other countries.

Keywords: medicinal plants, flora, Romania, foreign countries

1. Introduction

From the beginning of the appearance of man on Earth, plants have been used as food, shelter and sources of natural substances prepared for the treatment of diseases that occur during life.

How they discovered medicinal plants? By observing nature, understanding the connections between plants and animals, between climate and plants. Thus, they observed that animals preferred certain species while they were sick, that birds consumed only certain fruits that were edible.

The number of flowering plant species used for medicinal purposes today reached 50,000 out of a total of 422,127 known flowering plant species (Govaert, 2001, Schippman et al., 2002).

Romania has a rich vegetation and flora and is the only country that has 5 of the 11 biogeographical regions of Europe, respectively the steppe, pontic, panonic, continental, alpine region. Of the 3700 spontaneous species in Romania (Ciocârlan, 2009), over 756 species of medicinal plants are identified, of which 126 species are included on the Red List of Superior Plants, and for 122 species the collection is prohibited (Bujorean, 1936; Butura, 1979; Dihoru and Boruz, 2014).

Some of the medicinal species are collected and marketed for the extraction of various types of biologically active substances. Some of these are relatively well known by the inhabitants of Romania, but species with medicinal potential must be identified taxonomically only by botanists.

In accordance with the urging of the World Health Organization to all countries to use traditional medicine in primary care (WHO

1987), we set out to help complete the list of medicinal plants in Romania using information from traditional medicine of other countries.

The species mentioned in the study are mostly Eurasian phytogeographic element which explains the presence and knowledge of these species as medicinal plants in countries like Iraq, Iran, Bangladesh and India.

2. Materials and methods

The existing ethno-pharmaceutical literature was consulted on authenticated scientific sources such as Google Scholar which often provides links to full text PDF file about the medicinal species used by traditional and modern medicine.

The consultation of the literature allowed the identification of the medicinal species used in other countries and existing in the Romanian flora but not used.

3. Results and discussion

We specify the species of plants from the Romanian flora that are used in the traditional medicine of other countries but not known as medicinal plants in our country.

There were found 15 species of unused medicinal cormophytes in Romania.

Among these species *Amaranthus viridis* is rare, *Sisymbrium irio* is very rare, *Pinguicula alpina* is sporadic, *Ranunculus thora* is european endemit.

These species grow in different habitats distributed from the steppe to the alpine meadows, classified in 12 botanical families. The Asteraceae family contains 3 species, the Brassicaceae and Ranunculaceae families contain 2 species and the other families have one species each.

The species mentioned in this study are traditionally used in diseases of the auditory, digestive, respiratory system, nervous system, lipid metabolism, in the elimination of intestinal parasites etc. (**Table 1**).

Table 1. Cormophytes from the Romanian flora known as medicinal plants in the traditional medicine of other countries

Current Nr.	Scientific name; Vernacular name (Local name), Family; phytosociological taxon	Part Used	Preparation	Uses/ailments ameliorated	References
1.	*Allium scorodoprasum;* Aiul șarpelui; *Liliaceae; Prunion spinosae; Ulmenion*	Bulbils and leaves	Plant is eaten raw	Antihypertensive, high cholesterol	Hayta et al., 2014
2.	*Amaranthus viridis*; *Amaranthaceae*	Whole plant	Potherbs	Amenorrhoea, menorrhagia, haemoptysis, bleeding ulcer	Qureshi et al., 2008
3.	*Artemisia scoparia*; Pelin de mături; *Asteraceae; Festucion valesiacae*	Whole plant	Decoction Powdered	Asthma, spasms and nervous diseases, jaundice, anti-inflammatory to toothache Skin diseases	Qureshi et al., 2008
4.	*Brasica rapa*; Rapița *Brassicaceae;*	Seeds	Oil (Warm)	Applied externally, ear drop, sciatica	Semwal et al., 2010

	Chenopodietalia albi				
5.	*Carduus nutans L.* subsp. *nutans*; Ciulin; *Asteraceae; Onopordion*	Aerial parts	Infusion	Sedative, gastrointestinal disorders	Hayta et al., 2014
6.	*Elaeagnus angustifolia;* s Sălcioară*; Elaeagnaceae*	Fruit and seed	Powdered	Diarrhoea and osteoporosis (oral)	Naghibi et al., 2014
7.	*Falcaria vulgaris;* Dornic; *Apiaceae; Convolvio-Agropyrion*	Leaf	Powdered	Wounds	Naghibi et al., 2014
8.	*Gentiana acaulis;* Cupe; *Gentianaceae*; *Potentillo ternatae-Nardion*	Roots	Decoction	Gastrointestinal disorders	Vitalini et al., 2009
9.	*Oxalis corniculata*; *Oxalidaceae; Lolio-Plantaginion*	Leaves	Extract	Open sores, pimples, skin disease	Semwal et al., 2010
10.	*Pinguicula alpina; Lentibulariaceae; Caricetalia davallianae*	Leaves	Juice	External use: wound, cut healing	Vitalini et al., 2009
11.	*Phlomis herba-venti ssp. pungens;* Scorogoi; *Lamiaceae; Festucion valesiacae*	Aerial parts	Infusion	Anthelmintic, stomach-ache	Mirdeilami et al., 2011
12.	*Ranunculus thora*; *Ranunculaceae; Seslerion bielzii*	Leaves	Fresh put on the painful part	Arthritis, rheumatism, anti-inflammatory	Vitalini et al., 2009
13.	*Sisymbrium irio*; *Brassicaceae; Sisymbrion*	Leaves, seeds	Infusion	Throat and chest infections, expectorant stimulant and antiseptic	Qureshi et al., 2008
14.	*Sonchus arvensis*; *Asteraceae; Chenopodietalia albi*	Whole plant	Infusion	Cough, bronchitis, asthma. Phthisis. jaundice	Qureshi et al., 2008
15.	*Viola biflora*; Toporași galbeni; *Violaceae; Cystopteridion*	Fruit	Capsule paste	Diaphoretic and intestinal pain	Semwal et al., 2010

In traditional medicine, the use of medicinal plants is based on observations and empirical knowledge. For some of the 15 species mentioned in our list, the medicinal properties are confirmed by laboratory research.

Falcaria vulgaris is a Eurasian phytogeographic element, a segetal, ruderal and frequent species from the plain to the storey of the oak. Powder of *Falcaria vulgaris* showed gastroprotective effect of against ethanol-induced ulcers (it is a rich source of tannins and ascorbic acid) (Khazaei and Salehi, 2006).

Carduus nutans. subsp. *nutans* is a Eurasian phytogeographic element, frequent from the plain to the storey of the beech. It is

used to treat throat cancer (contain significant amount of polyphenols and flavonoids) (Bozyel et al., 2019).

Allium scorodoprasum is a central European phytogeographic element, frequent from the forest-steppe to the storey of the oak. Methanol extract of *A. scorodoprasum* has important antioxidant capacity (contain phenols and flavonoids) (Mitic et al., 2014).

Sisymbrium irio is a Mediterranean phytogeographic element, ruderal species, rare, in the counties of Mures, Alba, Prahova, Vaslui, Neamt, Iasi (Sârbu et al., 2013). Crude extracts of the seeds were tested for antipyretic, analgesic and antimicrobial effects (Hailu et al., 2019)

Amaranthus viridis, rare species identified in Constanta County (Sârbu et al., 2013), adventitious, origin South America. This species has the potential to treat diabetes mellitus and complications owing to its antidiabetic and antihyperlipidemic effect (contain phytoconstituents like steroids, alkaloids, glycosides, flavonoids, carbohydrates, amino acids, proteins and phenolic compounds) (Pandhare et al., 2012).

Viola biflora is a Circumpolar phytogeographic element, frequent from the storey of the beech to the storey of the subalpine. The alpine violet *Viola biflora* is a rich source of cyclotides. The cyclotides have been shown to be cytotoxic, anti-HIV, antimicrobial and hemolytic agents. (Herrmann et al., 2008)

Oxalis corniculata is a Mediterranean phytogeographic element, a sub spontaneous segetal and ruderal species. It showed activity in cough, scabies, itching, dysentery, anemia, piles, dyspepsia and fever (Rahman et al., 2014)

Conclusions

From the ethnopharmacological literature of the countries around Romania, close or less close, it was possible to identify species existing in the spontaneous flora of Romania with medicinal qualities in a wide range of diseases according to the traditional medicine.

Our study outlines the useful plant resources beneficial for the health of the inhabitants of our country by completing the list of medicinal plants in Romania.

Medicinal species is an important source of raw materials in pharmacological research and drug production in Romania.

The use of plants in traditional medicine has allowed the accumulation of much information that can be confirmed or refuted by research in specialized laboratories.

Conflict of interest

The authors declare that there are no conflicts of interest related to this article.

References

1. Bozyel ME, Merdamert Bozyel E, Canlı K, Altuner EM (2019) Anticancer Uses of Medicinal Plants in Turkish Traditional Medicine. KSU J. Agric Nat. 22(Suppl. 2): pp 465-484.
   DOI: 10.18016/ ksutarimdoga.vi.550334
2. Bujorean G (1936) Boli, leacuri și plante de leac cunoscute de țărănimea română. Publ Period a Asoc Astra [Internet]. Editura Asociatiunii Astra Sibiu.;26:1–398 Available from: http://dspace.bcucluj.ro/handle/123456789/68446
3. Butură V (1979) Enciclopedie de etnobotanică românească. București: Editura Științifică și Enciclopedică;

4. Ciocârlan V (2009) Flora ilustrată a României. Pteridophyta et Spermatophyta. 1141 pp. Edit. Ceres. Bucureşti
5. Dihoru Gheorghe, Boruz Violeta (2014) The list of main spontaneous medicinal plants from Romania, Analele Uniiversităţii din Craiova, seria Agricultură – Montanologie – Cadastru (Annalls of the University of Craiova - Agriculture, Montanology, Cadastre Series) Vol.. XLIV
6. Govaert R (2001) How many species of seed plants are there? Taxon 50, pp 1085–1090
7. Hailu T, Gupta RK, Rani A (2019) Sisymbrium irio L.: A Herb used in the Unani system of medicine for broad spectrum therapeutical applications, Indian Journal of Traditional Knowledge Vol 18(1), pp 140-143
8. Hayta Sukru, Polat Rıdvan, Selvi Selami (2014) Traditional uses of medicinal plants in Elazığ (Turkey), Journal of Ethnopharmacology 154 (2014) pp 613–623
9. Herrmann A, Myline J, Karlsson G (2008) The alpine violet, Viola biflora, is a rich source of novel cyclotides with potent cytotoxic cytotoxicity, Ohytochemistry, vol 69, no 4, pp 939-952
10. Khazaei Mozafar, Salehi Hossein (2006) Protective Effect of *Falcaria vulgaris* Extract on Ethanol Induced Gastric Ulcer in Rat, Iranian Journal of Pharmacology and therapeutics (IJPT), vol. 5, no. 1, pp 43-46
11. Mirdeilami Seyedeh Zohreh, Barani Hossein, Mazandarani Masumeh, Heshmati Ali Gholam (2011) Ethnopharmacological Survey of Medicinal Plants in Maraveh Tappeh Region, North of Iran, Iranian Journal of Plant Physiology, 2(1), pp 325 - 336.
12. Mitic V. D., Stankov-Jovanovic V P, Ilic M D, Cvetkovic J S, Dimitrijevic M V, Stojanovic G S (2014) In vitro antioxidant activity of methanol extract of *Allium scorodoprasum*, Bulgarian Journal of Agricultural Science, 20, no 5, pp 1130-1136
13. Naghibi F, Esmaeili S, Malekmohammadi M, Hassanpour A, Mosaddegh M (2014) Ethnobotanical survey of medicinal plants used traditionally in two villages of Hamedan, Iran, Research Journal of Pharmacognosy (RJP) 1(3) : pp 7-14
14. Pandhare Ramdas, Balakrishnan Sangameswaran, Mohite Popat, Khanage Shantaram (2012) Antidiabetic and antihyperlipidaemic potential of *Amaranthus viridis* (L.) Merr. in streptozotocin induced diabetic rats, Asian Pacific Journal of Tropical Disease, S180-S185
15. Qureshi S J, Khan M A, Ahmad M (2008) A survey of useful medicinal plants of Abbotttabad in northern Pakistan, Trakia Journal of Sciences, Vol. 6, no. 4, pp 39-51
16. Rahman Mahbubur A H M, Mosharof Hossain M, Rafiul Islam A K M (2014) Taxonomy and Medicinal Uses of Angiosperm Weeds in the Wheat Field of Rajshahi, Bangladesh, Frontiers of Biological and Life Sciences, 2(1): pp 8-11 DOI: 10.12966/fbls.03.03.2014
17. Sârbu I, Ștefan N, Oprea A (2013) *Plante vasculare din Romania. Determinator ilustrat de teren*, Edit. Victor B Victor, București
18. Schippman U, Leaman J Danna, Cunningham A B (2002) Impact of cultivation and Gathering of Medicinal Plants on Biodiversity: Global Trends and Issue, FAO 2002, Biodiversity and the Ecosystem Approach in Agriculture, Forestry and Fisheries. Satellite Event on the occasion of the Ninth Regular Session of the Commision on Genetic Resources for Food and Agriculture. Rome, pp 12-13

19. Semwal DP, Saradhi P Pardha, Kala CP, Sajwan BS (2010) Medicinal plants used by local Vaidyas in Ukhimath block, Uttarakhand, Indian Journal of Traditional Knowledge , Vol 9 (3), pp 480-485
20. Vitalini Sara, Tomèa Franca, Fico Gelsomina (2009) Traditional uses of medicinal plants in Valvestino (Italy), Journal of Ethnopharmacology 121 (2009) pp106–116
21. WHO (1987). Global Medium-Term Programme (Traditional Medicine) covering a specific period 1990-1995. (WHO document TRM/MTP/87.1)

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