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ARCHITECTURE. LANDSCAPE ARCHITECTURE.

Z.Kannazarova, L.Ryssalieva, S.Khamidov, K.Khamraev, G.Jaliliova, B.Najodov
Management practices for improving soil health in the Aral Sea Basin: a case study from Karakalpakstan.....5

ECONOMY. ECONOMIC SCIENCE. OTHER BRANCHES OF THE ECONOMY.

K.A.Chariev
Scientific and methodological bases of resource potential and its importance in the formation of organic agriculture in the conditions of a green economy.....9

U.Alimov, N.Omonov
Theory and strategy of the Bioeconomy: the case of Finland.....13

Kh.Khujamkulova, Z.Salomova, M.Uralova
Investments in agriculture and the efficiency of their usage.....16

M.Inoyatova
Development of organizational and economic land regulation mechanism relations in the arid zone.....19

M.Tosheva
Prospects for using the principles of "green economy" in agriculture.....23

Sh.Khamrayeva
Control innovative the development of the bioeconomic branches of the Republic of Uzbekistan.....30

K.Nosurullaev
Methodological basis of formation of agricultural insurance services in developing countries.....34

N. Abdurazakova
"Green economy" and its role in solving water and energy problems in Uzbekistan.....37

K.Shaakramov
On the issue of improving the processes of modernization the national economy.....40

E.Shodiyev, U.Matkarimov
Improving accounting of financial results in agricultural enterprises and financial analysis: evidence from Uzbekistan.....44

M.Kholikulov
The importance of investments and the organizational-economic basis of involvement in the field of fruit and vegetable sector.....47

A.Berdimurodov
The role and importance of digital technologies for innovative and sustainable development of the agricultural system of the Republic of Uzbekistan.....50

Z.S.Shokhojaeva, U.R.Sangirova
Improving the practice of subsidizing agricultural production.....53

I.Yunusov
Features and scientific-theoretical foundations of intensive development of the fish farming.....56

G. Shadmanova
Modern factors of modeling the development of production of farms and dehkan farms in Uzbekistan.....61

D.I.Mukumova,
The spatial gender equality and women's leadership in scientific activity in Uzbekistan.....63

ENVIRONMENTAL PROTECTION. WATER MANAGEMENT, HYDROLOGY.

M.Burkhonova, J.Narzullayev, B.Matyakubov
Comparison of furrow and sprinkler irrigation systems (in the example of carrot and cauliflower).....67

F.Bekchanov
Ensuring reliable operation of pump units.....71

E.Ozodov, N.Ozodova, D.Tadjiyev
Development of a multi-measuring system for control and prediction of process water resources on the arduino platform.....76

A.Djalilov, O.Nazarov
Implementation of intelligent control systems in water supply networks.....80

Kh.I.Muradov, A.U.Djalilov
Aquatic Elevation Tracking Mechanism.....84

Sh.Shoergashova, T.Liu, N.Ibrokhimova, B.Karimov
Land use impact on water quality of the zarafshan river basin.....88

HIGHER EDUCATION. PEDAGOGY.

S.Surmanov
A comparative analysis of reading skill development through graded readers.....92

O.Yoqubov
Implementing interactive learning methods requirements of time.....95

N.Yuldashova
English proficiency for advancing agricultural development.....98

M.Ziyadulloyeva
Enhancing agricultural development through teaching agricultural terms in English.....101

D.Madalieva
Study of the emergence of the concept of accounting in linguistic research.....104

POWER ENGINEERING, ELECTRICAL ENGINEERING, AUTOMATICS. COMPUTING TECHNOLOGY.

M.Ismailov, O.Ismailov, X.Temirova
Processing of blood cell images hybrid methods of acute lymphoblastic diagnosis CNN features.....106

M.Ismailov, O.Ismailov, X.Temirova
Dental Radiography Analysis Using YOLOv8 Deep Learning Using Raspbbery pi Device.....110

F.Kucharov, M.Begmatov
Electromagnetic consumer sensor.....113

S.R. Umarov, T.M.Bayzakov, Sh.B. Yusupov, A. Abduraxmonov, I. Kholmirzaev, S.Qurbonazarov
In greenhouses vegetable crops of seedlings cultivation electrotechnology effectiveness of assessment (sweet pepper plant on the example).....115

LAND USE IMPACT ON WATER QUALITY OF THE ZARAFSHAN RIVER BASIN

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Abstract

The Zarafshan River Basin, one of the crucial water resources in Central Asia, faces significant water quality challenges due to land use changes as urbanization and agricultural expansion. This study examines the impact of land use patterns on water quality during 2017-2022. By analyzing land cover and water quality data including ammonium nitrogen (N-NH4), nitrite nitrogen (N-NO2), nitrate nitrogen (N-NO3), chemical oxygen demand (COD), dissolved oxygen (DO) and temperature, the research identifies critical factors influencing water quality. It was found that most parameters remained below the maximum admissible concentration (MAC), except for N-NH4 in 2022 (2.6 MAC), and N-NO2 in 2020 (1.25 MAC). The land use data analysis revealed fluctuations in crop and rangeland coverages, a notable increase in built-up areas due to urbanization. Redundancy Analysis (RDA) showed a moderate positive correlation between built-up areas and N-NH4, N-NO3 (RDA 0.66). Moreover, a significant relationship (RDA 0.89) between built-up areas and organic pollution (COD) in the basin was investigated. Recommendations include integration of sustainable land use practices, improved wastewater management and monitoring to mitigate pollution and ensure the long-term health of the basin.

Key words: River pollution, Agriculture, Urbanization, Central Asia, Redundancy analysis, GIS

Introduction. Water is a necessary for everyday life. It is used for drinking, agriculture, industry, energy production and other purposes [1]. However, surface waters are negatively influenced by natural processes, as well as the anthropogenic activities [2]. Previous studies show that surface water quality has significantly worsened over the past decades due to poor land use practices [2, 3]. It has a strong correlation between declining water quality and increased agricultural development at the catchment scale [4-6]. Land use changes influence key environmental factors as soil properties, vegetation cover, and geomorphology [7]. These changes alter hydrological processes within the watershed, affecting the transport of nutrients, sediments, and pollutants into the river system [8]. As a result, variations in land cover can lead to significant degradation in water quality, impacting both human and ecological health [9]. For instance, agricultural activities often introduce fertilizers and pesticides into water bodies, leading to nutrient pollution and eutrophication [10]. Similarly, urbanization increases impervious surfaces, enhancing runoff and the transport of contaminants into rivers [11]. This underscores the importance of clean water and sanitation highlighted in Sustainable Development Goals 6 (SGD 6) [12]. It focuses on addressing critical water quality challenges, as it become a worldwide environmental problem [13].

The Zarafshan River Basin in Uzbekistan is a crucial water source for agriculture, industry, and domestic use. However, the region has experienced significant land use changes, including urbanization and agricultural expansion, which have impacted the river's water quality [14]. This study aims to analyze the relationship between water quality and the land use/land cover patterns in the Zarafshan River Basin from 2017 to 2022. Understanding these relationships is essential for developing effective strategies to mitigate pollution and ensure the long-term sustainability of the Zarafshan River Basin.

Materials and Methods

Study Area. The Zarafshan River is a transboundary river, with its upstream located in Tajikistan and its middle and downstream sections passing through Uzbekistan (Figure 1). The river primary sources of water are glaciers and seasonal snow, as it originates from the Zarafshan glacier [15]. The upper stream a glaciated mountain region has a high hydropower potential [15, 16]. However, the middle and downstream areas in southern Uzbekistan form a semi-arid lowland with high evaporation rates, where water resources are intensively used for irrigated agriculture, as well as municipal and industrial purposes [11, 18]. The majority of the Zarafshan River's runoff is used for irrigating Samarkand, Navoi, Jizzakh, and Kashkadarya Provinces [20].

Materials. In this research, land use data from 2017 to 2022 were obtained from Environmental Systems Research Institute's (ESRI U.S) land cover datasets (https://livingatlas.arcgis.com/landcoverexplorer/), which provide 10 m Land Use/Land Cover Time Series from Sentinel-2 [21]. Water quality data, including Ammonium Nitrogen (N-NH4), Nitrite Nitrogen (N-NO2), Nitrate Nitrogen (N-NO3), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), and river water temperature, were collected from Uzhydromet for 10 Gauging Stations (GS) located in Uzbekistan (Figure 1).

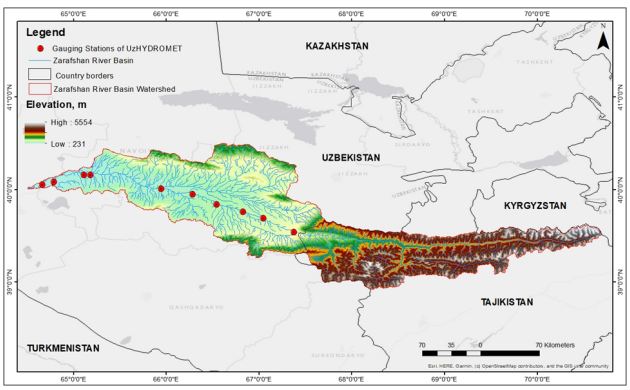


Figure 1. Study area - Zarafshan River Basin.

Methods. To assess the water quality parameters, the values of Maximum Admissible Concentration (MAC) were used [22]. The percentage of land covered by different categories (crops, buildup area, rangeland, water, trees, flooded vegetation, bare ground, snow/ice) were calculated in ArcMap 10.7. To assess the influence of

land use changes on water quality Redundancy Analysis (RDA) was conducted. The RDA is a ranking technique that merges regression analysis with principal component analysis and extends the concept of multiple response variable regression analysis [23]. RDA can illustrate the correlation between response (water quality parameters) and explanatory (land use type) variables [24]. The range of coefficients in RDA typically lies between -1 and 1. In the biplot, the angle between arrows indicates the correlation between variables. Smaller angles suggest a higher positive correlation. Principal Component Analysis (PCA) was used to emphasize the varying degrees of influence exerted by different land use types on water quality parameters. The analyses of Water Quality (WQ) parameters were implemented at UNESCO Chair on Water Diplomacy, Water Resources Management and Environmental Protection at "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University. To analyze nitrogen forms (N-NH4, N-NO2, N-NO3) in the water, a spectrophotometric method was employed based on the qualitative reaction with Nessler's [25], Griess [26] and sodium salicylate [27] reagents respectively. The COD was assessed using a method involving sulfuric acid and potassium dichromate at a high temperature (150 ± 5 °C) [28]. The concentration of Dissolved Oxygen (DO) in water was measured using the Winkler method [29]. Water samples were taken according General Requirements for Sampling [30].

Results and Discussion

The investigated water quality parameters (except N-NH4 and N-NO2) of the Zarafshan River, according to annual averages, were below the MAC during the years 2017-2022. Also, the average concentrations of ammonium nitrogen during 2017-2021 were below the MAC (0.39 mg/L). However, in 2022, its concentration exceeded the MAC by 2.6 times. The average value of nitrite nitrogen in 2020 exceeded the MAC (0.02 mg/L) by 1.25 times, while in 2022, it was equal to the MAC. The average values of COD and DO show an increasing trend over the 5 years. The temperature varied between 8.61°C and 9.5°C (Figure 2).

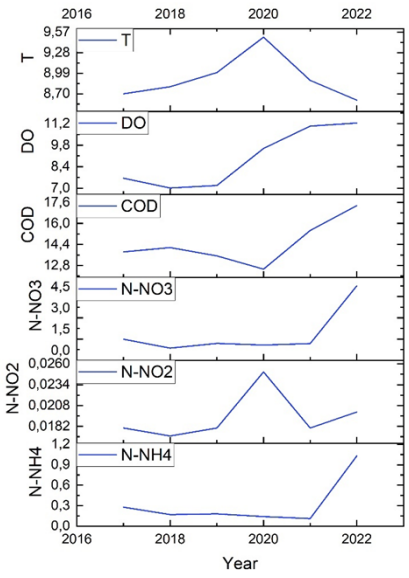


Figure 2. Multiannual (2017-2022) averages of water quality parameters in the Zarafshan River.

Conducted analysis revealed dynamic changes in land use patterns within the Zarafshan River Basin, with fluctuations observed in certain land use categories. The trend in crop and rangeland coverages from 2017 to 2022 included periods of both increase and decrease, fluctuated from 18.97% to 23.02% and from 52.21% to 57.42% respectively. The buildup area has remained relatively stable over the years, with slight fluctuations and an increasing trend. In 2022 the buildup area increased to 1.13 times compared to 2017. This may be explained by population growth and urbanization. The area covered by water bodies remains minimal and relatively consistent across the study period (0.52%-0.7%). The percentage of flooded vegetation is negligible, indicating limited presence or variability in flooded areas. There has been a slight decrease in the area of bare ground from 2017 (12.63%) to 2020 (8.79%). However, in subsequent years, the area of bare land increased by 1.33%. The percentage of snow/ice cover fluctuated over studied period, in contrast to other studies, the tendency was not observed (Table 1, Figure 3). These changes may reflect a combination of factors including agricultural practices, urbanization, and natural resource management policies [26, 27].

Table 1.
Area (%) of land cover and land use of the Zarafshan River Basin (based on LULC data from ESRI).

Year	Cropland	Build-up Area	Rangeland	Covered with water	Wetland	Bare Ground	Snow/Ice
2017	21.52	9.05	53.3	0.52	0.01	12.63	2.89
2018	18.97	9.31	57.42	0.52	0.004	11.40	2.32
2019	23.02	9.45	53.82	0.70	0.01	9.29	3.57
2020	24.58	9.8	52.21	0.69	0.01	8.79	3.79
2021	20.85	10.04	56.13	0.57	0.01	10.01	2.35
2022	21.43	10.28	55.53	0.68	0.01	10.12	1.85
Min/ Max	18.97/ 24.58	9.05/ 10.28	52.21/ 57.42	0.52/ 0.7	0.004/ 0.01	8.79/ 12.63	1.85/ 3.79
Average	21.73	9.65	54.73	0.61	0.009	10.37	2.79

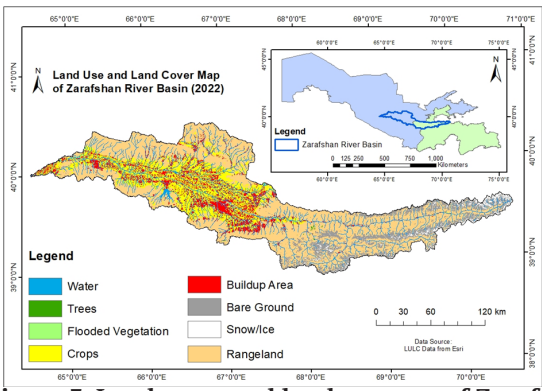


Figure 3. Land cover and land use map of Zarafshan River Basin (2022).

Due to the absence of the water quality data in the upstream (Tajikistan), the results obtained from the analysis of the whole basin land cover and land use impact on water quality of the Zarafshan River Basin were inappropriate. That's why, areas of land cover and land use were recalculated for middle and downstream of Zarafshan River Basin (Uzbekistan) for further RDA analysis (Table 2, Figure 4).

Table 2. Area (%) of land cover and land use in the middle and downstream of the Zarafshan River Basin (based on LULC data from ESRI).

Year	Cropland	Build-up Area	Rangeland	Covered with water	Wetland	Bare Ground
2017	35.77	14.47	47.44	0.67	0.01	1.59
2018	31.49	14.95	51.64	0.65	0.01	1.22
2019	38.22	15.14	44.93	0.95	0.01	0.67
2020	40.9	15.67	41.9	0.94	0.02	0.51
2021	34.65	16.07	47.97	0.73	0.01	0.54
2022	35.59	16.41	46.61	0.86	0.01	0.46
Min/Max	31.49/40.9	14,47/16.41	41.9/51.64	0.65/0.95	0.01/0.02	0.46/1,59
Average	36.10	15.45	46.75	0.8	0.012	0.83

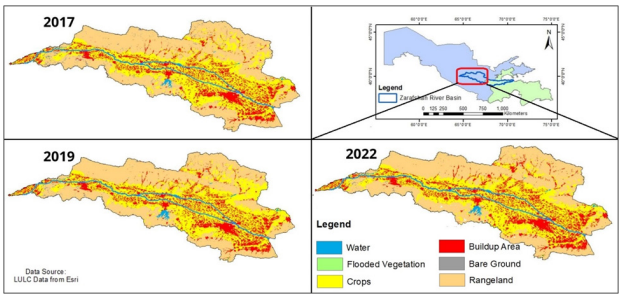


Figure 4. Map of land cover and land use change in the middle and downstream of the Zarafshan River Basin (2017, 2019, 2022).

To assess the influence of land use changes on water quality, RDA was conducted, focusing on three primary land use categories: rangelands, croplands, and built-up areas (Figure 5). The results showed moderate positive relationship for build-up area and ammonium nitrogen, nitrate nitrogen (RDA=0.66). This suggests that regions with more build-up areas have significantly higher ammonium and nitrate nitrogen compounds. The analysis revealed negligible impacts from rangeland and cropland uses on nitrogen compounds. However, a notably significant relationship was observed between N-NO3 and N-NH4. This may indicate possible synergies or common sources of nitrogen pollution [18, 19]. Furthermore, the results indicated a strong association between COD and built-up areas (RDA=0.89), suggesting a substantial influence of urbanization on its concentration [7, 30]. Several studies pointed, that agricultural activities affect water quality and reduce the concentration of DO [4, 31, 32]. In this study, croplands, as a subset of agriculture, did not show the significant influence on DO values (Figure 5).

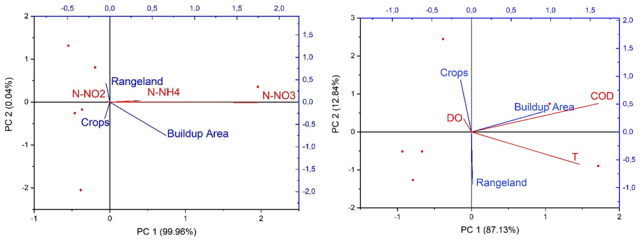


Figure 5. RDA ordination diagrams of impacts of land-use types (represented by blue lines) on water quality (represented by red lines).

These findings were supported by PCA, which emphasized the influence exerted by different land use types on specific water quality parameters. Understanding these trends is essential for informing land use planning and conservation efforts. Implementing strategies to mitigate the impact of urbanization, such as enhancing wastewater treatment and adopting sustainable agricultural practices, can help improve water quality in the Zarafshan River Basin.

Conclusion

In this study, we analyzed the impact of land use changes on water quality in the Zarafshan River Basin. It was revealed that most water quality parameters were below the MAC from 2017-2022, except for ammonium nitrogen (N-NH4) in 2022, which exceeded the MAC by 2.6 times, and nitrit nitrogen (N-NO2) - 1.25 times. Notable the values of COD and DO showed an increasing trend over five years. Also, an overall increasing trend (by 1.13 times) of built-up areas is observed primarily due to the population growth and expansion of urbanization. Moreover, the statistical analysis as RDA indicated the changes in built-up areas impacted N-NH4 and N-NO3 values (RDA=0.66). Furthermore, a significant relationship (RDA=0.89) between built-up areas and COD levels, highlighting urbanization's influence on increasing organic pollution. To ensure sustainable management of the basin's water resources, it is crucial to integrate land use planning with effective water quality monitoring and management strategies.

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