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Impact of efficiency of digital public administration services on quality of life

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Abstract: In the public administration sector, digitalisation is manifested in introducing electronic services for citizens and businesses to simplify interaction with government agencies and improve the accessibility of public services. To measure the effectiveness of digital public administration services, the E-Participation Index, Online Service Index, and Telecommunication Infrastructure Index were used for 143 countries in 2003-2022. Indicators of the population's quality of life were chosen based on its material well-being, the population's health level, the country's political stability and security, labour safety, the level of education and qualifications, involvement in public life, democratic rights and freedoms. To level the uneven data distribution, the sample countries were clustered by the indicators of civil services using the Kohonen self-organising map method. As a result, three clusters of countries with high, medium and low levels of digital services were formed. Then, the canonical analysis showed that the effectiveness of digital public administration services has the most significant impact on citizens' well-being, life expectancy, and digital inclusion. As a result, neural network predictive models were built to forecast the three most relevant characteristics of the population's life quality for each cluster of countries dependent on each indicator of the effectiveness of digital public administration services. The obtained results can be used in developing digital transformation strategies for the public administration of countries with different types of economic development.

Keywords: e-participation, online service, public administration, quality of life.

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Introduction

The modern digitalisation process covers various areas of life, changing approaches to the interaction between citizens and the state, optimising business processes and improving the overall quality of services. In the public administration sector, digitalisation is manifested in the introduction of electronic services for citizens and businesses, online consultations, electronic document management systems and e-voting. This simplifies interaction with government agencies and improves the availability of services. Government agencies allow citizens and businesses to receive various services online. This may include electronic forms, online applications, e-voting and other electronic services. Online chat systems, electronic feedback forms, and platforms for discussing and expressing citizens' views are being developed to facilitate communication between citizens and government agencies.

The introduction of electronic data management systems allows for the efficient collection, storage and processing of information, simplifying administrative processes and helping to manage public resources. Providing the public with open access to government agencies' data helps to ensure transparency and encourages civic participation in public affairs. Providing access to electronic financial services, such as online tax reporting, electronic payments and other financial transactions, simplifies the interaction of citizens and businesses with tax and financial services. Electronic document management allows replacing traditional paper-based processes with more efficient electronic ones, speeding up decision-making and facilitating document circulation.

In today's digital age, the development of technology and the introduction of digital services by the state are becoming critical factors in transforming the social, economic and political landscape. One of the crucial areas of influence of these innovations is the population's quality of life. The study of the relationship between the level of development of the state's digital services and the improvement of citizens' living conditions is critical in the context of rapid technological development. The state's digital services are becoming a convenient tool for obtaining services and an essential factor in forming a high-quality infrastructure and educational, medical, and social environment. In this study, we will try to reveal important aspects of the interaction between the digital development of the state and the quality of life of the population, determine the impact of digital services on various spheres of life and highlight the possibilities of improving the quality of life through modern technological innovations.

1. Literature review

The implications of Industry 4.0 and 5.0 have been rapidly applied in various spheres of society over the past twenty years. Some cyber-physical solutions have been successfully implemented, such as telemedicine in the medical field (Graf & Burrell,

2024), humanoid robots in the social sphere (Halicka & Surel, 2022), satellite systems in agriculture (Kubata et al, 2024), virtual reality in tourism (Hoang et al., 2023), and the conservation of flora and fauna in national parks and forests (Folgado-Fernández et al., 2023). Digital transformations in management processes have not been left out either, among them are Internet banking in finance (DingYi et al., 2024), neural networks in risk management (Roba & Moulay, 2024), e-government in public administration (Pakhnenko & Kuan, 2023), information and communication platforms for small and medium-sized enterprises (Ivashchenko et al, 2017), cloud ERP of large companies (Lozano Almansa et al., 2023), gamification in HR management (Prasad & Mangipudi, 2021), Fintech in the banking sector (Andronie et al., 2023), Internet of Things (IoT) in marketing (Constantinescu & Edu, 2022), etc.

A separate issue is Smart Cities, which have demonstrated greater readiness to overcome global crises such as COVID-19, despite still having some healthcare-related problems (Kuzior et al., 2022). They have become associated with the Sustainable Development Goals, the achievement of which contributes to solving social, economic, cultural and other problems in the world (Hrytsenko et al., 2024). Smart Cities also positively impact public administration and its digitalisation (Kuzior et al., 2023a; Hedegaard et al., 2024). This is also relevant for governance at the regional level (Ivashchenko et al., 2020). Smart Cities help ensure equal rights for the population by providing access to various digital services (Springs, 2024a). Digital services are also one of the areas of the city's citizen security strategy, which is manifested in the rapid response and detection of situations that threaten the life and health of the population (Springs, 2024b).

Thus, the mentioned technologies have a significant positive impact on improving the living standards of the population in general, increasing the efficiency of various processes and providing new opportunities for the development of society. That is why public interest in digital transformation has been growing since 2014, but it peaked in 2020-2023 and correlates with the spread of COVID-19 (Ponomarenko et al., 2024). On the one hand, the pandemic has become an incentive for the active introduction of digital technologies in various spheres of society (Mańka-Szulik et al., 2024). On the other hand, it has caused a financial and economic crisis in the world and a deterioration in the lives of certain population segments (Dobrovolska et al., 2022).

Today, digitalisation is more closely linked to business, education, economic development, and cybersecurity (Kozhushko, 2023). The results of Industry 4.0 and 5.0 are the drivers that stimulate the development of the business environment, which, in turn, also affects the level of digitalisation (Mursalov et al., 2023). For example, Bilan et al. (2022) and Červinka (2023) have shown close links between artificial intelligence and companies' development, change, management, and culture. Digital transformations increase the profitability and competitiveness of companies (Straková et al., 2022). It should not be underestimated that the digitalisation level significantly impacts human resources, increasing their potential and productivity (Filemon et al., 2024; Dobrovolska et al., 2024). Companies' active

promotion of digital services leads to increased customer satisfaction with their services (Demirel, 2022). Ensuring sustainable development goals also requires new business models based on information and computer technologies (Jean Vasile et al., 2023). For example, implementing Digital Servitisation allows for transitioning to service-oriented business models (Rakic et al., 2022).

Vasylieva et al. (2023) have shown that the level of primary education affects the quality of life in a few countries, which is typical for the least developed countries and not for developed and developing countries. On the other hand, the population's digital literacy level increases the chances of obtaining a high-paying job, which is possible with the proper education (Didenko et al., 2023; Andrei et al., 2021). The level of digital skills has dramatically affected the well-being of employees in companies, especially during and after the pandemic (Cramarenco et al., 2023; Androniceanu et al., 2023; Androniceanu, 2025; Androniceanu &Colesca, 2025). Today, humanity wants to consolidate its dominance in interaction with artificial intelligence technologies (Tugui et al., 2022). However, the growth of Internet use still has a negative impact on human development (Androniceanu & Georgescu, 2023). It also harms the protection of personal information. Among residents of EU countries such as Bulgaria, Romania, Serbia, Albania, North Macedonia, and Bosnia and Herzegovina, this problem is quite acute (Yarovenko et al., 2023).

One of the areas of formation of state strategies for ensuring economic security and development of the national economy is the development of digital services (Katkova et al., 2022; Zámek & Zakharkina, 2024). Digital transformations contribute to the growth of countries' economies, strengthen their competitiveness in the international market, protect national interests, improve the welfare of their population and ensure macro stability (Kusairi et al., 2023; Tiutiunyk et al., 2021). Integrating digital technologies with sustainable development strategies increases financial benefits for countries (Wang et al., 2024). It should be noted that digitalisation strategies are being actively implemented in public services, resulting in an increase in the quality of public administration and economic and social efficiency (Androniceanu, 2023; Dahmani et al., 2022). However, there is a significant digital divide between countries, which can be seen even in the EU (Kolupaieva & Tiesheva, 2023; Małkowska et al., 2021). This can be a serious reason for achieving the Sustainable Development Goals. It is worth noting that the countries with the most powerful digital economies are Denmark, Finland, and the Netherlands, whose experience can be useful for implementing their best practices in other countries (Kiseľáková et al., 2022).

Cyber threats are one of the serious problems that result from digitalisation. Therefore, in this context, the development of cybersecurity strategies is an important aspect both for the cyber defence of the country and also for the protection of its population from cyber threats, which is in sync with the sustainable development goals set by the World Economic Forum (Dobrovolska & Rozhkova, 2024). Although the introduction of advanced information and communication technologies improves the quality of life and stimulates business development, most companies prefer to ensure more effective cybersecurity measures (Kuzior et al.,

2023b). For example, developing systematic organisational and technical measures helps reduce such risks for businesses and citizens (Koibichuk & Dotsenko, 2023). Therefore, the main goal of such systems should be to ensure the availability, confidentiality and integrity of data, systems and resources (Wright, 2023).
Thus, digital technologies have a positive impact on various aspects of societal life and are aimed at improving the population's quality of life, increasing business profitability, and developing the national economy. Despite the significant scientific contribution of scholars from around the world to this issue, there is a need to study the impact of digital public administration services on the population's quality of life, which will be the focus of this study.

2. Research methodology

2.1 Methods

The methodology proposed in this paper is aimed at identifying those aspects of quality of life that are affected by digital services, as well as finding models that will allow us to predict their development in the future.
The *first stage* involves data preparation, logarithmisation, and standardisation. Next, the presence or absence of multicollinearity between the selected indicators of digital services is determined. To do this, it is enough to determine the Pearson correlation coefficients between pairs of indices, form a correlation matrix, and estimate its determinant. If its value is close to zero, it can be assumed that multicollinearity will be present in a given array of variables. Otherwise, it will be absent. If you get a controversial result, you can use advanced tests. Also, at this stage, the principal component analysis will be applied to eliminate multicollinearity.
The *second stage* involves cluster analysis. It is necessary for both technical and practical purposes. From a technical point of view, it will eliminate the scatter effect in the data, as it covers countries with different levels of economic development. From a practical point of view, cluster analysis will allow the classification of countries by the level of development of digital services. This will help identify general trends typical for the respective clusters. To apply this procedure, Kohonen's self-organising maps, which are based on neural network modelling, were chosen. This method allows for obtaining visual maps of clusters with confirmation of their effectiveness. This procedure requires determining the number of clusters, which will be done using the average silhouette score. It will allow assessing the effectiveness of data distribution by different numbers of clusters. The number of clusters with the highest silhouette score will be used in the clustering process.
At the *third stage*, a canonical analysis is carried out to select the quality-of-life variables that are most affected by the development of the state's digital services. This method is applied by creating linear combinations of variables from the two data sets that maximise the correlation between these combinations. As a result, the joint impact of the studied indicators will also be assessed.

At the *fourth stage*, predictive fully connected neural networks are built using the Keras Sequential API of the Keras library. In this case, the model will accept only one input and expect one output. It transmits data and goes through sequentially from top to bottom until it reaches the end of the model. The following parameters of the neural network are used for tuning: input shape - the number of input indicators (e-participation index, online services index, telecommunications infrastructure index, year and country name transformed into dummy variables); activation function - hyperbolic tangent; optimiser - an iterative optimisation algorithm for minimising the loss function during neural network training with Adaptive Moment Estimation chosen as the best option; loss - a loss function with Mean Squared Error selected as the best option; metrics - a list of indicators that evaluate the model during training and testing: Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), Mean Absolute Percentage Error (MAPE) and Mean Squared Error (MSE); epochs - the number of calculation iterations, which is set from 500 to 1500.

2.2 Data

To study the impact of the development level of the state's digital services on the population's quality of life, two groups of indicators were selected. The first one characterises the level of development of the state's digital services and is formed of three indicators: E-Participation Index (EPI), which reflects the mechanism of online interaction between the government and the population; Online Service Index (OSI), which measures the ability and willingness of the government to communicate with citizens and provide them with services using specialised electronic services; Telecommunication Infrastructure Index (TII), which characterises the existing infrastructure required to provide electronic services to the population. The dataset was compiled based on empirical United Nations (2023) data for 143 countries over 11 years from 2003 to 2022.

The selection of indicators in the second group was based on a synthesis of information from Eurostat (2023), The Economist Group (2023) and Statistics National Institute (2023). This set of indicators was compiled on the basis of empirical data from The World Bank Group (2023) for 143 countries from 2003 to 2022 in seven areas of quality of life.

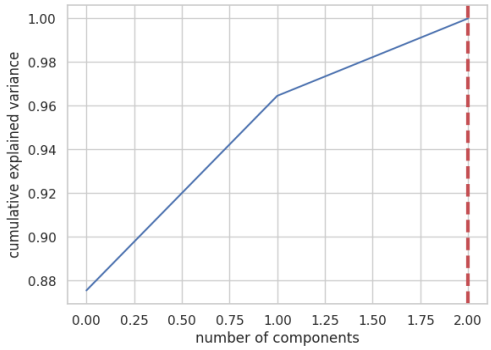
The population's material well-being is represented by GDP per Capita, PPP (current international $) (GDP), which characterises the country's economic situation and allows for a more accurate assessment of how this development affects each individual's life. Life Expectancy at Birth, total (years) (LE) identifies the population's health level and the medical sector's quality. Its growth indicates the healthcare system's and medical technologies' success in overcoming diseases and preserving the population's health. Political stability and security in the country are characterised by Political Stability and Absence of Violence/Terrorism: Estimate (PSAVT). Its high level creates favourable conditions for socio-economic development and ensures the country's attractiveness to investors and international partners. A country's level of labour safety is reflected in Unemployment, total (%

of total labour force) (UN). It represents the state of economic security, as it indicates the stability of the labour market and the ability of citizens to meet their basic needs through wages.
The level of education is characterised by the Labour force, total (LF). It considers a wide range of qualifications and levels of education among the working population, reflects the ability of the population to successfully implement knowledge and skills in the real economy and the level of access to education in the country. The involvement of the population in public life can be identified by the indicator Individuals using the Internet (% of the population) (II), which characterises the level of accessibility and prevalence of information technologies among the population, reveals aspects of digital literacy and the ability of citizens to adapt to the modern information environment. The exercise of democratic rights and freedoms is represented by Voice and Accountability: Estimate (VA). It is an indicator of the level of openness and transparency of the authorities, as it determines how accessible decision-making processes are to the public.

3. Empirical results

At the first stage of the proposed methodology, the values of the correlation coefficients between the variables were obtained, which show the presence of a strong relationship ($r_{EPI,OSI} = 0.8904$, $r_{EPI,TII} = 0.7545$, $r_{OSI,TII} = 0.7930$). The value of the determinant of the correlation matrix approaches zero ($det\ det\ r = 0.0745$). It can be argued that there is multicollinearity between the variables that characterise the level of digital development. To eliminate it, the data was standardised, and the principal component analysis was applied using the Python programming language, the results of which are shown in Figure 1. The obtained values of the cumulative and explained variance indicate the need to use only two components, which will form 96.4590% of the variation and explain more than 5% of it, which is statistically significant.

Figure 1. Results of the principal component analysis

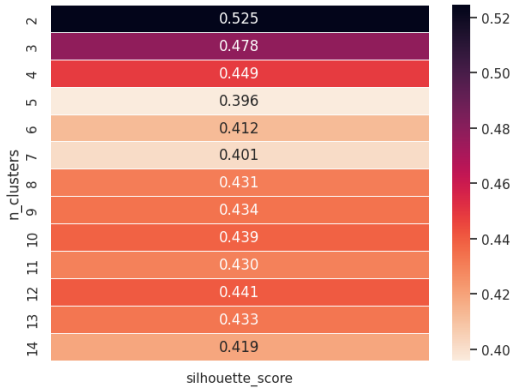


	Cumulative Variance Ratio	Explained Variance Ratio
0	0.875559	0.875559
1	0.964590	0.089030
2	1.000000	0.035410

Source: Authors' contribution

At the second stage, the Average Silhouette Width was implemented using the Python programming language (Figure 2).

Figure 2. Results of the calculated silhouette scores to justify the number of clusters



Source: Authors' contribution

The obtained scores indicate that the most efficient way to divide the data set would be to split it into two groups. Still, this division is not reasonable, since the gradation of the selected countries is wider. At the very least, the UN classifies countries into three groups according to their level of economic development: developed, developing and least developed. Therefore, it was decided that for the cluster analysis, it would be advisable to select the number of clusters equal to 3, which corresponds to the next highest silhouette score.

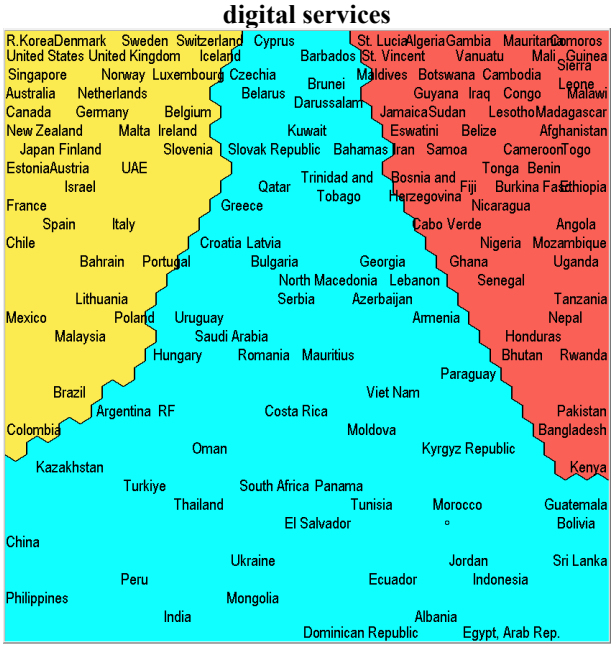
The cluster analysis was implemented using the software product Viscovery SOMine. Various settings of the neural network were tested, including the automatic setting, which also confirmed the need to divide the data into 3 clusters, as determined by the silhouette analysis. The resulting cluster map is shown in Figure 3.

The yellow cluster is made up of 37 countries, most of which are developed according to the UN classification (Figure 3). This group is characterised by a high level of development of telecommunications infrastructure, online services, and services for electronic participation of the population in the implementation of public policy. The top 10 countries in this cluster, which are characterised by the highest level of digital development and are the most progressive in this area, are the United States, the United Kingdom, Sweden, Singapore, the Netherlands, New Zealand, South Korea, Denmark, Canada, and Australia. Iceland, Lithuania, Slovenia, Portugal, Poland, Mexico, Brazil, Malaysia, Colombia, and Bahrain are the countries with the lowest level of development of public digital services in this group.

The blue cluster (Figure 3) includes 56 countries that are classified as developing. In terms of digital development, these countries are at an average level. The top 10 countries in this group are China, Argentina, Croatia, Cyprus, Greece, Hungary, Latvia, the Czech Republic, Kazakhstan, and Uruguay. The countries with the lowest

scores in this cluster are Armenia, the Bahamas, Bolivia, Egypt, Guatemala, Indonesia, the Kyrgyz Republic, Paraguay, Sri Lanka, and Lebanon.

Figure 3. Map of clusters of countries ranked by the level of development of public digital services

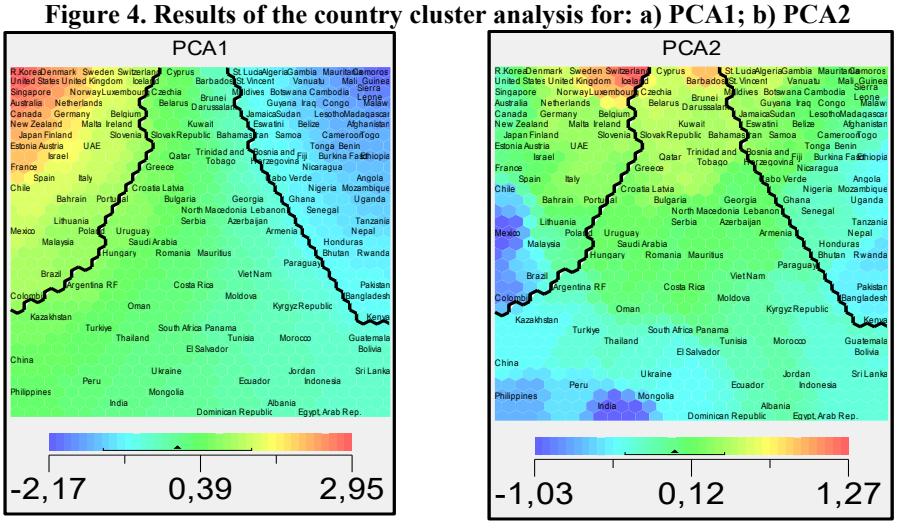


Source: Authors' contribution

The red cluster (Figure 3) is formed by 50 developing countries that are the least developed. The degree of their digital development can be defined as rather low. This is because most of them prioritise the development of programmes aimed at improving their populations' material and social well-being rather than increasing the state digitalisation level. The top 10 countries in this group are Bangladesh, Cape Verde, Bosnia and Herzegovina, Ghana, Iran, Jamaica, Kenya, Maldives, Pakistan, and Saint Lucia. The countries with the lowest digital development indicators are Congo, Gambia, Guinea, Madagascar, Malawi, Mali, Mauritania, Sudan, Sierra Leone, and the Comoros.

Let's analyse the results of the cluster analysis for each component (Figure 4a-4b). The countries in the blue cluster (Figure 4a) are evenly distributed, and their values fluctuate around the mean (0.39). The countries in the yellow cluster have the highest values of the first component, and those in the red cluster have the lowest. Figure 4b shows areas that can be defined as unevenly distributed, which is characteristic of all three clusters. This is clearly evident for Barbados, the Philippines, Peru, India, Mexico, Brazil, Colombia, Switzerland, Iceland, Luxembourg, Sweden, Pakistan, Bangladesh, and Rwanda. Since the weight of this component is not significant enough, the cluster map (Figure 3) is identified by the distribution of the first component (Figure 4a).

Figure 4. Results of the country cluster analysis for: a) PCA1; b) PCA2



a) b)

Source: Authors' contribution

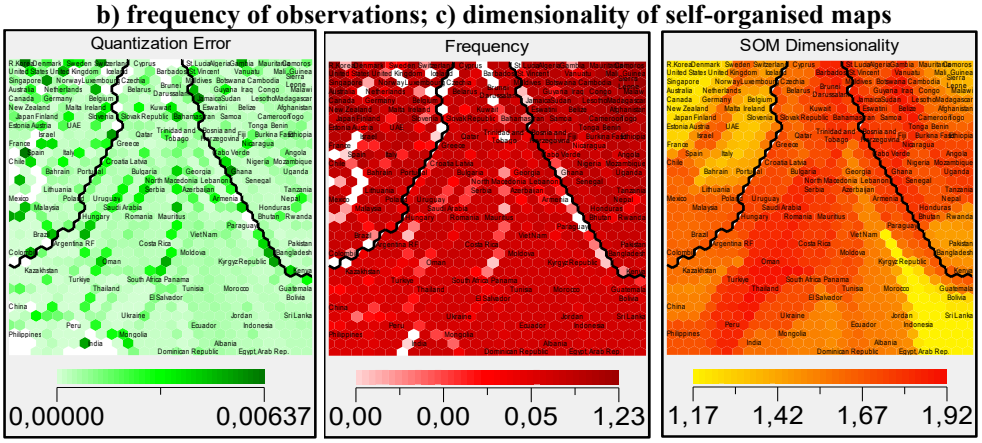
The quality of the cluster analysis is confirmed by the quantisation errors, the frequency of observations, and the dimensionality estimation (Figure 5). The quantisation error (Figure 5a) shows the discrepancy between the input and modelled datasets and does not exceed 0.637%, indicating a high quality of clustering. All groups are characterised by a high frequency of observations (Figure 5b). Still, some observations have a low value, which is acceptable in the context of cluster analysis. The dimensionality analysis (Figure 5c) shows that the vast majority of observations in the clusters are grouped by two characteristics. Only a few countries in the blue and yellow clusters are grouped by a single characteristic, highlighted by the yellow areas on the map. Since the weight of one characteristic exceeds the weight of the other, this grouping option is acceptable. The results obtained generally confirm the high quality of the clustering.

At the third stage of this study, a canonical analysis was conducted, where the most important for the selection of indicators are the determination of the values of total redundancy (Total redundancy) and canonical correlation (Canonical R), the statistical significance of which is confirmed by the values of Chi-square (Chi2) and p-value (p). The results of the calculations were carried out using the STATISTICA analytical package and are presented in Table 1.

The Left Set corresponds to a single indicator from the quality-of-life group, while the Right Set corresponds to a group of digital services indicators (Table 1). It has been determined that digital development explains 48.99% of changes in GDP per Capita, while it depends on the country's material well-being by only 24.49%. At the same time, the relationship between these indicators can be characterised as close (≈0.70). Its statistical significance is confirmed by a high Chi-square value and a p-

value of less than 0.05. The level of health, as measured by Life Expectancy at Birth, depends on the development of public digital services by 52.99%. It explains 26.50% of the variability in the country's digitalisation state. The relationship between these indicators is very close (0.73) and statistically significant.

Figure 5. Quality assessment of cluster analysis results: a) quantisation errors; b) frequency of observations; c) dimensionality of self-organised maps



a) b) c)

Source: Authors' contribution

Table 1. Results of the canonical analysis of the impact of digital services development indicators on the population's quality of life

Variable from Left Set	Variance extracted		Total redundancy		Canonical R	Chi2	p
	Left Set	Right Set	Left Set	Right Set			
GDP	100.00%	50.00%	48.99%	24.49%	0.70	1055.40	0.00
LE	100.00%	50.00%	52.99%	26.50%	0.72	1183.60	0.00
PSAVT	100.00%	50.00%	27.98%	13.99%	0.53	514.68	0.00
UN	100.00%	50.00%	2.46%	1.23%	0.16	39.01	0.00
LF	100.00%	50.00%	4.86%	2.43%	0.22	78.16	0.00
II	100.00%	50.00%	87.80%	43.90%	0.94	3298.20	0.00
VA	100.00%	50.00%	29.64%	14.82%	0.54	551.30	0.00

Source: Authors' contribution

A high level of dependence on state digital services is demonstrated by the engagement in public life through the indicator Individuals using the Internet, the change in which is 87.80% explained by online services, e-participation, and telecommunications infrastructure. The relationship between them is very close (0.94) and statistically significant, as evidenced by the high Chi-square value and p-statistic of less than 0.05. As for areas such as labour safety (UN) and education (LF), the relationship between them and the level of development of public digital services is very weak (R<0.5), although statistically significant. This result is also

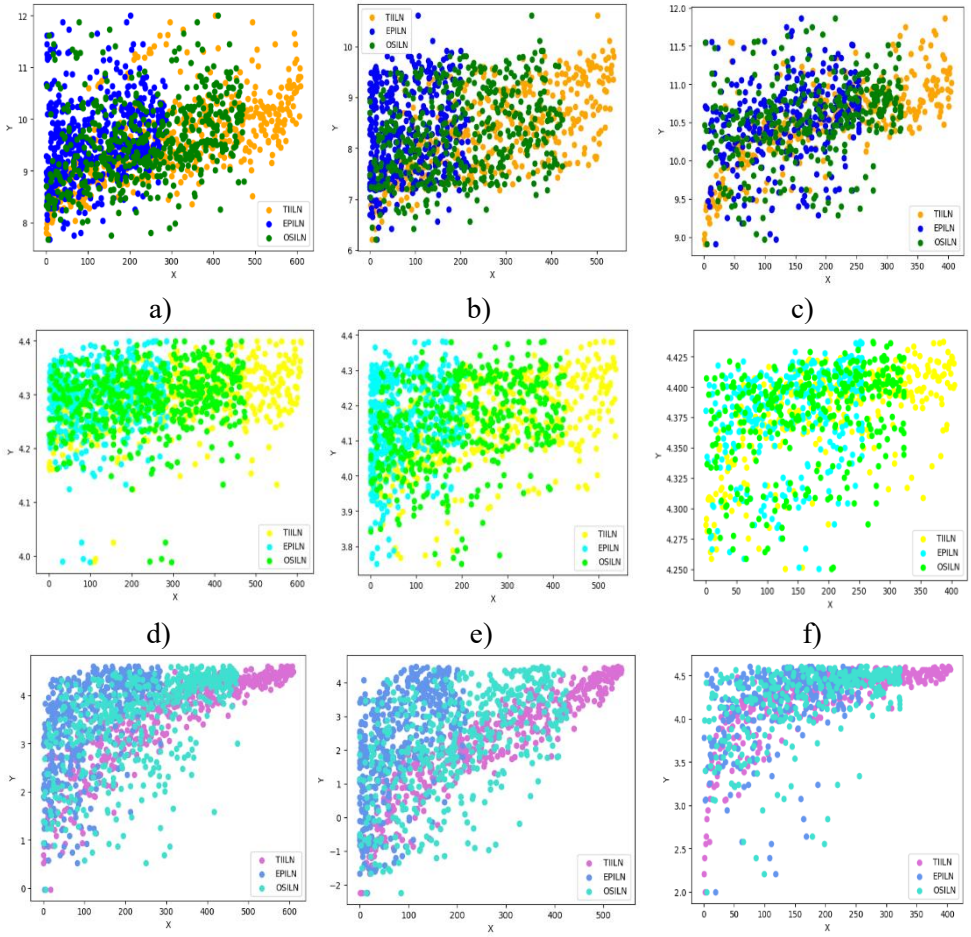
confirmed by the low values of total redundancy, which vary by less than 5% (Table 1). At the same time, we also found a weak impact of the level of development of public digital services on changes in the Labour Force and Unemployment. The relationship between political stability and security (PSAVT), democratic rights and freedoms (VA), and the level of development of public digital services can be described as medium. This is evidenced by the statistically significant values of their canonical correlation in the range from 0.5 to 0.7 (Table 1). At the same time, the impact of digitalisation on the Political Stability and Absence of Violence/Terrorism indicator accounts for only 27.98% of changes, and on the Voice and Accountability indicator - for only 29.64%.

The results of the canonical analysis show that the level of digitalisation significantly impacts changes in GDP per Capita, Life Expectancy at Birth, and changes in the number of Individuals using the Internet. All other indicators are either insignificantly or moderately affected.

Only indicators with a strong relationship were used to build the forecast models, as otherwise, the modelling results would be inaccurate. The models were built on the training set and the forecasts on the test set using the Python programming language. At the beginning of the simulation, we build scatter plots between the indicators of the development of public digital services and the quality of life for the three clusters of countries (Figure 6).

It was found that the dependence of GDP per capita on the three digitalisation indicators is reasonably uniform for countries in the yellow cluster, i.e. those with a high level of digital development (Figure 6c). For other countries, there is an unevenness, i.e. a shift to the right side of the diagrams (Figures 6a-6b). This may indicate that these clusters are dominated by certain groups of countries with low digitalisation indicators, which leads to low GDP. The scatterplot between the independent variables and life expectancy for the countries in the yellow cluster (Figure 6f) shows that there are countries for which a high level of digitalisation corresponds to a high level of health. The other group corresponds to countries with lower values. For other clusters, we observe a shift. While countries in the red cluster are clearly dominated by countries with very low levels of digital development and life expectancy (Figure 6e), countries in the blue group show outliers that may be due to several hard-to-identify factors (Figure 6d). If we abstract from this fact, we can also see a left-hand concentration of points, which indicates that most countries in the cluster have a low level of digitalisation for this group and a low level of life expectancy for this cluster. Figures 6g-6i show the outliers and bias for countries in the three clusters, which indicates the unevenness of digital inclusion within the panels.

Figure 6. Scatter plot between indicators of digital services and quality of life[5]



Source: Authors' contribution

The quality of the predictive neural models was assessed using errors, the results of which are presented in Table 2.

The obtained values for all models are close to zero. Although some of the indicators for the models for predicting individuals using the Internet do not approach zero, the

[5] a) GDP of the blue cluster countries; b) GDP of the red cluster countries; c) GDP of the yellow cluster countries; d) Life Expectancy at Birth in the blue cluster countries; e) Life Expectancy at Birth in the red cluster countries; f) Life Expectancy at Birth in the yellow cluster countries; g) number of Individuals using the Internet in the blue cluster countries; h) number of Individuals using the Internet in the red cluster countries; i) number of Individuals using the Internet in the yellow cluster countries.

Mean Absolute Percentage Error does not exceed 10%, which indicates that the obtained predictions are of high quality.

Table 2. Assessment of the quality of built neural network models

Name of error	Blue cluster countries	Red cluster countries	Yellow cluster countries
A neural model for predicting GDP per capita			
Mean Absolute Error	0.3906	0.3937	0.2974
Mean Squared Error	0.2431	0.2544	0.1567
Root Mean Squared Error	0.4930	0.5044	0.3958
Mean Absolute Percentage Error	0.0412	0.0480	0.0283
A neural model for predicting life expectancy			
Mean Absolute Error	0.0482	0.0948	0.0277
Mean Squared Error	0.0043	0.0166	0.0012
Root Mean Squared Error	0.0654	0.1288	0.0349
Mean Absolute Percentage Error	0.0113	0.0231	0.0064
A neural model for predicting individuals who use the Internet			
Mean Absolute Error	0.3139	0.7199	0.1182
Mean Squared Error	0.1818	0.9110	0.0263
Root Mean Squared Error	0.4263	0.9545	0.1621
Mean Absolute Percentage Error	0.1464	0.9624	0.0299

Source: Authors' contribution

Based on these results, we accept the results of the neural network modelling as qualitative and suitable for situations of predicting the impact of e-participation, online services and telecommunications infrastructure on GDP per capita, life expectancy at birth and the number of individuals using the Internet. The modelling results were visualised and presented in Figure A1 of Appendix A.

5. Conclusions

The study provided a comprehensive analysis of the impact of the country's development of digital services on the population's quality of life. The key point is clustering countries by indicators of digital services development, which was implemented using self-organising Kohonen maps. This allowed us to identify groups of countries with a similar level of digital development. Three clusters were identified - countries with a high, medium and low degree of digitalisation. The next step was to conduct a canonical analysis to select indicators of the population's quality of life that could be related to the level of development of digital services. Considering the calculated values of total redundancy, canonical correlation, Chi-square and p-value, it was found that the highest level of correlation is observed between GDP per capita, life expectancy at birth, individuals using the Internet, e-participation, online services and telecommunication infrastructure.

The most valuable part of the study was the neural network modelling of the impact of digital services development indicators on the indicators of material well-being,

health and social engagement of the population of countries. It was found that a high level of digital development correlates with an increase in GDP per capita, higher life expectancy at birth, and an increase in the number of individuals using the Internet. This suggests that countries with active development of digital services not only achieve high economic performance, but can also improve social aspects of life, such as health and access to information. Knowing this impact allows government leaders and international organisations to effectively develop strategies to improve the quality of life by advancing digital technologies.

Thus, the study's results provide convincing evidence that the development of digital services in countries can significantly impact the population's quality of life. Access to digital services contributes to a higher standard of living through economic growth and improved access to education and healthcare. It provides a greater flow of information, which positively impacts the consciousness and activity of the population. Given these factors, it can be concluded that investing in the development of digital technologies is becoming a critical factor in improving the population's quality of life. In today's world, where digital technologies are becoming a necessary part of everyday life, studying and understanding the impact of these technologies on socio-economic development is becoming a crucial task for governments and public organisations. This kind of research allows for the formulation of effective development strategies aimed at achieving harmony between economic growth and improving citizens' quality of life.

Conflict of Interest Statement

The authors declare no conflict of interest.

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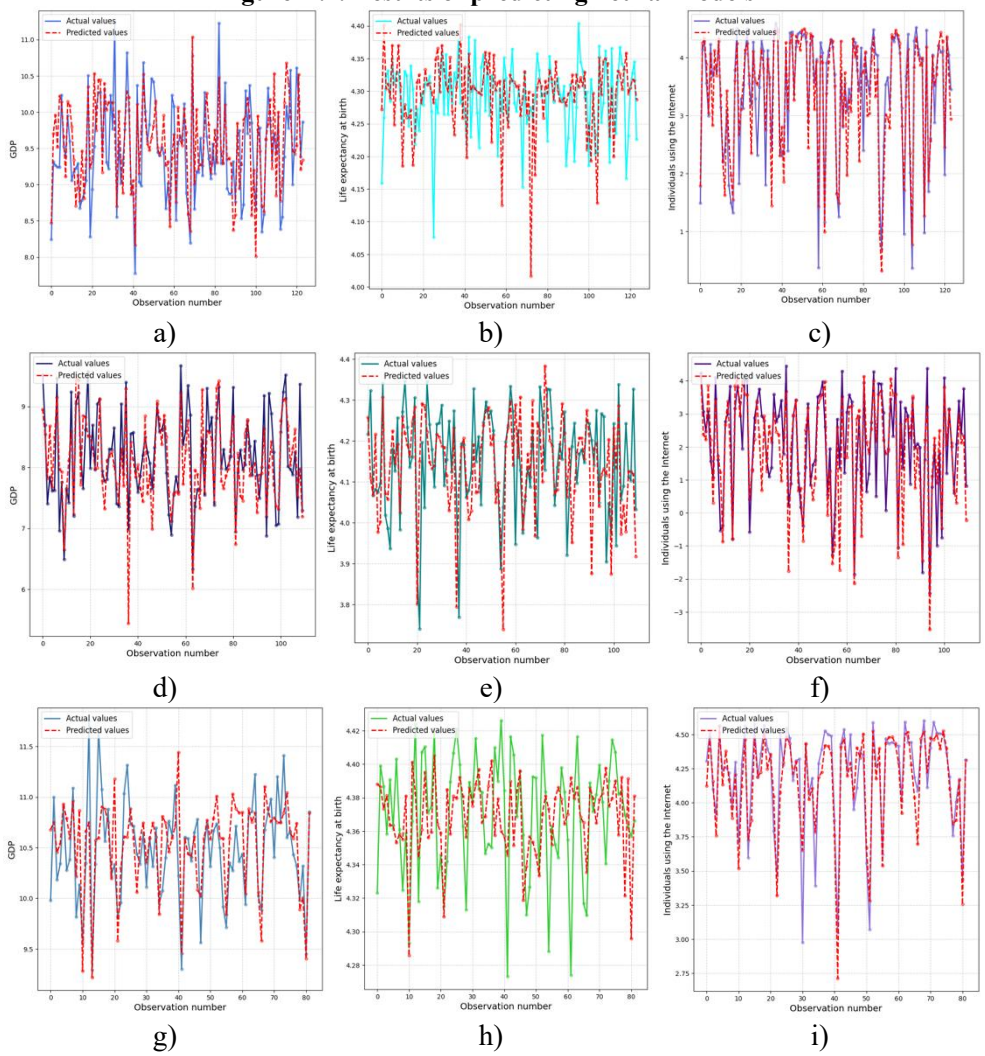
Appendix A

Figure A.1. Results of predicting neural models [6]



Source: Authors' contribution

[6] The impact of digital services on: a) GDP of the blue cluster countries; b) Life Expectancy at Birth in the blue cluster countries; c) number of Individuals using the Internet in the blue cluster countries; d) GDP of the red cluster countries; e) Life Expectancy at Birth in the red cluster countries; f) number of Individuals using the Internet in the red cluster countries; g) GDP of the yellow cluster countries; h) Life Expectancy at Birth in the yellow cluster countries; i) number of Individuals using the Internet in the yellow cluster countries.