Fundamentals of smart Village modeling in the context of integration of cognitive processes of artificial intelligence in the era of modern infrastructure challenges

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Abstract. The study focuses on the stages of implementation and development of smart villages, which are digital technologies for agriculture that increase efficiency and productivity in this area. We uncovered the stages of development of smart villages, then we looked at what is included in the Internet of Things within a smart village. After that, we looked at the specific digital solutions for agriculture and the purpose of smart village. As part of the study, we analyzed a number of indicators characterizing the development of the sphere of agriculture and its prospects. As the results of the study, we constructed and analyzed correlation matrices of indicators.

1 Introduction

In the age of intensive development of digital technologies and widespread introduction of artificial intelligence, the idea of creating a "smart village" becomes not only relevant, but also inevitable for the optimization and modernization of agriculture. The Russian Federation, with its vast agrarian resources and agricultural traditions, is facing the need to adapt to the new challenges of the time. Digitalization in agriculture can not only significantly improve the efficiency of land management and exploitation, but also contribute to the development of remote regions, improve the quality of life of the population and reduce migration to cities [1].

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2 Materials and methods

As a basis for the research, we used such methods as analysis, synthesis, observation, generalization, statistical and mathematical methods. We analyzed key statistical indicators, which allowed us to identify correlations between them, as well as to identify more "bottlenecks" in which to invest in the first place.

We chose the following set of indicators:

- Ratio of investment in fixed capital to the gross regional product.
- Level of innovative activity of organizations.
- Share of investments share aimed at reconstruction and modernization in the total volume of investments in fixed capital.
- Dynamics of investments in fixed assets, % compared to the previous year.
- Investments in fixed capital of agriculture, forestry, hunting and fishing.
- Share of investments in fixed capital of agriculture, forestry, hunting and fishing in terms of all incomes.
- Number of highly productive jobs in agriculture, forestry, hunting and fishing.
- Number of enterprises and organizations in agriculture, forestry, hunting and fishing.
- Production of agricultural products.

These indicators were analyzed using the statistical packages of pandas, numpy, scipy, geopandas and sklearn for the Python programming language. Various data visualizations were constructed using the matplotlib and seaborn graphical packages for the Python programming language.

3 Results

The smart village project uses digital technologies to create viable services that ease the difficulties of the agricultural sector, support the social ecosystem, and promote economic growth. The smart village design problem is highly dispersed and often involves many non-hierarchical structures. On the other hand, technological advances in communication and computer technology have changed health care, education, nutrition, energy access, and the way how we interact with the environment on a large scale. In recent years, the research community has focused on the development of sustainable community settlements, such as smart cities. Developing smart villages in parallel with smart cities is the time demand to bring them on the same level to maintain balance in holistic development [2]. The network creates a skeleton for anything that can give feedback. Wireless technology in rural areas should have low power, long range and less bandwidth [3].

The smart village modeling process involves several steps (Figure 1). The first step is to define the current challenge, assess the problems and map it to a cost-effective smart digital solution for long-term inclusive growth. The second important step is to identify relevant, appropriate and adaptable digital solutions for resource mobilization and sustainable growth. The success of a smart village depends on efficient and affordable solutions in the areas of electricity and connected uninterrupted communication. The key deciding factors of digital technologies are coverage, data rate, power and cost [4].

Trust in the privacy and secrecy of user data is important to the success of a smart village. To ensure this, the design should specify how data will be collected, used, stored and shared. The third step is to deploy a scalable prototype. Implementing the prototype helps to evaluate the deployed technology, explore possible vulnerabilities and other technology options for scalable, revenue-generating and cost-effective solutions. In the final step, the prototype will be replicated for the entire pool of villagers. This is often an iterative process to determine time, cost risk and resource savings or elimination [5].

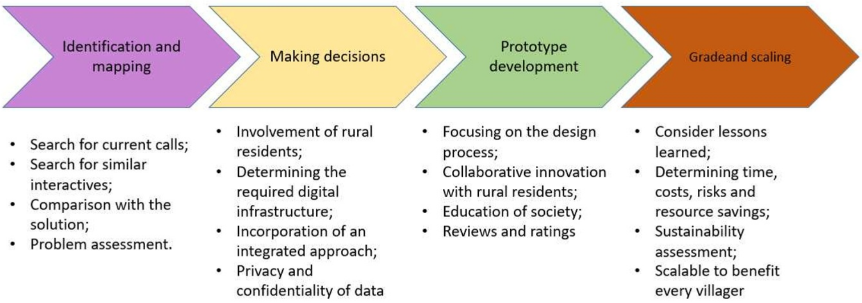

Fig. 1. StyleFigureCaption.

The challenge of designing a smart village can be complex and should be approached on several levels. The scope of IoT includes smart homes/huts, smart agriculture and dairy, smart cattle tracking, smart healthcare, smart water and waste management, smart energy management, smart transportation and smart governance, etc. Aspects of life in rural areas can be divided into three parts presented in Figure 2: agriculture, social, household and public services.

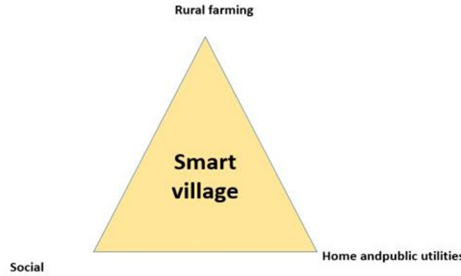

Fig. 2. Aspects of rural life.

Agriculture is an ancient industry that requires a farmer to be able to anticipate changes in the environment, analyze conditions and perform the necessary set of actions to improve the quality and quantity of crops and livestock. Intelligent agriculture based on the Internet of Things is seen as a prospect for revolutionizing change in many aspects. IoT sensors collect information on weather, soil moisture conditions, crop and livestock conditions. The ability to automate data analysis (using machine learning and big data) helps in better controlling of production cycle, growth and meeting a higher standard. Researchers have proposed an online semantic framework to analyze data in real time, identify important events, automate decision making and work seamlessly across different sensors, processes, applications and operations. Similarly, IoT sensors can be used to track location, monitor health, and create a log of animal performance [6].

In modern developed and developing countries, large numbers of elderly people live in villages. A large proportion of the village population lives below the poverty line. People in villages are often deprived of high-quality medical support and low-cost care. Intelligent healthcare based on the Internet of Things is a potential solution for providing evidence-based primary care. Chronic diseases (e.g., high blood pressure, high cholesterol and diabetes) often cause heart and kidney disease, diabetes, blindness and amputation [7].

Smart energy management is designed to generate green electricity (e.g., solar, wind) as well as monitor its utilization and control losses. IoT sensors, controllers, solar panels, energy storage and smart grids are key parameters for efficient and optimized use. IoT sensors placed on solar panels and windmills can detect weather and optimize power generation. In addition, the smart energy system also manages smart street lighting and electric vehicle charging. Additional energy generated from clean energy sources (e.g., solar panels, windmills, etc.) can also sell additional energy to urban areas. The researchers proposed a big data analytics model based on four key aspects, namely, power generation-side management, renewable energy and microgrid management, joint operations and demand-side management. In addition to limited employment and income opportunities, social aspects (e.g., education, security, governance, etc.) are a common reason for rural communities to migrate. IoT-based education can track attendance (using RFID, ZigBee), track progress in quizzes (using cloud computing), as well as create smart libraries (with sensors), interactive learning, and resource conservation. In addition, virtual reality-based smart education can be useful for vocational skills enhancement, health education, disaster management training, etc. The success of smart education concept has completely nullified the dropout rate of students with the implementation of smart education practices in the smart village model of Punsari, India [8].

Let us consider the objectives of creating a smart village (Table 1).

Table 1. Objectives of creating a smart village.

Aspects of life in rural areas	Prospects for the implementation of the Smart Village system	Problem-solving directions
Agriculture	- smart plant irrigation - smart livestock tracking - smart dairy farming - smart agricultural waste management	- climate monitoring and forecasting - irrigation and fertilizer management system - monitoring of agriculture structures quality - timely forecasting and meeting the demand for agricultural products - agricultural waste reduction and recycling management
Social sector	- education - surveillance and security - management - infotainment system	- implementation of online learning systems - improving management efficiency, tracking village-wide services - ensuring safety of rural residents
Household and public utilities	- smart village house - smart healthcare - smart energy - water and waste management	- gas, smoke and fire detection - energy management system setup - monitoring of chronic diseases - cost-effective allocation of natural resources and control of their quality (e.g., clean water)

The digital world is driven by efficient data collection, communication and intelligent decision making on a decentralized platform. A data-driven platform requires reliable and efficient information exchange between each "thing". The foundation of a smart village depends on selecting the right sensor, computing platform, power supply mechanism, communication networks and efficient information processing. This section presents a roadmap for building a data-driven ecosystem based on the Internet of Things for smart villages.

Internet of Things is the integration of sensors, actuators and small computing units to automate a system over the Internet. The digital transformation of the village is built mainly around the blocks supporting the Internet of Things and value-adding technologies. Technologies that contribute directly are listed below:

Blocks of IoT: IoT is essentially a set of machine-to-machine (M2M) communication protocols and interfaces. It includes sensors, microcontrollers, energy harvesting mechanism, positioning technology (e.g., GPS), radio frequency identification (RFID), Bluetooth low energy (BLE), Zig-Bee, Z-wave, low power wide area networks (LPWAN), and near field communication (NFC) [9].

Value-added technology: these technologies add value, assist in decision-making and improve overall service security. The list includes cloud computing, big data analytics, machine learning, artificial intelligence, virtual reality and blockchain. In addition, the use of drones and robotics may also fall into this category.

Thus, the concept of smart village encompasses many vital spheres of village life, involves multiple stakeholders and should be self-sustainable. Agriculture, education, health, energy, water and waste management, governance are the critical verticals of village life to achieve sustainable development. Internet of Things is a digital transformation platform that can serve as a foundation for developing a digitally driven ecosystem [10].

In the Russian Federation, the implementation of smart villages is not yet widespread. Solving this problem requires significant investments, the size of which is usually limited due to the multitude of existing challenges. Let us consider the matrix of indicator correlations. Since most of the indicator distributions do not tend to the form of normal distribution, we will use the Spearman rank correlation to calculate the matrix values.

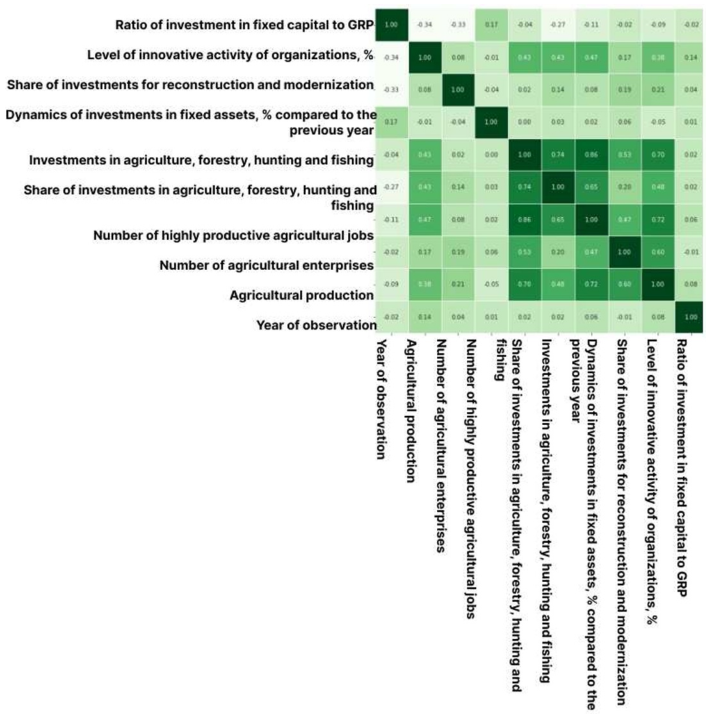

Fig. 3. Matrix of indicator correlations.

The ratio of investment in fixed capital to GRP has weak negative correlations with the signs of the indicators "Level of innovative activity of organizations" and "Share of investment for reconstruction and modernization". This means that the higher the share of investment in fixed capital is, the less of their volume is directed to modernization. Also, investments are directed to regions with a low level of innovative activity of organizations.

The level of innovative activity of organizations has a weak positive correlation with investment in fixed capital of agriculture, forestry, hunting and fishing and with the share of investments in fixed capital of agriculture, forestry, hunting and fishing in the context of all incomes, as well as with the number of highly productive jobs in agriculture, forestry, hunting, fishing and with the production of agricultural products. This suggests that the level of innovative activity of organizations is associated with the development of agriculture in the regions, as well as with the fact that regions with modern production manufacture more products.

The share of investment aimed at reconstruction and modernization, the dynamics of investment in fixed assets and the percentage compared to the previous year have no correlation with other indicators, except for those already described. This means that most of the investments in fixed assets are used for purposes other than modernization and agriculture.

Investments that are aimed at the development of agriculture have a strong positive correlation with all indicators of its development, such as: Number of enterprises, Number of highly productive jobs, Number of products, Level of innovative activity. This indicator is also positively correlated with the share of investments in fixed capital of agriculture, forestry, hunting and fishing in the context of all incomes. This means that the growth of investments in agriculture is purposeful and is associated with an increase in their share, rather than with the overall growth in the number of investments into the region.

The share of investment in fixed capital of agriculture, forestry, hunting and fishing in the context of all incomes has the same positive correlations as the volume of investment in agriculture, but they are expressed more weakly, except for the growth in the number of enterprises, which is virtually unrelated to this attribute. This means that an increase in the share of investment in agriculture in regions with low investment volume is not a sufficient condition for growth of the number of enterprises.

The number of highly productive workers has strong positive correlations with all agricultural development attributes and is a consequence of them, which in turn increases output.

Product output is closely related to the attributes of agricultural development. The absence of correlations between the indicators and the year of observation indicates that all the considered attributes are controllable and do not have a trend that cannot be influenced, and that there is no stable trend of agricultural development in all regions.

Let us build the significance matrix of correlation relationships (Figure 4).

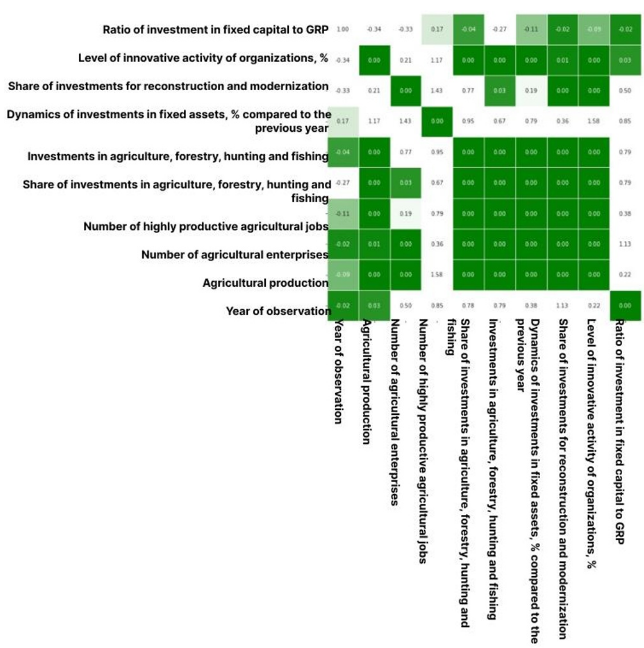

Fig. 4. Matrix of correlation significance.

According to the correlation significance matrix, it can be seen that the negative correlations of the indicators "Ratio of investment in fixed capital to GRP", "Level of innovative activity of organizations" and "Share of investments for reconstruction and modernization" are random and do not reflect the general pattern. The rest of the described correlations are statistically significant.

4 Discussion

When we talk about smart villages, it is important to understand that there is no universal template by which it should be created. Each country should implement elements of digitalization and artificial intelligence based on its own challenges, problems and threats. The bottlenecks that need to be improved and modernized with digital elements are crucial. For example, if there is a problem of low soil fertility, it is necessary to install tracking devices that would analyze the soil condition and signal the need to apply fertilizers [11].

One of the potential benefits of a smart village is the creation of jobs and improvement of the economic situation of the population. However, it is also important to consider possible negative consequences, such as the loss of traditional skills and professions [12].

The role of the state in the process of digitalization of agriculture cannot be underestimated. Initiatives and programs at the state level are necessary for the digitalization process in agriculture. Since many ideas for the implementation of smart villages have already been tested in other countries, Russia can use this experience to improve the efficiency and precision of the implemented technologies.

5 Conclusion

Thus, given the reliable values of the data, it can be said that a low level of investment in agriculture prevails in Russia, which means that there is a low contribution to the development of digitalization of this sphere. The analysis showed a clear correlation with job growth and agricultural output. By increasing investment activity and thus introducing "smart" solutions in the usual agricultural processes, it is possible to achieve an increased number of new jobs and higher production of agricultural products. Production growth is ensured in an intensive way, as digital and AI solutions are directly aimed at improving the quality and productivity of work. Given that only a few regions of the Russian Federation currently provide state agricultural output, Russia will be able to significantly increase its potential in this area by going through a cycle of implementing a smart village in agriculture.

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