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Application of digital hydrogeological mapping technology based on Global Positioning System

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ABSTRACT

In the hydrogeological survey work, comprehensive hydrogeological mapping is a very important working method in the traditional hydrogeology surveying and mapping work is often restricted by various natural factors, which affect the selection of information collection area, and even threaten the life of field personnel security. A detailed map is often needed to navigate in field hydrogeological mapping. The purpose is to promote the development of geological surveying and mapping, and expand the application scope of digital surveying and mapping technology. First, the method of Global Positioning System (GPS) and digital geological mapping are systematically expounded. Second, the digital mapping method of a geographic information system based on GPS is implemented on a campus in the northwest by using differential post-processing mode. Then, data acquisition and data processing are done after the working mode of GPS is selected. Finally, the experimental results are compared with the existing topographic map data. The experimental results show that GPS is feasible for digital geological mapping. The application of GPS technology can obtain accurate positioning information, and its internal data attributes meet the needs of data collection of geographic information system.

Keywords: Global Positioning System; Digital; Geological mapping

1. Introduction

In hydrogeological survey, comprehensive hydrogeological mapping is a very important working method. In traditional hydrogeological mapping, it is often restricted by various natural factors, which affect the selection of information collection area and even threaten the life safety of field personnel. A detailed map is often needed to navigate in field hydrogeological mapping. In traditional work, digital terrain map is often used as the base map of navigation, and two-dimensional points, lines and surfaces are used to describe objective things. Some ground objects are relatively simple and abstract to express, which cannot truly reproduce the scene of the surrounding environment of the survey route, and its performance ability is pale compared with the real world. It is usually necessary to sketch the navigation path in advance in Google Earth satellite image browsing software according to the survey route and then import it into OziExplorer navigation software for use. It takes a lot of work to sketch the navigation path every day and is easily limited by the network communication in the field work environment. In recent years, with the development of the measurement technology of Global Positioning System (GPS), geological mapping is greatly developed accordingly [1]. Differential GPS, namely the relative positioning of GPS, is widely used in the high-precision measurement. This is the observation of the two goals at one station, the observation of one goal at two stations, or the difference in the observation of one goal at two stations [2]. The ultimate goal is to eliminate common elements, errors, and common parameters [3].

The application of the GPS real-time dynamic difference technology is as follows. The GPS receiver at the reference station is sent to the GPS receiver at the mobile station through a data link [4]. Not only does the mobile station receive the data from the reference station, but also the data can transmit directly to the real-time place of the tablet through the GPS satellite at different observation stages, conducting real-time processing and having access to the system electronic mapping [5].

After the working mode of GPS is selected, the differential post-processing mode is used to process the data, and the application of digital mapping based on GPS is studied. The digital mapping based on GPS and the digital geological mapping are effectively combined to meet the needs of instruction, transportation, resource collection, construction of farmland, and other engineering construction projects for basic geographic data of each dimension. Especially in urban renewal mapping and engineering surveys, digital mapping based on GPS is more convenient and can provide accurate data. Therefore, it is hoped to have a positive impact on the geological industry and bring convenience to geological survey workers.

2. Digital mapping method based on GPS

Geographic image navigation is a new navigation method with geographic image as the main background data and digital map as the auxiliary background data. Based on oziexplorer geographic image navigation is to geographic image map for reproduction, will we care about topographical features and overflow with rivers, lakes, QuanQun, groundwater, wetlands and other hydrogeological characteristics and features a comprehensive, authentic, intuitively reflected, make up for the deficiency of the traditional map navigation, effectively increase the scene information navigation, Provide users with intuitive and rich navigation background information, thereby improving the visual effect of navigation.

2.1. Overview

2.1.1. Overview of the test area and equipment

In this study, a campus is selected as the test area, which is located between 105°9′–105°10′ from the East and 36°57′–36°58′ of the North. The regional digital mapping test based on GPS is carried out here, and the test area is about 3.5 km^2.

This area is selected because of its complex terrain and high mountains. Thus, the measurement results have obvious changes and the sensitivity of measuring tools is obtained. There are main roads in some areas, and the sky boundary is clear, which can better receive GPS signals. In places where buildings are concentrated, the measurement is conducted by the combination of GPS and a rangefinder.

The data acquisition instrument is a GPS receiver, which can receive code and carrier, and two data acquisition devices. GPS receiver can perform the data collection function with a simple interface and operation and input relevant data instantly. The ranging resolution of the rangefinder is 0.6 m when the distance is less than 120 m. If the distance is greater than 120 m, the ranging resolution is 1.2 m, and the accuracy is more than 1%.

2.1.2. Test method

The accuracy of data and the efficiency of data acquisition are the primary considerations for us. The difference is used to process data in the mode of data processing, and the receiver is also used for data acquisition. The GPS receiver is used for data acquisition of the reference station. In the whole process, due to some limitations, the representative factors are only measured and then output the measurement results. Finally, the measurement results are compared with the 1:10,000 topographic map.

2.1.3. Operation process

The whole operation process is shown in Fig. 1.

2.2. Preparation before measurement

First, the operation method of the GPS receiver should be well-known, and the operation process of regional measurement should be formulated. Second, the measurement team should be constructed. Finally, the data dictionary should be compiled and the coding plan should be proposed.

In this experiment, the data collection is conducted as follows: roads and walls are selected as the mainline elements, stations, control points, and landmark buildings as the main point elements, and buildings and the ground as the main surface elements for data collection, completing the editing of the data dictionary. The objects of the experimental site are set as the linear and planar elements respectively to facilitate the subsequent mapping work.

Because there is no corresponding geographic information database, it is not necessary to consider the compatibility between element attributes and geographic information database in the test. And attribute setting is relatively simple. The necessary attributes, such as the element name, measurement time, and road width are set.

In terms of data organization, the receivers established for the global positioning of two mobile stations are coded with letters and recorder numbers respectively to avoid the confusion of data in the differential post-processing. The data files at the mobile station are shown in the system default format, including file sequence number, machine number, time, and other information. The data files at the reference station should also be in the system default format, including file sequence number, station name, time, and other information. This helps to process internal data and manage the files.

2.3. Data acquisition

2.3.1. Encryption control network

The two points are set in the center of the test area with a wide vision and flat land, so that the machine is easily placed at the two points. The selection of the points is to use the prepared instrument to carry out the points in the test area based on the differential post-processing [6], and the two points are regarded as the control points. The control points

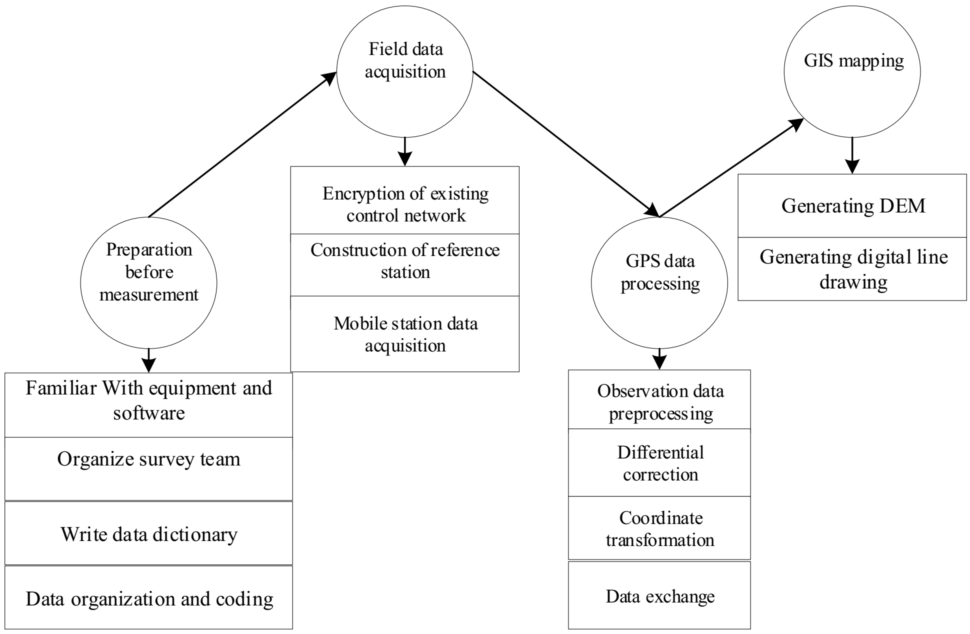

Fig. 1. Operation process.

are the result of the national observation of crustal movement, and its accuracy is relatively high. The antenna must be located above the center of the points and the measurement time of each point should not be less than 10 min.

2.3.2. Construction of the reference station

The two control points introduced meet the requirements of constructing the reference station, and there must be no interference of the magnetic field nearby [7]. GPS is placed on the tripod, and the receiver needs to be placed at the control point. In the whole operation process, they must be aligned. Before and after the measurement, the antenna height of the reference station needs to be measured. A triangle hook theorem is used to calculate the antenna height, which needs to be repeated several times. Finally, the average value is considered to be the final actual height of the antenna. The last step is very important, that is, ensure that the signal received from the reference station is normal, and can initialize and obtain data from the reference station. The samples are taken at the reference station every 10 s and the intercept angle of the satellite is 20°.

2.3.3. Data collection at the mobile station

Parameters are set as follows: (1) open the GPS receiver and start data acquisition software. The satellite cutoff angle is set as 20°, and the filtering speed is set as "correct" before entering into the antenna height adjustment area for registration. The file name of the pre-received code file is set as a prefix, its style as "time", the precise configuration as "carrier", the data as "yes", and the time as "10 s" to establish a coordinate with WGS84 as the reference. The height reference is the height above the ellipsoid and its unit is in meters. The unit parameters are selected as the offset, tilt, and dip.

The acquisition method of surface elements is the same as that of line elements. During data collection, the mobile station creates new data files about every 2 h to ensure data security, and the terrain data are stored in different files to facilitate data processing.

In the process of line element acquisition, the receiver is placed on the axis to acquire the road isometric characteristics, and the obtained position information is moved. The shell and other components are acquired by the location of components recorded by offset, that is, the location information can be obtained by moving a certain distance of components, and the distance value can be recorded as the offset. Several average peaks are obtained in the process of line feature acquisition to improve the accuracy of line element features. Each position of the line element is the vertex of the line, and the average vertex is the average value of several positions on each vertex. The average peak is obtained by the same method as the point feature. There are two ways to input line elements: one is to input directly when the information is collected, and the other is to input the line elements after they are selected.

Point elements are collected as follows: 15 min is left at each point to achieve the minimum support time specified by the software. If the support time is more than 15 min, data for multiple periods can be collected only by staying at the test point for a short time. For the point coordinates that cannot be obtained by GPS measurement, the rangefinder should be used for auxiliary measurement. For example, the GPS receiver cannot receive the signal of the satellite at the corner of the building or a canyon. Therefore, the point in the open sea area and the correct position of the satellite signal should be selected as the reference position for positioning. The dip angle between the reference position and the measured point should be measured by a rangefinder. It selects two reference locations for each point function, clicks the options/offsets in the property edit form, enters the measurements for each reference location as required, and records the direction of the function relative to the two reference location paths. The best reference position should be no more than one meter from the point to be measured, and the distance should be measured by ultrasonic, ensuring the accuracy of the measurement [8]. Input the required attributes when functions are collected.

2.4. Data processing

In the first step, observation data at the mobile station and the reference station are imported into the computer, and the data should be converted into the standard RINIX data format. In the second step, the data are preprocessed using software to modify the observation data and eliminate invalid data. In the third step, the observed data are processed by the differential post-processing method. Fragment measurement data and control network encryption data must be differential processed. When the data are processed, the smart code and carrier phase processing are selected, so that the carrier phase and code-related measurements can be involved in differential processing calculation, and the position to be corrected is selected. The processing setting at the mobile station selects velocity filtering, and the processing setting at the reference station selects filtering and smoothing data for further screening. The final measurement data are imported into the geographic information system. When the data are exchanged, the information generated by line elements in the process of data export disappears, and only the location of linear terrain data is exported. In data processing, the following points should be paid attention to:

- Data processing errors. The main aspects are as follows: the results will be wrong due to the calculation method used by the data processing software. Generally, the results are likely to have a certain deviation in the use of different data processing software. Second, there are errors in coordinate transformation parameters. In the experiment, the coordinate transformation parameters are solved by the measured results. The accuracy of the transformation parameters depends on the accuracy of the measured results and the accuracy of the calculation model. The accuracy of the transformation parameters directly affects the accuracy of the measured results. The accuracy of the measured results and the calculation model determine the accuracy of the conversion parameters, and the accuracy of the conversion parameters also directly affects the accuracy of the measured results. Finally, the altitude conversion is not accurate enough. Due to the lack of horizontal data in the test area, the quasi-geoid model of the test area cannot be accurately fitted. The test adopts the U.S. world geoid model, which must have a certain deviation from the terrain environment of the test area. When the test data are converted into coordinates, the standard height is used to replace the ground height to solve the coordinate conversion parameters, and the standard height of the test area can be directly obtained in the coordinate conversion process. However, due to the lack of sufficient horizontal data, the calculated high normal values do not have any remaining adjustments. Therefore, the elevation error of the final solution is large.
- Some errors in the known data. The known point data used in the experiment is the result of the national observation of crustal movement. Although the accuracy of the results is quite high, there are also some measurement errors. There may be some operation errors in the test process. The errors mainly include three aspects: (a) although there is no shelter on the top of the mountain, the locking phenomenon often occurs in the process of data acquisition due to the short measurement period and the poor geometric shape of the satellite. The obtained test data cannot reach the measurement accuracy of coding; (b) the mobile data acquisition adopts the on/off measurement mode and manual measurement and the actual antenna height is slightly different from the input antenna height before measurement; (c) the control point error in the test area is too large. The exact estimates are listed above. Although this is the best result obtained by the current equipment, there are too many errors in the measurement process. In the differential correction process, this error is transmitted to the result at the mobile station.

3. Result analysis

3.1. Difference correction results at the control point

The results after processed by the difference are shown in Table 1.

In the whole process, the coordinate results of WGS84 (the coordinate system established for the use of GPS GPS, established through the coordinates observed by satellite observation stations all over the world) obtained by GPS measurement is switched to the Xi'an 80 benchmark in Shaanxi Province to facilitate the comparison and integration with the existing map data [9]. Then the difference post-processing method is used to measure the coordinates of the known points, the two sets of coordinates of the known points are used to calculate the conversion parameters between Xi'an coordinate system, and their mean is used to convert the different results. The results are as follows (Table 2):

In the experiment, the real height is directly substituted into the solution parameters, because it is difficult to obtain the height under the Xi'an benchmark. In addition, due to the large coordinate error measured at the station, the

Table 1
Difference correction table

Number	Longitude	Latitude	Height	Confidence	Vertical, horizontal accuracy
1	36°56'34.778	105°10'14.575	1,700	99%	0.3, 0.8
2	36°56'34.652	105°10'18.456	1,700	99%	0.3, 0.4

final three parameters of coordinate system conversion are DX = 91.607, DY = 73.0655, DZ = 20.6225, which are converted by the calculation mean of 1 and 2 points.

When the elevation reference is determined, the quasi-geoid model in the experimental area cannot be finally determined because of the lack of accurate measurement data in the experimental area. In the coordinate system, the coordinate transformation reference is defined by the solved three parameters. Finally, the U.S. global geoid model is used to simulate the model. And because there is no leveling data, there is no way to fit the converted normal height. The coordinate transformation results of the measured values of the two stations are shown in Table 3:

3.2. Analysis of the results of the topographic survey compared with existing data

Based on the above operation, the data in Table 4, and Fig. 2 are obtained.

UKI (Universal Kriging Interpolation) method is adopted to interpolate the field original data [10]. The reasons for selecting the method are: (1) the values of the semi-equalities of the covariance matrix of the sampling points are close and the sampling points have strong spatial autocorrelation; (2) the trend analyzed by the method shows the dominant trend of each sampling point. When the method is used to calculate the interpolation, the position is selected

Table 2
Difference conversion results

Number		1	2
Xi'an 80 coordinates	X	3,989,937.5646	3,989,956.7865
	Y	401,429.3656	4,014,257.665
	Z	1,532.6458	1,530.569
WGS84 coordinates	J	37°01′67.687	37°01′67.643
	W	104°55′78.578	104°55′78.433
	H	1,489.6	1,477.6
Conversion parameters	DX	94.567	88.647
	DY	67.456	78.675
	DZ	16.567	24.678

Table 3
Results after the coordinate transformation

Number	1	2
X	3,979,427.9	3,979,429.4
Y	423,538.7	4,253,700.1
Z	1,755.1	1,756.2

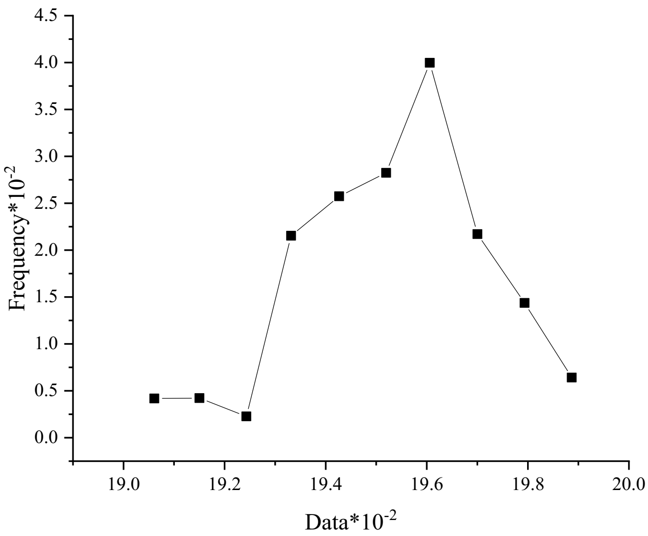

Fig. 2. Line chart of training samples.

Table 4
Semivariogram/covariance function of training samples

Distance, h 10^{-2}	Semivariogram	Distance, h 10^{-2}	Semivariogram	Distance, h 10^{-2}	Semivariogram
0.324352498	0.269505252	2.940421779	0.333974822	3.934247454	0.662496993
0.894475182	0.467003448	2.949162056	0.985807072	3.971373587	0.28450004
1.190121081	0.359714538	2.945954615	1.260364045	4.151711972	0.24753428
1.1877155	0.565632267	3.175366851	1.22267661	4.261005533	0.692005453
1.412717505	0.905460669	3.148263972	0.742683025	4.255392511	1.172480154
1.500521209	0.389463555	3.216502285	0.501483442	4.248576698	1.75591372
1.628177372	0.662096063	3.333012589	0.328201427	4.454815171	2.301900409
1.663298853	0.455697218	3.45706038	0.909710528	4.51303023	2.918691364
1.98444391	0.965680378	3.492983722	0.63467244	4.609654398	1.647662577
1.990457862	0.450886056	3.432764013	0.189479593	4.535883249	0.962472937
2.184347687	0.653917088	3.689279128	0.631785743	4.543901852	0.276080507
2.197097266	0.962553123	3.684067036	1.077940823	4.916927271	0.545104643
2.429716943	0.650308716	3.790153155	1.796968968	4.888942346	1.540614225
2.709004891	0.543260364	3.833213054	2.311041617	4.878919092	2.398604763
2.638360998	0.990377676	3.942185871	1.382968487	4.937134151	3.015395718

Table 5
Comparison between the established coordinates and the existing topographic map coordinates

Number	Digitized value of the topographic map			Measured value			Difference		
	x	y	z	x	y	z	x_1–x_2	y_1–y_2	z_1–z_2
1	423,993	3,979,649.6	1,741.6	423,992.3	3,979,651.1	1,743.9	–0.7	1.5	1.3
2	424,033.3	3,979,648.1	1,741.1	424,034.1	397,949.7	1,741.92	0.8	1.6	01.8
3	424,034.6	3,979,636.5	1,741.4	424,033.6	3,979,636.7	1,742	–1	0.2	0.6
4	423,992.9	3,979,637.9	1,742.9	423,991.6	3,979,637.7	1,744.4	–1.3	–0.2	1.4
5	423,993	3,979,618.6	1,742.4	423,992.7	3,979,618.9	1,744.4	–0.3	0.3	2
6	424,035.4	3,979,618.4	1,742.7	424,035.1	3,979,620.8	1,745.1	–0.3	2.4	2.4
7	424,035.1	3,979,607.8	1,742.8	424,036.4	3,979,607.8	1,744.2	1.3	0	1.4
8	423,993	3,979,607.3	1,742.7	423,991.7	3,979,607.8	1,743.9	–1.3	0.5	1.2
9	423,993.5	3,979,588.7	1,743.2	423,993	3,979,590.3	1,743.9	–0.5	1.6	0.7

as training data and test data. Table 4 shows that the value of the variation range is about 4.9, and the sampling points have strong spatial autocorrelation, which is the dominant trend [11].

The line chart of training samples in Fig. 2 shows that the data of training samples conform to the normal distribution and does not need to be transformed. There are some errors in the specific analysis of deviation sources, especially in the following aspects of the existing data. The existing data come from the digitization of paper maps, which is obtained by aviation. In data acquisition, the accuracy of data is usually affected by instruments, drawings, experience, and so on. In the process of the digitization of the data in paper charts, there are also scanning and line acquisition errors. In addition, the contour distance of the original image is in meters, and the interpolation process also has a certain impact on the data accuracy in the process of contour extraction [12].

Positioning errors of GPS mainly include the satellite orbit error and the satellite and receiver error, and the tropospheric and ionosphere atmospheric delay error, and they cannot be eliminated. The error of the measuring instrument is mainly caused in the process of data transmission to the mobile station during the differential calculation, and data are acquired by a data receiver at the mobile station. The measurement accuracy of the receiver is that the carrier data can reach the plane measurement accuracy after the difference correction, the plane accuracy of the coded data after the difference correction is in meters, and the elevation error is usually about twice the plane error [13].

3.3. Analysis of the comparison between measurement results and existing topographic map data

Table 5 compares the coordinates obtained by a portable ultrasonic laser finder with existing topographic map coordinates.

The measurement results listed in Table 5 reach the supporting accuracy. The measurement range of the laser rangefinder does not exceed M, and the measurement accuracy is about M. Among the measured values of plane position deviation, the digital topographic map distributed in the result table is mainly within meters, including the measurement error and data error. This meets the requirements of the 1:10,000 digital topographic map.

4. Conclusion

The principle and method of GPS are studied in digital mapping of geographic information systems, and the digital mapping method based on GPS is briefly discussed. The test results are compared with the existing topographic map data, and the data deviation sources are analyzed systematically based on the selection of GPS working mode, data acquisition, and data processing. In hydrogeological survey, comprehensive hydrogeological mapping is a very important working method. In the traditional hydrogeological mapping work, it is often restricted by various natural factors, which affect the selection of information collection area and even threaten the life safety of field personnel. A detailed map is often needed to navigate in field hydrogeological mapping. Using GPS for digital mapping is very desirable. The GPS can obtain the positioning results of the required accuracy, and capture and store the attribute information of the object by using the computer integrated into the receiver, which directly meets the requirements of data mapping. With its development, GPS will be widely used in the field of digital mapping, which will become the next hot research topic.

References

[1] E. Gunawan, T. Nishimura, S. Susilo, S. Widiyantoro, N.T. Puspito, D.P. Sahara, N.R. Hanifa, S. Hidayati, A. Omang, A. Agustan, Fault source investigation of the 6 December 2016 MwMw 6.5 Pidie Jaya, Indonesia, earthquake based on GPS and its implications of the geological survey result, J. Appl. Geodesy, 14 (2020) 405–412.

[2] G. Chen, Application of GPS technology in space geological survey, Arabian J. Geosci., 12 (2019) 1–5, doi: 10.1007/s12517-019-4842-x.

[3] A. Takahashi, M. Hashimoto, J.-C. Hu, K. Takeuchi, M.-C. Tsai, Y. Fukahata, Hierarchical cluster analysis of dense GPS data and examination of the nature of the clusters associated with regional tectonics in Taiwan, JGR Solid Earth, 124 (2019) 5174–5191.

[4] R. Hetzel, A. Hampel, P. Gebbeken, Q. Xu, R.D. Gold, A constant slip rate for the western Qilian Shan frontal thrust during the last 200 ka consistent with GPS-derived and geological shortening rates, Earth Planet. Sci. Lett., 509 (2019) 100–113.

[5] R. Castaldo, R. de Nardis, V. De Novellis, F. Ferrarini, R. Lanari, G. Lavecchia, S. Pepe, G. Solaro, P. Tizzani, Coseismic stress and strain field changes investigation through 3-D Finite Element Modeling of DInSAR and GPS measurements and geological/seismological data: The L'Aquila (Italy) 2009 Earthquake Case Study, Adv. Earth Space Sci., 123 (2018) 4193–4222.
[6] A. Abdul Sattar, Preparation of novel hybrid (Almond Shell and *Pleurotus Sajor Caju*) biosorbent for the removal of heavy metals (nickel and lead) from wastewater, Water Conserv. Manage., 4 (2021) 1–7.
[7] J.D. Prasetya, D.H. Santoso, E. Muryani, T. Ramadhamayanti, B.A.S. Yudha, Carrying capacity of mercury pollution to rivers in the gold mining area of Pancurendang Village, Banyumas, J. Clean WAS, 5 (2021) 1–4, doi: 10.31098/ess.v1i1.108.
[8] J.J. Gairhe, S. Khanal, S. Thapa, Soil organic matter (SOM): status, target and challenges in Nepal, J. Sustainable Agric., 5 (2021) 90–94.
[9] Anonymous, Aranz' Leapfrog Aspect Allows Users to Visualize Geological Models, 2016.
[10] V.G. Bykov, S.V. Trofimenko, Slow strain waves in blocky geological media from GPS and seismological observations on the Amurian plate, Nonlinear Processes Geophys., 23 (2016) 467–475.
[11] G.D. Clemenson, A. Maselli, A.J. Fiannaca, A. Miller, M. Gonzalez-Franco, Rethinking GPS navigation: creating cognitive maps through auditory clues, Sci. Rep., 11 (2021) 7764, doi: 10.1038/s41598-021-87148-4.
[12] X.R. Wang, X.Y. Liu, Z.T. Lu, H.F. Yang, Large scale GPS trajectory generation using map based on two stage GAN, Data Sci. Action, 19 (2021) 126–141.
[13] I.T Gross, R.F Coughlin, D.C Cone, S. Bogucki, M. Auerbach, M.X. Cicero, GPS devices in a simulated mass casualty event, Prehosp. Emerg. Care, 23 (2019) 290–295.