ithenticate_78502360.docx

Assessing Water Quality in Rivers Flowing into the Caspian Sea through Remote Sensing and Water Quality Indices

\begin{abstract}

Ensuring the water quality of the rivers flowing into the Caspian Sea is crucial for preserving the delicate ecosystem and safeguarding the environmental health of the region. In this study, we conducted a comprehensive assessment of the water quality in the Hazar, Babulroud, and Talar Rrivers during the Taistan and Fall seasons of 2020. The research objectives encompassed determining water quality using various indices, creating zoning maps through ordinary kriging to identify contamination locations, employing Principal Component Analysis (PCA) to identify crucial parameters, and establishing the relationship between water quality indices and spectral reflections. The rResults revealed significant variations in pollution levels across the studied rivers. The Haraz River exhibited the highest chemical pollution (chemical wWater qQuality indexIndices (WQI): 0.87), while the Talar River demonstrated the highest physical WQI (6.36) and overall water pollution (6.53). Additionally, the Babulrod River registered the highest pollution in the Dissolved Oxygen Deficit Index (DODI) (84.12) and Dissolved Oxygen Saturation (Dosat) (7.45), while the Talar River topped Domeasured (18), and both the Talar and Haraz rivers were identified as the most polluted based on the Pollution Load Index (PLI) (26.21) and Eutrophication Index (EI) (120.68), respectively. Utilizing the PCA method highlighted the pivotal role of the chemical WQI (-0.932 and - 0.896) in assessing water quality in the Babelrod and Talar Rrivers, while the Dosat index (0.943) emerged as crucial for accurate evaluation ofin the Haraz River. Further analysis of the relationship between water quality and remote sensing indices revealed the pronounced association ofunveiled the Modified Normalized Difference Water Index (MNDWI) index pronounced association with chemical WQI in the Talar River (coefficient: -0.705) and the robust correlation between Dosat and the MNDWI index in the Haraz River (correlation rate: -0.824). Conversely, the Talar River exhibited a direct correlation between the chemical WQI and BSI (correlation level: 0.827), indicative of increased turbidity. Spatial analysis using ordinary kriging underscored that the southern parts of the Babelroud River and northern s of the Talar and Haraz rivers ares more prone to pollution, primarily attributed to industrial activities.

\end{abstract}

\begin{IEEEkeywords}

Water Quality indices, River Pollution, Remote Sensing Indices, Caspian Sea Basin, Spatial Analysis.

\end{IEEEkeywords}

\{Introduction}

\IEEEPARstart{M}{onitoring} river water quality is of paramount importance, as it provides crucial insights into the health of aquatic ecosystems and the well-being of communities relying on these water sources \cite{giri2021water}. Rivers play a fundamental role in supporting biodiversity, supplying freshwater for agricultural and industrial activities, and serving as a source of drinking water for humans \cite{abell2019freshwater}. Regular monitoring helps to identify potential pollutants, such as industrial discharges, agricultural runoff, and urban effluents, enabling timely intervention to mitigate adverse environmental and public health impacts. By assessing key parameters, such as nutrient levels, sedimentation, and the presence of contaminants, monitoring programs contribute to the early detection of water quality degradation and help formulate effective management strategies. Furthermore, monitoring data aids in compliance with environmental regulations, facilitates sustainable water resource management, and enhances our understanding of complex interactions within river ecosystems \cite{hamid2020local}. Ultimately, it is important to monitor river water quality to safeguard both the ecological integrity of water bodies and the health and prosperity of communities that depend on these vital resources \cite{mokarram2020effects}.

The flow of river water into the sea can exacerbate water pollution and pose significant environmental challenges. As rivers traverse various landscapes, they accumulate pollutants from urban, industrial, and agricultural sources along their course \cite{njuguna2020application}. These contaminants, including chemicals, nutrients, and sediments, are carried by river currents, eventually reaching the sea. The discharge of untreated urban and industrial effluents, agricultural runoff containing pesticides and fertilizers, and other pollutants significantly affect the water quality of rivers \cite{singh2022challenges}. When these rivers are discharged into the sea, they introduce a concentrated mix of pollutants into marine ecosystems, adversely affecting aquatic life and biodiversity. The accumulation of contaminants in coastal areas can lead to degradation of water quality, posing threats to marine organisms, fisheries, and overall ecosystem health. Addressing water pollution at the river-sea interface is crucial for maintaining the integrity of both freshwater and marine environments, thereby emphasizing the interconnectedness of inland and coastal water systems \cite{iqbal2022seasonal}.

Investigating the water quality of rivers flowing into the Caspian Sea is of paramount importance because of its unique geopolitical and ecological significance \cite{dahmardeh2021assessing}. The Caspian Sea is a closed basin, bordered by several countries with distinct geological and geographical features \cite{pietkiewicz2021legal}. As the largest enclosed inland body of water on Earth, it serves as a critical resource for surrounding nations \cite{hatami2022personal}. Rivers flowing into the Caspian Sea, such as Haraz, Talar, and Babulrud, play a crucial role in influencing the sea's overall water quality \cite{abedi2023seasonal}. These rivers transport pollutants from various sources, including urban, industrial, and agricultural activities, which, when discharged into the Caspian Sea, pose significant threats to the delicate ecosystem. Monitoring and understanding the water quality of these rivers is essential for sustainable management and conservation. A comprehensive investigation can provide valuable insights into the nature and extent of pollutants, helping formulate effective strategies to mitigate pollution and protect the ecological integrity of the Caspian Sea. As a shared resource among multiple nations, cooperative efforts to monitor and manage river water quality are vital to ensure the health and sustainability of the Caspian Sea and the well-being of communities dependent on its resources \cite{amirgaliev2022water}.

The importance of assessing water quality using a combination of water quality indices, such as WQI the (Water Quality Index (WQI) \cite{mokarram2021investigation}, EI (Eutrophication Index (EI) \cite{liu2019assessment}, PLI (Pollution Load Index (PLI) \cite{khalili2021evaluating}, DOD (Dissolved Oxygen Deficit (DOD) \cite{jaiswal2023diurnal}, DOsat (Dissolved Oxygen Saturation (DOsat) \cite{kannan2022investigating}, and DOmeasured (Measured Dissolved Oxygen (DOmeasured), cannot be overstated. These indices collectively provide a comprehensive understanding of the ecological health and contamination levels in aquatic systems. Water quality indices are serve as valuable tools for monitoring the presence and concentration of various pollutants, nutrients, and oxygen levels in water bodies. Each indicator offers unique insights into different aspects of water quality. For example, Dissolved Oxygen (DO) indices, including DOD, Dosat, and DOmeasured, reflect the oxygen levels crucial for supporting aquatic life \cite{chakraborti2021impact}. The eEutrophication Index (EI) and Pollution Load Index (PLI) help identify nutrient enrichment and pollutant loads, respectively, thereby shedding light on potential sources of contamination \cite{porush2023application}. The selection of the most important indicator depends on the specific goals of the water quality assessment. In many cases, the Water Quality Index (WQI) serves as a comprehensive metric that, considering multiple parameters to provide an overall assessment of water quality \cite{nong2020evaluation}. However, choosing the most relevant indicator may vary based on the targeted pollutants, the ecosystem under study, and regulatory requirements. To achieve more accurate and meaningful results, it is crucial to tailor the choice of indices to the characteristics of the water body and the potential sources of pollution. In some instances, focusing on specific indices, such as DOD or PLI, may offer a more nuanced understanding of particular water quality challenges.

The preparation of spatial maps offor water quality indices is of paramount importance in contemporary environmental management \cite{dandge2022spatial}. These maps serve as powerful visual tools tothat depict the spatial distribution of key water quality parameters across different regions. By integrating geospatial data with water quality indices, these maps provide a comprehensive overview of the environmental health of water bodies. Policymakers, researchers, and environmentalists can ustilize these spatial representations to identify pollution hotspots, discern trends, and formulate targeted interventions for water quality improvement. In aAdditionally, spatial maps enhance public awareness by presenting complex scientific information in an accessible format, fostering community engagement in environmental conservation efforts \cite{tasseron2020plastic}.

Determining the relationship between the best-selected water quality indicator and various parameters measured in the water samples is a crucial step in understanding comprehending the overall water quality status. The Principal Component Analysis (PCA) method plays a pivotal role in unraveling these intricate relationships \cite{hou2022unraveling}. By employing PCA, complex datasets comprising multiple water quality parameters can be reduced to a smaller set of uncorrelated variables, known as principal components. This reduction aids in identifying the most influential factors that influencing water quality.

Investigating water quality using through spectral reflectance is of paramount importance in contemporary environmental monitoring \cite{topp2020research}. Spectral reflectance, measured using through remote sensing technologies, provides a unique perspective on water quality by capturing the electromagnetic signatures associated with different water constituents \cite{sagan2020monitoring}. This method allows for the identification and quantification of various pollutants, including suspended sediments, algae, and dissolved organic matter, based on their distinct spectral characteristics. The advantages of remote sensing in water quality monitoring are manifold, offering wide spatial coverage, frequent revisit times, and the ability to monitor remote or inaccessible areas \cite{chawla2020review}. The non-invasive nature of remote sensing enables large-scale assessments, facilitating a comprehensive understanding of dynamic water systems. Moreover, the temporal and spatial resolution of remote sensing data allows for real-time monitoring and trend analysis, contributing to more informed decision -

making in water resource management. Continuous and systematic surveillance using remote sensing helps to detect changes in water quality over time, identify potential pollution sources, and assess the impact of human activities on aquatic ecosystems. Overall, the integration of spectral reflectance and remote sensing technologies enhances our ability to monitor and manage water quality on a regional or global scale, supporting sustainable practices, and safeguarding water resources for future generations \cite{sagan2020monitoring}.

In light of the significance of this study, it aims to achieve the following objectives:

\begin{enumerate}

\item Assessing the water quality of the Haraz, Babelrod, and Talar rivers during two months of summer and autumn by employing key water quality indices, namely WQI, EI, PLI, DOD, Dosat, and DOmeasured.

\item Utilizing Principal Component Analysis (PCA) to discern the most influential parameters impacting the investigation of each water quality indicator for the studied rivers.

\item Investigating the correlation between each water quality indicator and spectral reflections. This analysis seeks to elucidate the connections between the measured water quality parameters and their corresponding spectral signatures, providing valuable insights into the environmental dynamics of the rivers under study.

\item Generating spatially explicit maps for each water quality indicator using the ordinary kriging method.

\end{enumerate}

\{Material and methods}

21

In this S, Awe provide an overview of the characteristics of the study area (A), describe the data characteristics specific to the study area (B), and outline the methodologies employed in this study (C). C-1 delves into the water quality indicators utilized, including the WQI, Dosat, Domeasured, DODI, PLE, and EI. C-2 elaborates on the application of the kKriging method, while C-3 discusses the implementation of the PCA method to identify the most influential parameters affecting water quality. In C-4, we present the remote sensing indicators investigated in this research and, exploreing the correlation between remote sensing data and water quality indicators.

\{Case study} \label{2.1}

16

This study focused on three significant rivers located in the northern region of Iran near the Caspian Sea: Babelrud, Haraz, and Talar. These rivers cover approximate areas of 236.47, 173.40, and 485.14 square kilometers, respectively, with lengths measuring 173.79, 122.81, and 340.39 km. The highest elevation is associated with the Haraz River, reaching 1135 m.

{Haraz River}

The Haraz River, situated in the Mazandaran province of northern Iran, originates from the Lar Valley in the south of Damavand Mountain and ultimately flow into the Caspian Sea. This river provides agricultural water to communities such as Amol, Faridoonkanar, Babol, and Noor. The slope of the Haraz River ranges from 13 per thousand at the mountain border to 7 per thousand within the city limits of the Amol. The river flows through a relatively narrow valley in the mountainous region, exhibiting two distinct deposits: medium-grained alluvial deposits resulting from the river's activity and alluvial deposits, primarily light brown loss color. The Haraz River is a protected watercourse that foster diverse native fish species, colored trout, and serves as a migration route for certain economically important fish from the Caspian Sea for reproduction.

{Babolroud River}

The Babolroud River, one of the largest rivers in northern Iran situated in the Mazandaran province, boasts high water flow due to the presence of dams, notably the Alborz Dam (Lafur Dam) in Lafur Village, Northern Swadkoh County. This earthen dam is among the largest dams in the country. Cities along the riverbanks, such as Babol and Babolsar, feature recreational and sports facilities, including a coastal roads, and parks with amenities such aslike coffee shops, children play areas, football fields, boating facilities, and restrooms.

{Talar River}

33

Also known as Telar, the Talar River is located in the Mazandaran province and originates from the Alborz Mountains in Swadkoh. It spans a distance of 180 km before flowing into the Caspian Sea. One significant issue facing the Talar River is sand mining on the Khatirkoh Rroad, leading to frequent turbidity. The construction of a dam at the Rosie Spring has contributed to water shortages, and the river faces challenges from improper waste disposal. The watershed experiences an average annual temperature of 8.9 degrees Celsius, with a corresponding annual rainfall averaging 400 mm. The bedrock of the study area is sedimentary and is, primarily composed of sandstone and limestone.

34

The geographical locations and characteristics of each river are visually presented in Fig. 1 and summarized in Table 1, respectively.

Position of the study area

\{Data description} \label{2.2}

To evaluate the water quality of the three investigated rivers, 25 water samples were systematically collected from the Haraz River, 32 from Babelrod River, and 36 from Talar River. The analysis includ a range of parameters, including BOD$_5$, COD, NO$_3$, NO$_2$, PO$_4$, SO$_4^{2-}$, Cl, Na, CO$_3^{2-}$, HCO$_3^-$, DON, Ca, Mg, K, NH$_4$, Fe, temperature (T°C), electrical conductivity (EC), dissolved oxygen (DO), pH, turbidity, total dissolved solids (TDS), and total suspended solids (TSS). These samples underwent precise measurements within a controlled laboratory environment to generate a comprehensive dataset for thorough water quality assessment.

The water quality assessment was conducted during two distinct seasons—summer and autumn—to enable a comparative analysis of the rivers' water quality under varying environmental conditions. By examining water parameters in these two seasons, this study aimed to capture potential seasonal variations that could influence the water quality of the rivers.

The outcomes of these measurements, delineating the values associated with each parameter for both the summer and autumn seasons, are shown depicted in Fig. 1. This graphical representation serves as a valuable tool for comprehensively comparing and comprehending the variations in the water quality parameters across the studied rivers during different periods of the year. An analysis of these results offers insights into potential seasonal trends and variations in the water quality of the Haraz, Babelrod, and Talar Rivers, contributing to a nuanced understanding of their environmental dynamics.

\{ Methodology} \label{2.3}

{Investigation of water quality indicators}

{Water Quality Indices (WQI)}

The Water Quality Index is a comprehensive numerical expression that summarizes the overall water quality of a water body. It combines multiple water-quality parameters into a single value.

\begin{equation}

WQI = \frac{{W_1(Q_1) + W_2(Q_2) + W_3(Q_3) + \ldots + W_n(Q_n)}}{{W_1 + W_2 + W_3 + \ldots + W_n}}

\end{equation}

Where:

\\

W_n represents the weight assigned to each water quality parameter and Q_n represents the quality rating for each parameter. These ratings can be determined based on the water quality standards and guidelines.

\\

The Water Quality Index (WQI) is a composite parameter that provides a single value for the overall water quality. The calculation of the WQI often involves sub-indices related to different water quality parameters. There are various methods for calculating the WQI, and the specific equations can vary based on the methodology used. Here are simplified representations of the equations for the Physical, Chemical, Biological, and Overall WQI:

1- Physical WQI: Physical parameters may include temperature, turbidity, and conductivity. The specific parameters included can vary, but a simplified physical WQI equation might look like this:

\begin{equation}

\begin{split}

\text{Physical WQI} &= a_1 \left(\frac{T - T_{\text{ref}}}{T_{\text{ref}}}\right) + a_2 \left(\frac{\text{Turb} - \text{Turb}_{\text{ref}}}{\text{Turb}_{\text{ref}}}\right)

\\

&\quad + a_3 \left(\frac{\text{Cond} - \text{Cond}_{\text{ref}}}{\text{Cond}_{\text{ref}}}\right)

\end{split}

\end{equation}

Where:

Where

\(T\) is temperature,

\(T_{\text{{ref}}}\) is a reference temperature,

\(\text{{Turb}}\) is turbidity,

\(\text{{Turb}}_{\text{{ref}}}\) is a reference turbidity,

\(\text{{Cond}}\) is conductivity,

\(\text{{Cond}}_{\text{{ref}}}\) is a reference conductivity,

\(a_1, a_2, a_3\) are coefficients.

\\

2- Chemical WQI: Chemical parameters often include concentrations of pollutant,s such as dissolved oxygen, nutrients, and heavy metals. A simplified chemical WQI equation may be:

\begin{equation}

\begin{split}

\text{Chemical WQI} &= c_1 \left(\frac{\text{DO} - \text{DO}_{\text{ref}}}{\text{DO}_{\text{ref}}}\right) \\

&\quad + c_2 \left(\frac{\text{Nutrient} - \text{Nutrient}_{\text{ref}}}{\text{Nutrient}_{\text{ref}}}\right) \\

&\quad + c_3 \left(\frac{\text{Metal} - \text{Metal}_{\text{ref}}}{\text{Metal}_{\text{ref}}}\right)

\end{split}

\end{equation}

Where:

DO is dissolved oxygen,

DO_{ref} is a reference dissolved oxygen,

Nutrient is the nutrient concentration,

$\text{Nutrient}_{\text{ref}}$ is the reference nutrient concentration,

Metal is the heavy metal concentration,

$\text{Metal}_{\text{ref}}$ is the reference heavy-metal concentration,

$c_1, c_2, c_3, d_1, d_2, d_3$ are coefficients.

sub{Dissolved Oxygen Saturation (Dosat)}

Dissolved oxygen saturation represents the amount of oxygen present in the water as a percentage of the maximum amount of oxygen that water can hold at a specific temperature and pressure. This is an important parameter in aquatic ecosystems.

\begin{equation}

\text{Dosat (\%)} = \left(\frac{\text{Dissolved Oxygen (DO)}}{\text{DO at 100\% saturation}}\right) \times 100

\end{equation}

sub{Dissolved Oxygen Deficit (Domeasured)}

The Dissolved Oxygen Deficit measures the amount of dissolved oxygen present in the water compared to its full saturation. It is a critical parameter for assessing the oxygen levels in water bodies.

\begin{equation}

\text{Domeasured (mg/L)} = \text{DO at 100\% saturation} - \text{DO}

\end{equation}

sub{Dissolved Oxygen Deficit Index (DODI)}

The DODI is an index that quantifies the severity of the dissolved oxygen deficit in a water body. It assesses the degree to which the oxygen levels fall below the saturation point.

\begin{equation}

\text{DODI} = \left(\frac{\text{Domeasured}}{\text{DO at 100\% saturation}}\right) \times 100

\end{equation}

sub{Pollution Load Index (PLI)}

The Pollution Load Index was utilized to evaluate the overall pollution load in a water body based on multiple water quality parameters. This provides a relative measure of pollution level.

The PLI is calculated using the formula:

\begin{equation}

\begin{split}

\text{PLI} = \frac{1}{n} \Bigg[&\left(\frac{\text{Concentration of Pollutant 1}}{\text{Standard for Pollutant 1}}\right) \\

&+ \left(\frac{\text{Concentration of Pollutant 2}}{\text{Standard for Pollutant 2}}\right) + \ldots \\

&+ \left(\frac{\text{Concentration of Pollutant n}}{\text{Standard for Pollutant n}}\right)\Bigg]

\end{split}

\end{equation}

Where

$\text{Concentration of Pollutant n}$ is the measured concentration of each pollutant,

$\text{Standard for Pollutant n}$ is the regulatory standard or guideline for pollutants,

n is the total number of pollutants considered.

sub{Eutrophication Index (EI)}

The Eutrophication Index assesses the level of eutrophication, which is the excessive nutrient enrichment in a water body.

\begin{equation}

\text{EI} = \frac{P + N}{2}

\end{equation}

Where

P typically represents the phosphorus concentration in the water.,

N typically represents the nitrogen concentration in water.

{Remote Sensing Indices}

In this , the remote sensing indices BSI (Built-up Index), EBBI (Enhanced Built-Up and Bareness Index), NDBI (Normalized Difference Built-Up Index), NDVI (Normalized Difference Vegetation Index), and MNDWI (Modified Normalized Difference Water Index (MNDWI) were used to check water quality, and the formulas for each of them are given below.

\begin{equation}

\text{BSI} = \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR}}

\end{equation}

```
\begin{equation}
    \text{EBBI} = 1.01 \times \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR} + 0.02}
\end{equation}

\begin{equation}
    \text{NDBI} = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}}
\end{equation}

\begin{equation}
    \text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}
\end{equation}

\begin{equation}
    \text{MNDWI} = \frac{\text{Green} - \text{SWIR}}{\text{Green} + \text{SWIR}}
\end{equation}
```

{Ordinary Kriging}

Ordinary Kriging is a geostatistical interpolation technique that is widely used in environmental studies, including water quality assessments. It provides a robust method for spatial interpolation, allowing the estimation of values at unsampled locations based on the observed values in the surrounding area.

Ordinary Kriging estimation for an unsampled location $Z(u_0)$ can be expressed using the following equation:

\begin{equation}

Z(u_0) = \sum_{i=1}^{n} \lambda_i \cdot Z(u_i)

\end{equation}

Where:

$Z(u_0)$ is the estimated value at an unsampled location.,

$Z(u_i)$ represents the values observed values at the sampled locations.,

λ_i is the Kriging weight assigned to each observed value.

The kriging weights were determined based on the spatial autocorrelation structure, which was calculated using a semivariogram. The semivariogram provides information about the spatial dependence between pairs of sample points, helping quantify the degree of spatial variability.

{Principal Component Analysis (PCA)}

Principal Component Analysis (PCA) is a data transformation technique used for dimensionality reduction and feature selection. It simplifies complex datasets by transforming them into a smaller set of uncorrelated variables called principal components. In the context of feature selection, PCA helps identify the most important features.

For the jth data point in the original dataset, the PCA calculates the values in the reduced dataset using the following equation:

$$\text{PCA}_j = a_1 \cdot \text{PC}_1 + a_2 \cdot \text{PC}_2 + \ldots + a_k \cdot \text{PC}_k$$

Where:

PCA_j represents the data points in the reduced dataset for observation j.,

a_i represents the coefficients (weights) of the principal components,

PC_i represents the ith principal component.,

These coefficients were determined through eigendecomposition, and the contribution of each original feature to each principal component was specified.

Results

In this , we present the findings of our research, aimed at assessing the water quality of the three rivers. A provides separate study area data for each river. In B, we present the outcomes of the studied indicators for each river, and C highlights the results of the PCA method, pinpointing the most crucial indicators in water quality assessment. In D, we showcase the zoning maps generated using the kriging method for each river. E presents the results detailing the relationship between the remote sensing indicators and water quality indicators for each river. Finally, in F, we expound on the outcomes of land use changes and their consequential impact on water quality.

Input Parameters

To assess water quality in the three rivers—Babelrod, Haraz, and Talar—sampling was conducted at 32, 25, and 36 points during two distinct seasons, namely summer (September) and autumn (December). The sampling locations are illustrated in Fig. 2. Comprehensive water quality analyses were carried out for each sample, encompassing parameters such as BOD, COD, NO_3, NO_2, PO\textsubscript{4}, Cl, Na, CO\textsubscript{3}, HCO\textsubscript{3}, DON, Ca, Mg, K, NH\textsubscript{4}, Fe, temperature (T), electrical conductivity (EC), dissolved oxygen (DO), pH, turbidity, total dissolved solids (TDS), and total suspended solids (TSS) during the investigated seasons.

Fig. 2 depicts the spatial distribution of sampling points and serves as a reference for the subsequent discussion. Notably, the concentration of elements in the Talar River during the summer season exceeded that in the fall season for most elements. In the case of the Haraz River, the concentrations of elements in the summer and autumn seasons exhibit values in close proximity. Conversely, in the Babol River, the concentration of elements during the summer season surpasses that in the autumn season. This disparity could be attributed to water thickening caused by heightened water evaporation. These observations, presented graphically in Fig. 2, underscore the seasonal variations in element concentrations across the rivers. The higher concentrations in certain elements during the summer months, especially in the Talar River, merit further investigation and analysis. This comprehensive examination contributes valuable insights into the dynamic water quality characteristics of Babelrod, Haraz, and Talar rivers across distinct seasons.

Characteristics of input data

\{Results of Water Quality Indices}

To evaluate the water quality of the examined rivers, this study utilized essential indices, including the Water Quality Index (Physical WQI, Chemical WQI, and Overall WQI), Dosat, Domeasured, DODI, PLI, and EI. A detailed explanation of each indicator is provided below.

{Results of WQI}

The examination of Physical WQI focused on parameters such as temperature (\(T\)), Turbidity, and Electrical Conductivity (EC). Chemical WQI incorporates parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrate (NO\textsubscript{3}), Nitrite (NO\textsubscript{2}), phosphate (PO\textsubscript{4}), sulfate (SO\textsubscript{4}), chloride (Cl\(^-\)), sodium (Na), Carbonate (CO\textsubscript{3}), Bicarbonate (HCO\textsubscript{3}), Dissolved Organic Nitrogen (DON), calcium (Ca), magnesium (Mg), potassium (K), ammonium (NH\textsubscript{4}), and iron (Fe).

In Fig. 3, the highest values for Physical WQI were recorded for samples 27 and 28, measuring 3.37 and 3.42, respectively, while the lowest level of pollution was observed at point 12, with a value of 2.63. Chemical WQI analysis indicated the lowest contamination at point 12 (0.95) and the highest contamination at points 15 and 27 (0.992 and 0.994, respectively). For the Overall WQI, the highest pollution levels were identified at points 27 and 28, with values of 4.36 and 4.41.

Water Quality Index (WQI) results for each Rivers

In the Haraz River, Fig. 3 reveals that the highest Physical WQI values were found in samples 15, 19, and 20, measuring 5, whereas the lowest pollution level occurred at point 16, with a value of 4.33. Chemical WQI analysis identified the lowest pollution levels at points 15 and 22 (0.78) and the highest at points 5, 16, and 17 (0.87). The overall WQI for the Haraz River showed the highest pollution at point 5, with a value of 5.82.

Turning to the Talar River, Fig. 3 displays the highest Physical WQI for at sample 30 (6.36) and the lowest at point 32 (0.948). The lowest Chemical WQI was at point 24 (0.162), whereas the highest was at points 5 and 34 (0.68). For Overall WQI, the highest pollution level was observed at point 30, with a value of 6.53.

Fig. 3 provides a comprehensive overview, indicating that physical pollution levels across all three rivers surpass chemical pollution. The Haraz River exhibits the highest chemical pollution levels (Chemical WQI), while the Talar River exhibits the highest Physical WQI and overall water pollution. These findings underscore the varying pollution dynamics in rivers and emphasiz the need for targeted environmental management strategies.

{Dosat, Domeasured, DODI}

In this segment, Dissolved Oxygen (DO) values were utilized to assess water quality using the Dosat, Domeasured, and DODI indices. As depicted in Fig. 4, for Babulrod River, the highest Dosat value was recorded at point 21, reaching a value of 22, while the lowest Dosat value was observed at point 16, with a value of 7.45. Domeasured showed the highest value at point 26 (7.1), whereas the lowest was at point 1 (0.5). The DODI index peaked at point 21 (84.12), with zero values corresponding to points 2 to 18, 20, and 21.

Results of Dosat, Domeasured, and DODI indices for each Rivers

For the Haraz River (Fig. 4), the highest Dosat value occurred at point 7 (9.29), with the lowest at point 25 (7.16) and The Domeasured index showed its highest value at point 15 (12.3) and the lowest at point 6 (1.8). For the DODI, the highest value was recorded at point 6 (80.62), and the lowest (zero) at points 15, 19, and 20.

In the Talar River, the Dosat index displayed its highest value at point 31 (9.59) and lowest at point 6 (5.88). The Domeasured index reaches its peak at point 28 (18) and its nadir at point 8 (1.6). The DODI index demonstrated the highest value at point 8 (79.4) and was zero at points 6, 16, 18, 22, 26, 28, and 30.

In summary, the results of the Dosat and Domeasured indices collectively designate Babelrod River as the most polluted, whereas the DODI index designates the Talar River as the most polluted among the studied rivers.

{PLI, EI}

The PLI index was used to measure the relative level of water pollution. For this index, all effective water quality parameters were considered. In additional, the amounts of phosphorus and nitrogen in water were used to determine the EI. As shown in Fig. 5, the highest value of the PLI index for the Babulrod River is point 2 with a value of 11.52, and the lowest value is related to point 27 with a value of 5.76. For the EI index, the highest value of this index corresponds to point 24 with a value of 8.7, and the lowest value corresponds to point 10 with a value of 1.06.

Results of PLI and EI indices for Babulrod, Haraz, and Talar Rivers

As shown in Fig. 5, the highest level of the PLI index for the Haraz River is point 15 with a value of 13.46, and the lowest value is related to point 25, with a value of 5.27. For the EI index, the highest value corresponds to point 1 with a value of 120.68, and the lowest value corresponds to point 24 with a value of 1.24.

According to Fig. 5, the highest value of the PLI index for the Talar River is point 6 with a value of 26.21, and the lowest value is related to point 33 with a value of 5.30. For the EI index, the highest value of this index corresponds to point 6 with a value of 29.04, and the lowest value corresponds to point 3 with a value of 3.65.

\{PCA-Based Approach for Selecting Effective Indices}

In this , the Principal Component Analysis (PCA) method was employed to address the challenge posed by a larger number of measured parameters. The objective was to reduce the complexity of water quality variables and identify the most influential variable. To achieve more accurate and scientifically robust results, a subsequent application of the factor analysis method was undertaken to discern fundamental variables or factors explaining the correlation patterns among observed variables. The results, as presented in Table 2, indicate that the factor analysis successfully identified one main component for all variables. Table 2 provides the percentage of the variance explained by each calculated combination. In the case of the Babulrod River during the summer season, PC1 revealed that parameters such as Fe, EC, average temperature, Dosat, and PLI carry the highest weights (0.922, -0.909, 0.922, -0.918, 0.9), indicating a strong interrelation among them. In autumn, the key parameters included BOD, HCO3, Ca, Mg, surface temperature, TDS, physical WQI, overall WQI, and PLI, with weights reflecting their significant interdependence (0.727, 0.883, 0.765, 0.944, 0.866, 0.771, -0.829, -0.838, 0.869). For the Haraz River in both autumn and summer, the dominant factors encompass parameters such as HCO3, Ca, Mg, K, surface temperature, EC, Physical WQI, average temperature, Dosat, DOmeasured, and DODI, each exhibiting substantial weights (ranging from -0.747 to 0.95). These parameters are intricately related and form cohesive compositions. The Talar River in the summer season highlights the importance of parameters such as BOD, surface temperature, Physical WQI, average temperature, and Dosat, with weights indicating their strong interconnectivity (0.769, 0.855, 0.796, 0.855, -0.831). In contrast, during the same season, COD, surface temperature, EC, average temperature, and dosage emerged as crucial factors with significant interrelations (weights ranging from -0.849 to 0.826). In summary, BOD, surface temperature, Physical WQI, average temperature, and Dosat consistently emerged as pivotal parameters across various seasons and rivers. Fig. 6 schematically represents the significance of each parameter in the overall context, providing a visual representation of their status. Across different seasons and rivers, parameters such as BOD, surface temperature, Physical WQI, average temperature, and Dosat consistently emerged as pivotal, forming cohesive compositions that significantly contributed to the overall water quality dynamics. These results underscore the importance of these key parameters in assessing and monitoring the water quality of the studied rivers.

Results of PCA method

Based on the outcomes derived from the Principal Component Analysis (PCA) method, it is evident that the chemical Water Quality Index (WQI) plays a paramount role in assessing the water quality in the Babelrod and Talar rivers, with values of -0.932 and -0.896, respectively. The significance of the chemical WQI underscores the importance of parameters such as heavy metal concentrations, nutrient levels, and other chemical constituents, indicating the influence of anthropogenic activities on water quality. The high concentrations of certain elements in these rivers can be attributed to human activities, such as industrial discharge, agricultural runoff, and urban effluents. Understanding the variations in these parameters is crucial for managing and mitigating the impact of human-induced pollution on these water bodies. In the case of the Haraz River, the Dissolved Oxygen Saturation (Dosat) index, exhibiting a value of 0.943, has emerged as a pivotal parameter crucial for precise water quality assessment. Dosat reflects the oxygen saturation levels in rivers and provides valuable insights into the health of aquatic ecosystems. High Dosat values suggest well-oxygenated water, which is essential for supporting aquatic life, whereas low values may indicate oxygen depletion, often associated with pollution or organic matter decomposition. The selection of Dosat as the key indicator emphasizes the importance of monitoring and addressing oxygen levels in the Haraz River, considering its vital role in sustaining a balanced and healthy aquatic environment (Fig. 6).

Relationship between input data and water indices.

\{Relation between Water Quality Indices and Remote Sensing Indices}

In this , it is crucial to note that, based on the results obtained from PCA, the water quality chemical index (WQI) assumes a pivotal role in the assessment of water quality for Babelrod and Talar rivers, manifesting values of -0.932 and -0.896, respectively. Concurrently, the dissolved oxygen saturation index (Dosat) has emerged as a central parameter with a value of 0.943, which is instrumental for the precise evaluation of water quality in the Haraz River. This investigation delves into the intricate relationship between these two key indices and remote sensing indices, including the BSI, EBBI, NDBI, NDVI, and MNDWI. To facilitate this exploration, the spectral index conditions within the study area were initially scrutinized using Landsat 8 satellite images.

In Fig. 7, the lowest values for BSI, EBBI, NDBI, NDVI, and MNDWI indices are associated with points 4, 9, 12, 5, 2, and respectively, with values of -0.38, 0.0205, 0.19, 0.134, and -0.327 respectively. Conversely, the highest values were observed at points 9, 4, 4, 25, and 4, with values of -0.013, 0.454, 0.617, 0.592, and 0.0269, respectively, along the Haraz River.

Examining Fig. 7 for the Babolroud River, the lowest values for the BSI, EBBI, NDBI, NDVI, and MNDWI indices were identified at points 6, 14, 14, 13, and 14, with corresponding values of -0.412, -0.045, 0.068, 0.156, -0.026. Conversely, the highest values were recorded at points 14, 6, 25, 36, and 6, with values of 0.026, 0.495, 0.642, 0.668, and 0.412, respectively.

As shown in Fig. 7, the lowest values for the BSI, EBBI, NDBI, NDVI, and MNDWI indices along the Talar River were observed at points 4, 18, 25, 25, and 16, with values of 0.383, 0.043, 0.156, 0.177, and -0.365, respectively. Conversely, the highest values were found at points 18, 4, 30, 34, and 17, with corresponding values of -0.030, 0.454, 0.681, 0.642, and 0.007, respectively.

Considering these indices, the points with the lowest values for each indicator in each river were potentially more polluted in terms of the corresponding water quality indicator.

4 Values of remote sensing indices in sampling points

The correlation between 4 remote sensing indices and water quality indices (WQI) for the Babulrod and Talar rivers, as well as Dosat for the Haraz River, was analyzed using the linear regression method, and the findings are depicted in Fig. 7. In the case of the Babulrod and Talar Rivers, the MNDWI index exhibited a more pronounced relationship with the chemical WQI, indicated by a higher coefficient of -0.705 compared to other vegetation indices. This negative coefficient signifies that, as the MNDWI index decreases (indicating lower water content), the chemical WQI tends to increase, suggesting a potential link between reduced water content and higher pollution levels. The Haraz River, on the other hand, demonstrated a stronger association between Dosat and the MNDWI index, displaying a correlation rate of -0.824, surpassing correlations with other indices. The negative correlation indicates that as Dosat decreases (reflecting lower dissolved oxygen saturation), the MNDWI index tends to decrease as well, implying a potential connection between reduced dissolved oxygen and higher pollution levels. The observed inverse relationships in both cases align with the expectation that higher WQI values correspond to increased pollution, whereas lower MNDWI values indicate elevated pollution levels. Conversely, the Talar River exhibited a direct relationship between the chemical WQI and BSI, with a correlation level of 0.827. This positive correlation suggests that, as the BSI index increases (indicating higher bare soil content), the chemical WQI tends to increase, implying a potential association between increased bare soil and water pollution. Generally, the research outcomes highlight the potential of utilizing remote sensing indices to predict and assess water pollution in the studied regions. The observed relationships between these indices and water quality indices provide valuable insights into environmental dynamics and contribute to a more comprehensive understanding of water quality in the respective river systems (Tables 3, 4, and 5).

Correlation Matrix between remote sensing 1 indices and water quality indices in Babolroud River

Correlation Matrix between remote sensing indices and water quality indices in Haraz River

correlation Matrix between remote sensing indices and water quality indices in Talar River

\{Application of Ordinary Kriging Method for Water Quality Assessment}

In this , the Ordinary Kriging method was employed to comprehensively investigate water quality across the three rivers under scrutiny. To generate zoning maps during the autumn and winter seasons, a suite of indices, including the WQI, temperature (T), Dosat, Domeasured, DODI, Pollution Load Index (PLI), and Ecological Index (EI) were derived from the measured data. The data collection include 25 samples from the Haraz River, 32 from the Babulrod River, and 36 from the Talar River. As depicted in Fig. 8, the analysis of the Babelrod River revealed distinct seasonal variations. During the summer season, most indices exhibited higher values than during to the autumn season. This phenomenon can be attributed to increased evaporation from the water surface, leading to elevated elemental concentrations and, subsequently, higher indicator values. Fig. 8 provides additional insights into the spatial distribution of various indices within the Babelrod River during the summer season. The southern regions show higher values for Physical WQI, overall WQI, Domeasured, and PLI, with corresponding values of 5, 2.9, and 80.7, respectively. In contrast, the northern parts exhibited higher values for Chemical WQI, Dosat, and EI, with values of 0.92, 27.4, and 6.9, respectively. During autumn, a shift in spatial distribution was observed. The southern parts now demonstrate the highest values for Chemical WQI, Dosat, DODI, and EI, registering 0.99, 16, 88, and 8.7, respectively. Conversely, The physical WQI, overall WQI, Domeasured, and PLI reach their zenith in both the southern and northern regions, with values of 3.4, 2.1, 7.1, and 11, respectively. These findings underscore the dynamic nature of water quality in the Babelrod River, highlighting the impact of seasonal variations and heterogeneous distribution of pollutants across different regions. The application of the Ordinary Kriging method enhances our understanding of spatial patterns and aids the formulation of targeted environmental management strategies.

Interpolation maps for each water quality indices for Babolroud River

Analysis of Fig. 9 reveals a pattern in the Haraz River, similar to that of the Babelrod River. During the summer season, the majority of the indices exhibited higher values compared to the autumn season. This phenomenon can be ascribed to the increased evaporation from the water surface, resulting in elevated elemental concentrations and subsequently higher indicator values. Fig. 9 provides a detailed spatial breakdown of various indices within the Haraz River during the summer season. The northern regions consistently show higher values for Physical WQI, Chemical WQI, overall WQI, Dosat, and DODI, with corresponding values of 4.9, 0.96, 2.9, 13, and 92. In the same season, the southern parts exhibit higher Domeasured, PLI, and EI values of 8.9, 11, and 466, respectively. In autumn, a shift in spatial distribution was observed. With the exception of the DODI and EI indices, where the southern parts displayed higher values, the rest of the indices exhibited the highest values in both the northern and southern regions. These spatial variations emphasize the complex interplay of environmental factors influencing water quality in the Haraz River. The Ordinary Kriging method facilitates a nuanced understanding of these patterns, aiding in the identification of critical areas and formulation of targeted interventions for effective water quality management.

Interpolation maps for each water quality indices for Haraz River

Similar to the observed trend in the other two rivers, the Talar River displays seasonal variation in water quality. During the summer season, most indices exhibited higher values than during the autumn season, indicating an increase in the overall water quality indices. Fig. 10 shows the spatial breakdown of various indices within Talar River during the summer season. The northern parts consistently exhibited higher values for Chemical WQI, Overall WQI, Domeasured, and EI, with corresponding values of 0.96, 2.5, 12, and 29. The DODI values were highest across most sectors, reaching a peak value of 82. Physical WQI and Dosat show varied distribution, with northern and southern parts having values of 6.3 and 16, respectively. In autumn, a shift in the spatial distribution was apparent. The northern parts showed the highest values for Physical WQI, PLI, and EI, with values of 6.1, 26, and 16, respectively. Conversely, for the chemical indices, including WQI, Overall WQI, Dosat, and Domeasured, the highest values were observed in both the the southern and northern regions, with values of 0.68, 2.2, 9.5, and 17, respectively. The DODI maintained high values (approximately 79) across most parts of the study area. These findings underscore the intricate relationship between seasonal variation and the spatial distribution of water quality parameters in the Talar River. The Ordinary Kriging method enhances our understanding of these dynamics and provides valuable insights into targeted interventions and sustainable water quality management strategies.

Interpolation maps for each water quality indices for Talar River

\{Impact of Spatial and Temporal Trends on the Water Quality}

The findings of this study underscore a concerning trend in the Talar River, particularly in its northern s (head branches), where higher pollution levels are observed across multiple indices than in other regions. A comparative analysis between 2022 and 1985 revealed a substantial expansion of urban lands in two key areas of the region, significantly contributing to the degradation of crucial water quality indices in the Talar River (Fig. 11). Specifically, the central part of the Talar River experienced notable urban land expansion in 2022, which is indicative of increased human activities in this region compared to 1985. This expansion is closely linked to a discernible increase in the pollution levels, as shown in Fig. 11. Furthermore, the northern parts of the region around the Babulrud River have witnessed a robust and noteworthy expansion of urban land in 2022 compared to 1985, as illustrated in Fig. 11. Urban development is associated with environmental consequences, including potential impacts on water quality indices. It is crucial to note that while urban expansion is a primary driver of water pollution, the southern parts of the studied area also face challenges. Agricultural lands in these regions has expanded, leading to increased pesticide and herbicides usage. Agricultural runoff contributes significantly to water pollution in the southern parts of the study area. In conclusion, this study highlights the intricate relationship between land-use changes, urban expansion, and water quality in the Talar and Babulrud Rivers. The trends emphasize the need for effective environmental management strategies to mitigate pollution and ensure the sustainability of these vital water resources.

The sources of pollution in the Talar River can be broadly categorized into three groups: urban, industrial, and agricultural. These pollutants encompass a wide range of contaminants, including urban and human waste, industrial byproducts, such as chemicals and organic substances, and agricultural runoff containing pesticides. A significant portion of the Talar River traverses urban areas, villages, and their outskirts, ultimately discharging into the sea. Consequently, substantial amounts of urban waste, domestic sewage, public facility runoff (e.g., from bathrooms), and discharges from riverside workshops find their way into the river or its vicinity. Leachate from garbage is particularly hazardous and contain pathogenic bacteria and toxic organic substances.

Land use changes have emerged as key environmental indices of soil erosion and have contributed to increased sediment production in the Haraz River. Approximately 300,000 ha of land in the upstream watershed are designated as pastures. Over the last two to three decades, this area has experienced significant land use changes, with high-quality pastures transforming into those of medium to poor quality and others being converted for agricultural, residential, mining, road construction, dam building, and various other purposes. Ongoing transformations, including hydraulic structures, livestock farming, waste disposal sites, pipelines, and developments in oil, gas, and telecommunications, have contributed to the deterioration for land use. The equation of land use change in the Haraz catchment has persistently shown a negative trend over the past two decades. This alteration in land use is expected to correlate with an increase in river sediments, diminishing ecosystem resilience and amplifying environmental degradation and river pollution. An examination of the Haraz River revealed that effluents from dairy factories, chicken slaughterhouse and soft drink factories tended to enter more polluted areas. Additionally, in the terminal part of Vardkhaneh, wastewater from sand-harvesting workshops consistently contributed to river pollution.

The Babulrud River faces pollution from the inflow of urban effluents and domestic sewage. Moreover, human sewage discharge poses a substantial threat to river health. Pollutants entering these three rivers ultimately reach the Caspian Sea, posing a severe threat to the ecosystem of the region.

Land use changes in the Rivers studies

\{Discussion}

In this study, a wide range of parameters, including BOD, COD, NO3, NO2, PO4, SO4, Cl-, Na, CO3, HCO3, DON, Ca, Mg, K, NH4, and Fe, were thoroughly investigated, setting this study apart from others. Although previous studies, such as Yang et al. (2022) \cite{yang2022review}, have focused on a subset of these parameters, the inclusion of the entire set enhances the granularity of water quality assessment, providing a more accurate depiction of pollutant concentrations and their potential impacts.

Comparing the pollution hotspots identified in this study with findings from studies such as Fleming et al. (2019) \cite{fleming2019legacy} contributes to a deeper understanding of regional changes and potential pollution sources. Notably, areas with significant pollution, such as sampling points 27 and 28, were identified as potential sites of urban runoff due to industrial activities, consisten with the results of Charters et al (2021) \cite{charters2021influence}.

Unlike some studies such as Wu et al. (2021) \cite{wu2021water}, our study utilized various water quality indicators, fostering more accurate results through inter-indicator comparisons. Spatially investigating pollution hotspots, similar to the studys by Ijumulana et al. (2020) \cite{ijumulana2020spatial}, allowed us to examine water quality across different regions.

The analysis of dissolved oxygen (DO) values, focusing on the Dosat, Domeasured, and DODI indices, provided crucial insights into the water quality of the Babelrud, Haraz, and Talar rivers. Changes in Dosat values at different sampling points offered a unique perspective on oxygen saturation levels in each river, which is consistent with Gupta et al.'s (2022) \cite{gupta2022assessment} findings.

The results of the Dosat and Domeasured indices highlighted the Babelrod River as being the most polluted, emphasizing its vulnerability to oxygen dynamics. PCA results underscored the significance of the chemical water quality index (WQI) in water quality assessment, aligning with Fatima et al.'s (2022) \cite{fatima2022geospatial} research.

The chemical importance of the WQI stressed the impact of heavy metal concentrations, nutrient levels, and other compounds on water quality, offering insights into human activities such as industrial discharges and agricultural runoff. This study further revealed that the Dosat index plays a crucial role in evaluating water quality, especially in understanding oxygen saturation levels vital for assessing aquatic ecosystem health.

An innovative aspect of this research is the examination of the intricate relationship between key indices (WQI and Dosat determined by PCA) and remote sensing indices, including BSI, EBBI, NDBI, NDVI, and MNDWI. Correlations observed in the Haraz and Babelrod Rivers (MNDWI index) and Talar River (BSI index) indicate the potential use of remote sensing indices in water quality studies.

The research findings underscore the usefulness of remote sensing indicators in predicting and assessing water pollution, offering valuable insights into environmental dynamics and contributing to a comprehensive understanding of water quality in river systems.

Lastly, the study of land-use changes since 1985 revealed a significant expansion of urban land, contributing to river water quality degradation. Urban, industrial, and agricultural pollution have emerged as key pollution sources, emphasizing the intricate relationship between land-use changes, urban expansion, and water quality, consistent with De et al.'s (2020) \cite{de2020multiscale} findings. This study need the necessity for effective environmental management strategies to reduce pollution and ensure water resource sustainability. It provides crucial insights into the seasonal and spatial dynamics of water quality in the Haraz, Babelrod, and Talar Rivers. The use of advanced methods, such as conventional kriging, enhances the water quality assessment accuracy and facilitates targeted management strategies that are essential for maintaining the health and sustainability of these vital water resources.

\{Conclusions}

In conclusion, this study underscores the critical importance of monitoring and evaluating the water quality of rivers flowing into the Caspian Sea, emphasizing its significant impact on the regional ecosystem. Focusing on the Hezar, Babulrod, and Talar Rivers during the Taistan and Fall seasons in 2020, this study employed a comprehensive approach involving various water quality indicators, spatial mapping techniques, and advanced statistical methods. The results revealed distinct patterns of pollution across the studied rivers, with Haraz exhibiting higher levels of chemical pollution, Talar showing elevated physical and overall water pollution, and Babulrod demonstrating notable pollution in specific indices. The application of Principal Component Analysis (PCA) pinpointed key parameters influencing water quality, with the Chemical Water Quality Index (WQI) identified as pivotal for the Babelrod and Talar rivers, while the Dissolved Oxygen Saturation (Dosat) emerged as crucial for the Haraz River. Additionally, the integration of remote sensing indicators provided valuable insights into the relationships between water quality and environmental parameters, enhancing our ability to predict and manage water pollution. The spatial analysis highlighted localized pollution hotspots, emphasizing the role of industrial activities in contributing to contamination. This study contributes valuable knowledge to environmental management and lays the foundation for ongoing efforts to safeguard the Caspian Sea ecosystem.

ithenticate_78502360.docx

ORIGINALITY REPORT

9%

SIMILARITY INDEX

PRIMARY SOURCES

1	Winfred Kilonzo, Patrick Home, Joseph Sang, Beatrice Kakoi. "The Storage and Water Quality Characteristics of Rungiri Quarry Reservoir in Kiambu, Kenya, as a Potential Source of Urban Water", Hydrology, 2019 Crossref	63 words — 1%
2	www.ncbi.nlm.nih.gov Internet	45 words — 1%
3	www.mdpi.com Internet	44 words — 1%
4	Anita Sabat-Tomala, Anna Maria Jarocińska, Bogdan Zagajewski, Artur Stanisław Magnuszewski et al. "Application of HySpex hyperspectral images for verification of a two-dimensional hydrodynamic model", European Journal of Remote Sensing, 2018 Crossref	42 words — < 1%
5	link.springer.com Internet	42 words — < 1%
6	Oliounine, I.. "Leadership seminar on Caspian Sea and its Deltas region sustainable development and regional security 27-30 May 2003, Astrakhan, Russian Federation", Ocean and Coastal Management, 200308 Crossref	38 words — < 1%

7	docs.digitalearthafrica.org Internet	37 words — < 1%
8	Lamidi, Torib Hamzah, Triwiyanto Triwiyanto, Nuristadarro, Deny Elfredo. "Baby Incubator Monitoring Center Using Wi-Fi Network for Data Transmission", Journal of Biomimetics, Biomaterials and Biomedical Engineering, 2022 Crossref	32 words — < 1%
9	Andreas Klassen, Marcus Bistron, Philip Dellinger, Jörg Schaup et al. "Chapter 3 Werkzeugtechnologie", Springer Science and Business Media LLC, 2014 Crossref	29 words — < 1%
10	A. Zarei, M. Masihi, K. Salahshoor. "Comparison of Different Univariate and Multivariate Geostatistical Methods by Porosity Modeling of an Iranian Oil Field", Petroleum Science and Technology, 2011 Crossref	24 words — < 1%
11	Christopher Ndehedehe. "Satellite Remote Sensing of Terrestrial Hydrology", Springer Science and Business Media LLC, 2022 Crossref	22 words — < 1%
12	journals.pan.pl Internet	21 words — < 1%
13	griesshaber.pages.mi.hdm-stuttgart.de Internet	20 words — < 1%
14	M. Elshemy, G. Meon. "Chapter 96 Water Quality Assessment of Aswan High Dam Reservoir", Springer Science and Business Media LLC, 2016 Crossref	19 words — < 1%

15	Terence Darlington Mushore, John Odindi, Timothy Dube, Onisimo Mutanga. "Prediction of future urban surface temperatures using medium resolution satellite data in Harare metropolitan city, Zimbabwe", Building and Environment, 2017 Crossref	18 words — < 1%
16	scholar.smu.edu Internet	18 words — < 1%
17	www.science.gov Internet	17 words — < 1%
18	training.digitalearthafrica.org Internet	15 words — < 1%
19	Liya Fu, You Gan Wang. "Chapter 24 Statistical Tools for Analyzing Water Quality Data", IntechOpen, 2012 Crossref	14 words — < 1%
20	Olandia Ferreira Lopes, Raildo Mota de Jesus, Lucas Farias de Sousa, Felizardo Adenilson Rocha et al. "Comparison between water quality indices in watersheds of the Southern Bahia (Brazil) with different land use", Environmental Science and Pollution Research, 2020 Crossref	14 words — < 1%
21	Shanyou Zhu, Huade Guan, Andrew C. Millington, Guixin Zhang. "Disaggregation of land surface temperature over a heterogeneous urban and surrounding suburban area: a case study in Shanghai, China", International Journal of Remote Sensing, 2012 Crossref	14 words — < 1%
22	www.researchgate.net Internet	14 words — < 1%

23	www.coursehero.com Internet	13 words — < 1%
24	Chiara Garau, Giulia Desogus, Erika Orrù, Claudia Loggia. "Chapter 16 A Theoretical Framework for Climate Change Adaptation Participatory Planning in Vulnerable Coastal Zones", Springer Science and Business Media LLC, 2023 Crossref	11 words — < 1%
25	www.hindawi.com Internet	11 words — < 1%
26	worldwidescience.org Internet	10 words — < 1%
27	www.nature.com Internet	10 words — < 1%
28	www.researchsquare.com Internet	10 words — < 1%
29	SpringerBriefs in Water Science and Technology, 2015. Crossref	9 words — < 1%
30	amsdottorato.unibo.it Internet	9 words — < 1%
31	researchspace.ukzn.ac.za Internet	9 words — < 1%
32	Yanjun Zhu, Hongyun Li, Peng Yang, Dong Li, Ziyan Wang, Yunpeng Qi, Jie Zhang. "Aluminum speciation in polymerized aluminum chloride: Roles and	8 words — < 1%

chloride ion migration in sludge dewatering", Journal of Environmental Chemical Engineering, 2024
Crossref

33 environmentalsystemsresearch.springeropen.com — 8 words — < 1%
Internet

34 mts.intechopen.com — 8 words — < 1%
Internet

35 A. K. Gupta, S. K. Gupta, Rashmi S. Patil. "A Comparison of Water Quality Indices for Coastal Water", Journal of Environmental Science and Health, Part A, 2003 — 7 words — < 1%
Crossref

36 Li, Kun, Chunguang He, Jie Zhuang, Zhenxing Zhang, Hongyong Xiang, Zhongqiang Wang, Haijun Yang, and Lianxi Sheng. "Long-Term Changes in the Water Quality and Macroinvertebrate Communities of a Subtropical River in South China", Water, 2014. — 7 words — < 1%
Crossref

37 Roohollah Noori, Abdulreza Karbassi, Amir Khakpour, Mohammadreza Shahbazbegian et al. "Chemometric Analysis of Surface Water Quality Data: Case Study of the Gorganrud River Basin, Iran", Environmental Modeling & Assessment, 2011 — 7 words — < 1%
Crossref

38 Justine Labory, Evariste Njomgue-Fotso, Silvia Bottini. "Benchmarking feature selection and feature extraction methods to improve the performances of machine-learning algorithms for patient classification using metabolomics biomedical data", Cold Spring Harbor Laboratory, 2023 — 6 words — < 1%
Crossref Posted Content