The Estimation of Turbid-water Occurrence Possibility in Basins for the Environmental Improvement of Dam Reservoirs

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Abstract : Soil erosion by rain splash decreases agricultural productivity and causes natural disaster such as landslide. Also soil particles transported into the downstream areas and reservoirs have great impact on settlement and water quality contamination. Especially, turbid-water problem of reservoirs due to soil erosion constitutes a major issue in dam operation recently. And Imha dam (Typhoon Maemi, 2003) and Soyanggang dam (Typhoon Ewiniar, 2006) are typical examples of turbid-water problem in reservoir. Imha dam organized "Water Quality Conservation Council" in March 2003 for the diminution of turbid-water. And projects come into effect such as the improvement of stream, the reduction of non-point sources, and the construction of debris barriers. K-water has examined the main reason for turbid-water and studied countermeasures. Especially, K-water has analyzed the sediment yield and the geological characteristics of soil that are pointed out as the main source of turbid-water. This study presents the methodology to quantitatively analyze the occurrence possibility of turbid-water in Sayeon dam, Degok dam, Gwangdong dam, and Imha dam basins. Especially, this study suggested a process to estimate the weighting value of turbid-water occurrence in reservoirs using geological characteristics such as the distribution of soil particle size, settlement time, and landslide besides existing sediment yield. This estimation process can analyze the risk factor of turbid-water occurrence in basins, and therefore it can be efficient data to estimate the turbid-water occurrence of reservoir in dam construction.

Key words : turbidity, soil erosion, geological characteristics, GIS, AHP

1. Introduction

Soil erosion is a natural process affected by natural and anthropogenic factors (Wischmeier and Smith, 1978), and it transports absorbed chemicals to downstream lakes or reservoirs. Top soil removal reduces the productivity of land(on-farm impact) and the suspended sediment and sediment-bound nutrients increase the growth and proliferation of aquatic organisms like algae (off-farm impact) (Pionke and Blanchard, 1975). Extremely heavy rainfall events have increased over the last decades and it is also supported by some observations in

Korea. Then soil erosion may be exacerbated in the near future because of anthropogenic climate change (Houghton et al., 2001). In Korea, soil erosion is unexceptionally a serious problem that is mainly caused by agricultural intensification, rainstorm, and/or their combination. Water quality degradation due to soil erosion has been a threat to turbid water and ecosystem integrity but the infrastructure for soil conservation and management is poorly developed in Korea. Accordingly effective soil conservation planning and management are in urgent need and controlling soil erosion by water is an important issue. The direct cause for the occurrence of turbid water is sediment yield affected by rainfall; however, to assess the high density turbid water in reservoirs, it is necessary to assess both geology and soil components. This paper offers techniques to evaluate the possibility of turbid water occurrence targeting the exclusive water supply dams such as Sayeon Dam, Daegok Dam and Gwangdong Dam. To this end, it collects samples of turbid water in reservoirs and representative soil in the vicinity of rivers, conducts indoor tests such as a laser analysis of particles, XRD (X-ray powder diffraction method), and SEM(Scanning Electron Microscope). The test evaluates the distribution of soil particles and types of minerals contained in turbid water, as well as chemical characteristics. Also, on the basis of a soil map, a DEM (Digital Elevation Map), and landcover map, sediment yield is calculated using the RUSLE (Revised Universal Soil Loss Equation) model and the SDR (Sediment Delivery Ratio).

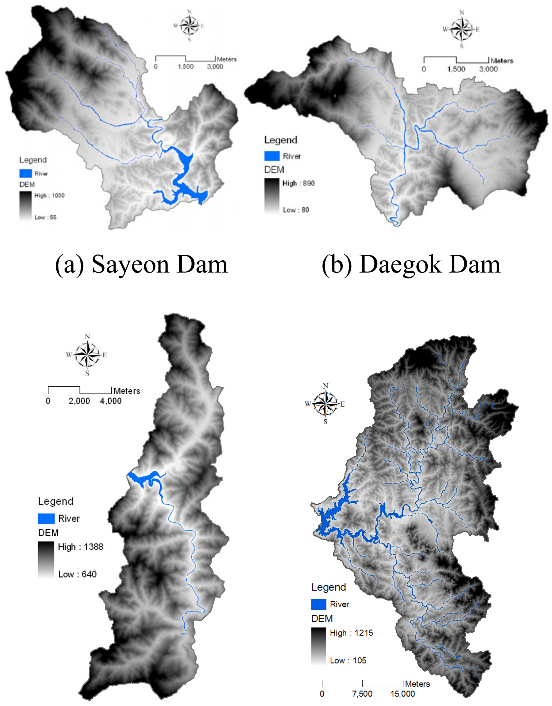
Using these test results and GIS data, the study classifies factors for evaluating the possibility of turbid water occurrence into geology, soil yield, landslide and soil components, and these evaluation items' weighting and score are presented using the AHP (Analytic Hierarchy Process) technique along with the survey of water-related experts (Saaty, 1987; Thomas, 2002). These scores are compared with those of Imha Dam, a representative high-density turbid-water occurrence site, to quantitatively determine the possibility of turbid water occurrence at Sayeon Dam, Daegok Dam, and Gwangdong Dam.

2. Study sites and GIS DB

This study evaluates the possibility of turbid water occurrence at such exclusive water supply dams as Sayeon Dam, Daegok Dam and Gwangdong Dam, and compares the turbid water occurrence between these dams, and Imha Dam, a representative site with high-density turbid-water occurrence. The basin area of Sayeon Dam, Daegok Dam, Gwangdong Dam and Imha Dam is 67km^2, 60km^2, 121km^2, and 1360km^2, respectively.

Fig. 1 Study sites

To determine the characteristics of soil erosion within the basin, the cause of turbid water occurrence, it basically calls for the information on the geology, landcover, and GIS database necessary for determining geological characteristics. The DEM distribution of Sayeon Dam, Daegok Dam, Gwangdong Dam, and Imha Dam covers 55~1030m, 80~890m, 640~1388m, and 105~1215m, respectively.

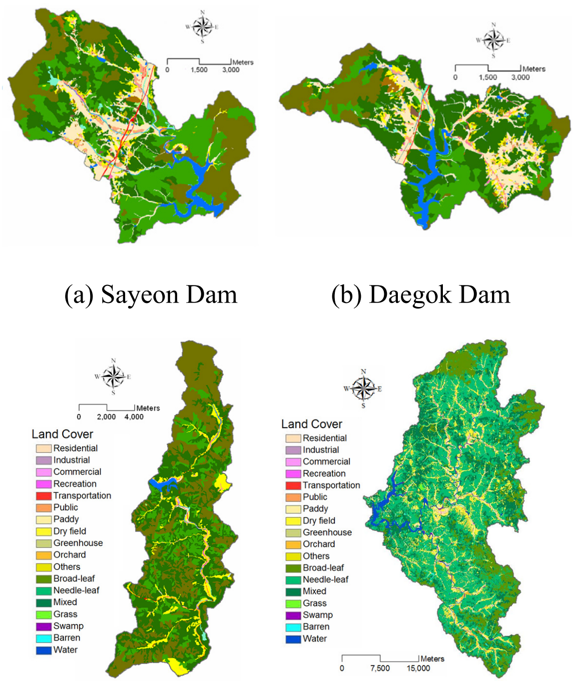


(a) Sayeon Dam (b) Daegok Dam

(c) Gwangdong Dam (d) Imha Dam

Fig. 2 DEM map

The landcover plays a decisive role in causing soil erosion and then turbid water occurrence according to the intensity of rainfall. Therefore, it is crucial to secure an accurate landcover map; to overcome the limit of the existing 30m-resolution LANDSAT satellite images, this study crafts a basic landcover map with 10m-resolution SPOT 5 images using the MLM(Maximum Likelihood Method) classification. On the basis of the landcover map, a digital topographic map (1/5,000), a forest type map, and an ecological and natural map are used to craft a final level-2 landcover map. Figure 3 shows the landcover maps of Sayeon Dam, Daegok Dam, Gwangdong Dam, and Imha Dam.



(a) Sayeon Dam (b) Daegok Dam

(c) Gwangdong Dam (d) Imha Dam

Fig. 3 Landcover map

The study crafts a geological map by converting KIGAM's (Korea Institute of Geoscience And Mineral Resources) data into 10m resolution grid data, and then uses the GIS spatial analysis method to assess the geological area by geological code as the basin unit.

3. Collection of Samples, Test and Analysis

3.1 Collection of Samples

The study collects turbid water samples in reservoirs and representative soil samples in the vicinity of rivers to analyze the characteristics of turbid matter contained therein. In particular, to define the characteristics of turbid water, the study collects 57 20-liter turbid water samples created during actual rainfall to conduct a settlement speed test, an analysis of mineral components of turbid matter, a particle size analysis, a fine-structure analysis, and a chemical component analysis. Also, for actual turbid water, NTU (Nephelometry Turbidity Unit) and pH are measured, and for the selected representative samples with high-density turbidity a settlement speed test is conducted in the laboratory. To define the cause of turbid water occurrence, soil in reservoirs or in their vicinity is collected to analyze the kinds and content of the components. The soil's potential impact on turbid water occurrence during future rainfall is analyzed. Flowed into reservoirs and rivers are clay minerals contained in soil that is eroded from slopes, agricultural land and waterfront areas in the vicinity of reservoirs due to rainfall, thus triggering turbid water occurrence in reservoirs. Soil samples are collected from river contact points, midstream points, and upstream points according to geological distribution and major river development situations.

3.2 Test and Analysis

For the turbid water samples collected from reservoirs during rainfall and the soil samples, tests are conducted to define the kinds and structures, physiochemical characteristics and settlement characteristics of fine-grained matter that could contribute to turbid water occurrence. First, the research conducts a mesh analysis (a particle size analysis method in geological engineering) of soil samples, and a laser-assisted particle size analysis of fine-grained matter. A settlement analysis, which can indirectly predict the possibility of turbid water occurrence, is conducted to measure settlement speed and turbidity of particles according to the passage of time. To quantitatively determine the characteristics and content ratio of mineral components of soil, XRD analysis is conducted. SEM- (Scanning Electron Microscopy) assisted image analysis is conducted to observe the shape, size and texture of fine-grained matter, and also SEM-assisted chemical component analysis, EDS (Energy Dispersive Spectrum Analysis), is conducted.

1) Laser-assisted Particle Size Analysis

The laser particle size analyzer measures laser beam scattering angles according to the size of particles, thus continuing to measure particles with a range of 0.02~2000 ㎛. Using an interference phenomenon created when laser beams are scanned onto the sample, the analyzer measures the size of each particle, and defines the particle size distribution by segment. In this study, ultrasonic waves are applied for ten minutes to soil particles that are dispersed in a beaker of 800 ㎖ water to analyze the characteristics of particle size using the British Malvern's Mastersizer 2000 laser particle size analyzer. Also, this study measures the 10% particle size (d0.1) in the fine-grained segment, 50% medium particle size (d0.5), and 90% particle size (d0.9) in the coarse particle segment to compare the particle size distribution and particle size between samples. Table 1 shows an average particle size of turbid water in reservoirs. The average particle diameter of d(0.1) is 3.709 ㎛ and 3.753 ㎛ for Gwangdong Dam and Daegok Dam, respectively, making them similar. It is 4.284 ㎛ 7.089 ㎛ for the middle basins of Sayeon Dam and Daegok Dam, respectively, making them somewhat big. This suggests that Gwangdom Dam and Daegok Dam contained a little greater amount of fine-grained matter, compared with Sayeon Dam, and that if the medium diameter particles d(0.5) included, the average particle diameter is 13.399 ㎛ for Sayeon

Dam, making it smaller than Daegok Dam's 20.140 ㎛ and Gwangdong Dam's 18.350 ㎛.

Table 1 Average particle size(㎛)

	Sayeon Dam (n=6)	Daegok Dam (n=15)	Sayeon Dam & Daegok Dam (n=22)	Gwangdong Dam (n=14)
d(0.1)	4.284	3.753	7.089	3.709
d(0.5)	13.399	20.140	24.522	18.350
d(0.9)	44.895	77.067	88.327	61.033

2) Settlement Test

Turbid water particles' settlement speed in water is determined by gravity; the speed initially grows faster until a certain speed when it is nearly steady. Thereafter, the settlement speed has a consistent value, and this speed is referred to as settlement speed. The settlement test defines settlement characteristics of particles in a stationary state under the influence of gravity alone, and these characteristics are closely related to suspension characteristics of turbid water particles. The test measures the turbidity of turbid water by time to compare particle settlement characteristics. Specifically, 200g of a soil sample is mixed and stirred in water, manufacturing a kind of artificial turbid water; then, the turbidity of turbid water is measured in a 2-liter measuring cylinder at various points of time – 10^{th} minute, 1 hour, 3 hour, 6 hour, 24 hour, and 48 hour, and visual changes also are recorded. Of a total of 57 turbid water samples collected from reservoirs, Figure 4 shows the turbidity reduction rate according to settlement time for Nos. point 1 and 2 of Sayeon Dam, Nos. point 1 and 2 of Daegok Dam, and Nos. point 1 and 4 of Gwangdong Dam. At the time of turbid water collection time, the rainfall for Sayeon Dam, Daegok Dam, and Gwangdong Dam stood at 109mm, 124mm, and 78mm, respectively, giving Gwangdong Dam the lowest figure, but Gwangdong was found to offer the highest initial turbidity at 1,000NTU of these reservoirs presumably because it was locally affected by silt which flowed in from the cold highland dry fields in the basin. Figure 4 shows turbidity reduction rates of Sayeon, Daegok and Gwangdong Dams according to settlement time. Compared with Sayeon Dam and Daegok Dam, Gwangdong Dam offered a very high initial turbidity, giving it a limitation.

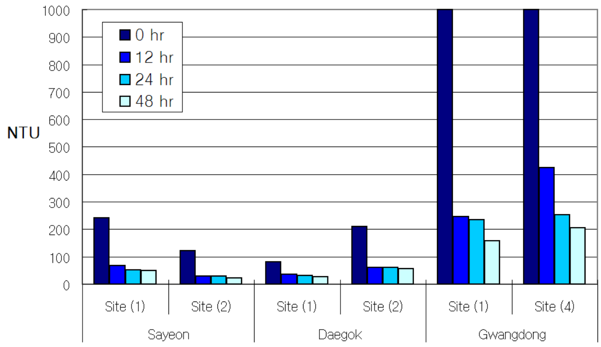


Fig. 4 Turbidity change according to the settlement time

3) X-ray Powder Diffraction Method

The XRD (X-ray powder diffraction method) has been widely used over the past several decades to assess minerals and their characteristics. In this study, the high resolution X-ray diffractometer Philips X'pert MPD and the SIROQUANT software are used to quantitatively analyze the content of various minerals contained in soil. The analysis is targeted at 39 turbid water samples (13 from Daegok Dam, five from Sayeon Dam, ten from the middle basins of Daegok Dam and Sayeon Dam, and eleven from

Gwangdong Dam), as well as at 33 soil samples (four from Daegok Dam, eight from Sayeon Dam, six from the middle basins of Daegok Dam and Sayeon Dam, and 15 from Gwangdong Dam). Crucial for evaluating the possibility of turbid water occurrence also is the information on the absolute amount of fine-grained particles of soil, and their component minerals (kinds of minerals, mineral composition ratio, and the amount of clay minerals). Therefore, the study needs to determine the content of fine-grained matter through particle size measurement, as well as the kinds of minerals and the amount of clay minerals through an XRD analysis. Figure 5 shows an XRD analysis of soil samples of Sayeon Dam. The clay mineral contains various components according to samples, but major components are illite, kaolinite, and vermiculite, and are in disproportion with quartz. The clay mineral content ratio in turbid water samples was found to be 55.8% for 13 Daegok Dam samples, 55% for four Sayeon Dam samples, 57.5% for ten samples in the middle basins of Daegok and Sayeon Dams, and 54.5% for eleven Gwangdong Dam samples. Of the clay minerals, illite was found to represent the largest ratio, followed by kaolinite and vermiculite.

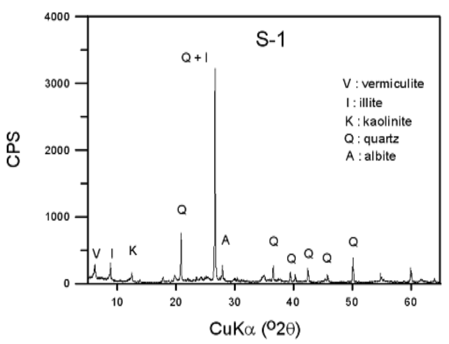


Fig. 5 X-ray powder diffraction method of Sayeon Dam (Site 1)

4) SEM

A SEM (Scanning Electron Microscope) and an EDS (Energy Dispersive Spectrum) equipped with it are used to observe various turbid-water suspended solids in target reservoirs, texture of soil, and kinds, shapes and sizes of component minerals. To determine the chemical components of turbid water in these reservoirs is crucial for closely examining major turbid water occurrence areas in the upstream rivers. For instance, SEM analysis data on the soil collected from upstream rivers and the turbid water in reservoirs are compared to effectively examine what kind of soil flows into reservoirs and from which areas. Figure 6 shows an analysis of chemical components of soil samples of Sayeon Dam, using the SEM and the EDS; O represents 62.23%, Na 0.63%, Mg 0.95%, Al 6.42%, Si 24.19%, K 1.81%, Ca 0.15%, Ti 0.47, and Fe 3.15%. A long-time monitoring of soil's chemical components in turbid water is essential for determining major causes of soil erosion in the upstream basin.

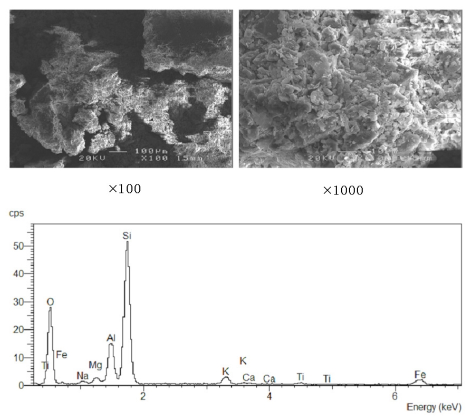


Fig. 6 SEM and EDS analysis results of Sayeon Dam

4. Soil Erosion Modeling and Sediment Yield

This study selects a RUSLE model that involves GIS data and that is usually used in basins. RUSLE is the advanced experimental equation of USLE(Loss model in existing agriculture area). RUSLE was developed by Renard et al.(1991) in order to apply to watershed, and much research is performed based on this experimental data. The RUSLE model is shown as below(Renard et al., 1991).

$$A = R \times K \times L \times S \times C \times P \qquad (1)$$

where, A is annual soil loss($ton/ha/yr$), R is rainfall erosivity factor($10^7 J/ha \cdot mm/yr$), K is soil erodibility factor($ton/ha/R$), L is slope length factor, S is slope steepness factor, C is cover management factor and P is support practice factor.

Rainfall conditions are a crucial factor for evaluating soil erosion, and the design rainfall varies according to dam basins. This study aims to assess structural weaknesses such as soil, topography and landcover that affect soil erosion in reservoirs; thus, to possibly exclude the impact of the uncertain factor rainfall, the study equally applies the rainfall settlement factor of the 2006 Typhoon Ewiniar to all target basins.

Soil erosion amounts, which are calculated using the RUSLE factor, are shown in Table 2. Compared with the Imha Dam basin, Sayeon, Daegok, and Gwangdong Dam basins created soil erosion amounts 14-25 times as small, suggesting that compared with the Imha Dam basin, Sayeon, Daegok, and Gwangdong Dam basins were more stable in terms of soil erosion associated with the occurrence of rainfall. RUSLE-simulated soil erosion amounts are sheet erosion; thus a modeling of soil particles that are yielded to rivers and reservoirs should consider SDR (Sediment Delivery Ratio). This study considers SDR calculated by using soil erosion amounts within the basin and the Boyce(1975) equation, and estimates sediment yield. The sediment yield ratio of Sayeon and Daegok Dams, and Gwangdong Dam was found to stand at 10~11.6% and 15% of that of Imha Dam, respectively, suggesting that in the case of the occurrence of rainfall like with Typhoon Ewinia, Sayeon, Daegok and Gwangdong Dams offered a very low possibility of sediment yield, compared with Imha Dam. Since Gwangdong Dam consists mostly of cold highland dry fields, it will create a great deal of sediment yield and turbid water, compared with Sayeon Dam and Daegok Dam.

Table 2 Analysis results of soil erosion

Dam	Soil Erosion (ton)	Ratio (%)
Sayeon	333,187	4.7
Daegok	280,134	3.9
Gwangdong	517,963	7.1
Imha	7,121,007	100.0

Table 3 Analysis results of the sediment yield score

Dam	Soil Erosion (ton)	SDR	Sediment Yield	
			(ton)	(%)
Sayeon	333,187	0.117	38,983	11.6
Daegok	280,134	0.120	33,616	10.0
Gwangdong	517,963	0.097	50,242	15.0
Imha	7,121,007	0.047	334,653	100.0

5. Estimation of Turbid-water Occurrence Possibility

To estimate the possibility of turbid water occurrence within the basin, the test and analysis of soil collected from the site should be linked up with the analysis of sediment yield. This study designs evaluation items and scores to estimate the possibility of turbid water occurrence. Evaluation items consist of geology, sediment yield, landslide, and soil components, with 20 points determined as the maximum score for each item. Of these, landslide is divided into weathering state and maximum rainfall intensity. And, soil components are divided into clay mineral content and settlement time. KIGAM's geological map offers information on era and period only, making it difficult to know the geological impact on the occurrence of turbid water. To calculate geological scores, this study analyzes diverse geologies' era, period, rock types, and formation to design a geological code. Based on this geological code table, this study draws up maps by geological code for each basin, observes the turbidity for representative soil by geological code according to the intensity of rainfall, and gives it a score. Generally, the turbid water in reservoirs is closely related to the geology of the upstream basin. Therefore, if the geology of the upstream basin is not segmented in detail to be analyzed, it is difficult to accurately predict the mechanism of turbid water occurrence and the point of turbid water occurrence. Second, sediment yield is calculated by using the RUSLE model-based soil erosion, and SDR (Sediment Delivery Ratio). On the basis of the sediment yield of Imha Dam converted into a score of 20, the possibility of sediment yield of Sayeon, Daegok, and Gwangdong Dams is converted into a score. Of landslide factors, the score of weathering state is calculated on the basis of HW's (High Weathering) depth and joint, and determined as the maximum rainfall intensity is a score of ten points when a day's maximum rainfall exceeds 100mm. Of soil components, clay mineral content is estimated using the content ratio of ingredients such as ilite and kaolinite that influence the occurrence of turbid water. Settlement time is determined by measuring the time that turbidity takes to reach 20NTU. Imha Dam offered the highest scores all in geology, sediment yield, landslide, clay content, and settlement time. First, in terms of the geology score, Gwangdong Dam offered a higher point at 13.240 than Sayeon Dam and Daegok Dam did, presumably because the score reflected the influence of clay created in the cold highland dry fields of Gwangdong Dam. Also, in terms of the sediment yield score, Gwangdong Dam offered a higher score at 3.020 due to soil erosion caused in the cold highland dry fields in the basin, compared with Sayeon Dam's 2.320, and Daegok Dam's 2.010. In terms of the landslide score, Sayeon Dam and Daegok Dam offered a higher score at 18 points compared with Gwangdong Dam's 16, while in terms of clay content, Gwangdong Dam was 1.5 times higher at 8.560 than Sayeon Dam's 5.887. In particular, the clay content score, calculated on the basis of the analysis of particle size, is a key factor that can predict the possibility of turbid water. The settlement time was 9.370 for Sayeon Dam, which was a little greater than Daegok Dam's 8.656 and Gwangdong Dam's 8.571. Gwangdong Dam offered a small settlement time despite a high clay content, making it difficult to estimate the reason accurately; however, given that the number of samples for settlement test was smaller than the number of samples for particle size test, presumably, uncertainty associated with the selection of samples underlay such a result. Overall, Gwangdong Dam, compared with Sayeon Dam and Daegok Dam, offered higher scores of geology, sediment yield and mineral content. This is presumably because Gwangdong Dam's well-developed cold highland agriculture due to a high elevation, the creation of much clay at cold highland farmlands, and sediment yield triggered during rainfall all combined to contribute to such a result. Evaluation items such as geology, sediment yield, landslide, and soil components influence the occurrence of turbid water with different impact levels. Therefore, weighting of each item is needed; this study applies the AHP (Analytic Hierarchy Process) along with the survey of turbid-water-related experts, thus determining the weighting of each item as geology (50%), sediment yield (25%), landslide (10%), and soil component (15%). The findings indicate the turbid water occurrence possibility of Sayeon Dam, Daegok Dam and Gwangdong Dam as 53.1%, 49.1%, and 57.7%, respectively, compared with that of Imha Dam. Gwangdong Dam offered an 8~15% greater possibility of turbid water occurrence, compared with Sayeon Dam and Gwangdong Dam.

5. Conclusion

This study presents techniques to estimate the possibility of turbid water occurrence in such exclusive water supply reservoirs as Sayeon Dam, Daegok Dam, and Gwangdong Dam. The direct cause for turbid water occurrence is sediment yield due to rainfall, but to evaluate the high-density turbid water in reservoirs, geology, soil components and other factors together need to be analyzed.

This study conducts indoor tests such as laser-assisted particle size analysis, XRD analysis, and SEM observation of turbid water samples from reservoirs, and representative soil samples collected in the vicinity of rivers. This process analyzes the turbid water to estimate its soil particle size distribution, kinds of minerals, and chemical characteristics. The study also uses RUSLE models and SDR on the basis of soil maps, DEMs and landcover maps to estimate sediment yield.

To estimate the possibility of turbid water occurrence using these diverse data, the study determines evaluation items such as geology, sediment yield, landslide, and soil components, as well as their scoring criteria. In particular, to evaluate geology, the study designs a geological code table by taking into account the geology's era and period, rock types, and formation. This geological code table, which is not included in existing geological maps, is expected to be used as a standard to estimate the possibility of turbid water occurrence due to geological influence. On the basis of a survey of turbid water-related experts and AHP (Analytic Hierarchy Process), the weighting of each evaluation item is determined as geology (50%), sediment yield (25%), landslide (10%), and soil components (15%). With the weighting applied to each evaluation item, the possibility of turbid water occurrence is examined; the findings indicate that the possibility of turbid water occurrence was 53.1%, 49.1%, and 57.7% for Sayeon Dam, Daegok Dam, and Gwangdong Dam, respectively, compared with that of Imha Dam. Gwangdong Dam was found to offer an 8 – 15% greater possibility of turbid water occurrence than Sayeon Dam and Daegok Dam did. Due to unavailability of database on the kinds of crops cultivated in dry fields, this study could not take into account the kinds of such crops in estimating sediment yield. Generally, vegetable fields in cold highlands like the upstream area of Gwangdong Dam offer a high level of sediment yield compared with fields of crops cultivated in other dam basins. Therefore, the possibility of actual turbid water occurrence in Gwangdong Dam is estimated to be greater compared with Sayeon Dam and Daegok Dam. Future research is expected to reflect crop cultivation situations in dry field areas in estimating sediment yield.

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