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Research paper

Association between Lineaments and Groundwater Intrusion into Tunnel Built in Granitic Rock Mass

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Abstract

Groundwater flow is controlled by geological structures such as lineaments. Lineaments existing in and around major infrastructures can cause problems because they commonly control the flow of groundwater. A tunnel built in granitic rock mass was chosen for this study with the objective of identifying and correlating the connection(s) between existent lineaments and groundwater intrusion. Two methods are applied in this study, i.e. lineament interpretation and groundwater intrusion mapping along tunnels. Lineaments are interpreted manually using satellite image before being digitized in ArcGIS software. Four sets of lineaments are identified in the study area and are oriented in NW-SE, NE-SW, E-W and N-S directions. Existence of lineaments around a tunnel constructed in granitic rock mass is identified and cross-checked with location of groundwater intrusion inside the tunnel. Comparison between these outputs show that the location of groundwater intrusion is related to existent lineament(s). The groundwater flow is mostly uncontrolled and excessive.

Keywords*: satellite image; lineament; groundwater intrusion; granitic rock mass.*

1. Introduction

A tunnel is a common structure built nowadays to fulfill modernization demands. Most countries around the world use this structure for railways, roads, electricity generation, shelters, etc. The size of tunnels varies from small to huge, depending on utilization. Constructing a tunnel inside a rock mass is harsh work, especially in an area that has a huge amount of groundwater. The presence of groundwater can negatively impact the stability of the tunnel [1]. Groundwater flow is a natural process and it flows in fractures that exist in rock mass. Granitic rock mass is normally a massive body. However, deformation processes caused by tectonic activity will create geological structures, and one of the major geological structures associated with aforementioned deformation processes is lineament.
Remote sensing technique is used widely in many geological settings to delineate major tectonic structures, especially lineaments [2–5]. Lineaments can be mapped, identified and mostly characterized by linear topographic features on the Earth's surface, some of which can be joints, faults, or shear zones [6, 7]. The size of a lineament can range from several hundred meters up to kilometres. At this large size, lineaments are normally interpreted as major faults, fault zones or zones of intense jointing in rock mass. They can be mapped using various sources such as topographic mapping, satellite images and aerial photographs [8, 9]. In satellite images, lineaments have topographic relief and often are represented by a 3-D geological structure in the subsurface [10]. Lineaments naturally act as a typical pathway for groundwater flowing in massive rock masses and are always used in potential groundwater assessment and extraction [11–15]. A tunnel located in Jeli, Kelantan has serious issues regarding groundwater intrusion. Huge amounts of groundwater flow into the tunnel and cause serious problems. This paper will discuss the connection between groundwater intrusion and lineaments existing in surrounding study area.

2. Geology and Site Condition

The study area is located in Jeli, the western part of Kelantan State. Geologically, the Jeli area is made up of three major types of lithology which are granitic, sedimentary and metasedimentary rocks [16] (

Fig. 1). Specifically, the study area is located within the Lawar granite. The Upper Jurassic to Triassic Lawar Granite is part of the Main Range Granite which forms the backbone of Peninsular Malaysia. The Lawar Granite is characterized by light grey, fine-grained, equigranular biotite-hornblende granite which is partly sheared and modified [17]. Microscopically, it is granite to granodiorite in composition. This rock is strongly deformed because of tectonic activities and can be classified as cataclasite [17].

Field mapping shows that the exposed rock masses vary in weathering grade from fresh (grade I) to slightly weathered (grade II) and moderately weathered (grade III) rocks. The fresh and slightly weathered rocks are generally exposed at the unlinking shotcrete area, while the moderately rock masses are exposed at the major structure effected area. The fresh to slightly and moderately weathered granite rock materials are generally very strong to extremely strong rocks. The surface of tunnels is normally covered with shotcrete which functions as a support system.

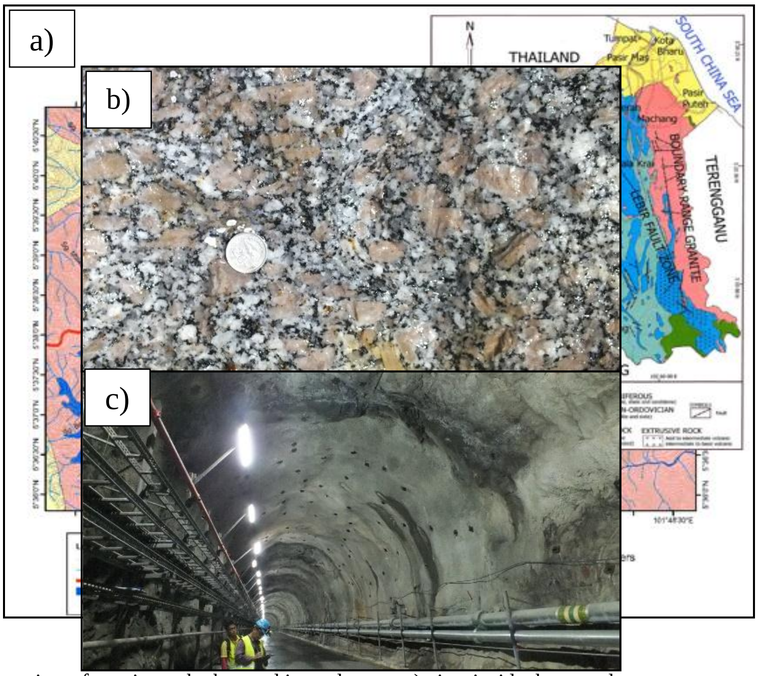

Fig. 1: The figure shows a) Geological map of study area [16], b) close up view of granite rock observed in study area, c) view inside the tunnel

3. Methodology

3.1. Lineament Interpretation

Lineament interpretation using satellite image has been widely used since the introduction of Landsat MSS in 1980 [2]. In this research, satellite image was downloaded from USGS portal and the satellite type is Landsat 8. The image from USGS portal was used because it is accessible, unrestricted and can be downloaded for free. A satellite image with 1:15000 scale was used in interpretation (**Error! Reference source not found.**). Lineament distribution and orientation can be easily extracted from satellite image due to its good quality and resolution [18, 19].

There are two methods used to interpret lineaments, which are manual interpretation and automatic lineament extraction. In this research, lineaments were delineated manually and then were digitized in ArcGIS software. The purpose of digitization was to determine accurately the location of lineaments respective to tunnel alignment. In this research, only negative lineaments are traced out and considered, because flow of groundwater into the ground is control fracture zone in rock mass [12, 14]. DIPS software ver. 6.017 was employed to plot the lineaments' orientations into rose diagrams [20].

Fig. 2: Satellite image used in lineament interpretation

3.2. Field Mapping

Field mapping was conducted by walk-over survey using mosaic photographs, which were captured along the tunnel (

Fig. 3). Both sides of tunnel (right and left side of the wall) was captured and stitched together manually in Corel Draw software. The length of area covered in specific areas vary, depending on the size of the picture. These photographs are used as base maps during field mapping. Major geological features, in this case water intrusion location along the tunnel, was recorded in the mosaic photograph.

4. Results and Discussion

4.1. Lineament Interpretation

Lineaments are often apparent in geological or topographic maps and can appear obvious on aerial photographs or satellite images [21]. Lineaments represent zones or planes of weakness in the rock mass along the offset bedrock that have undergone accelerated weathering and erosion, and provide the preferred path for water percolation or dissolution to take place in soluble rocks like limestone and dolomite. The satellite image interpretation shows a well-developed lineament system in this area (Fig. 4). From the resultant rose diagrams, the number of major lineament sets can be readily visualized. Four sets of lineaments can be encountered in study area which are oriented in NW-SE, NE-SW, E-W and N-S. However, the most predominant sets are the NW-SE and NE-SW lineaments.

Generally, lineaments features are existing from along both tunnel (main and ventilation tunnel), but more focussed from CH 50-375 and CH 550-800 in the main tunnel. Other parts of tunnel are slightly effected by lineaments, while for ventilation tunnel, lineaments are mostly concentrated from CH 150-275, CH 325-400 and CH 625-725. The correctness of lineament interpretation is verified at the site. Based on the structural mapping in the field, these lineaments sets correspond to the faults and major joints (Fig. 5).

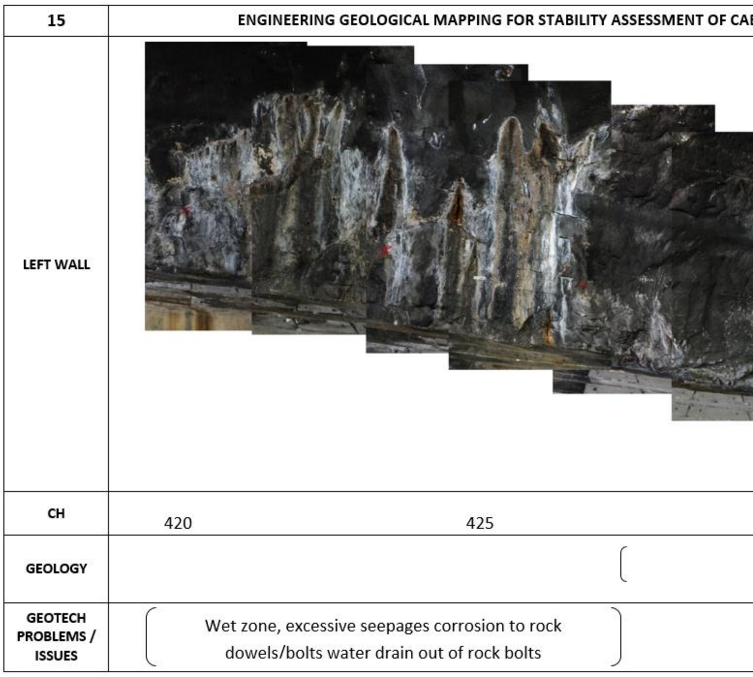

Fig. 3: Example of tunnel mapping conducted during field assessment

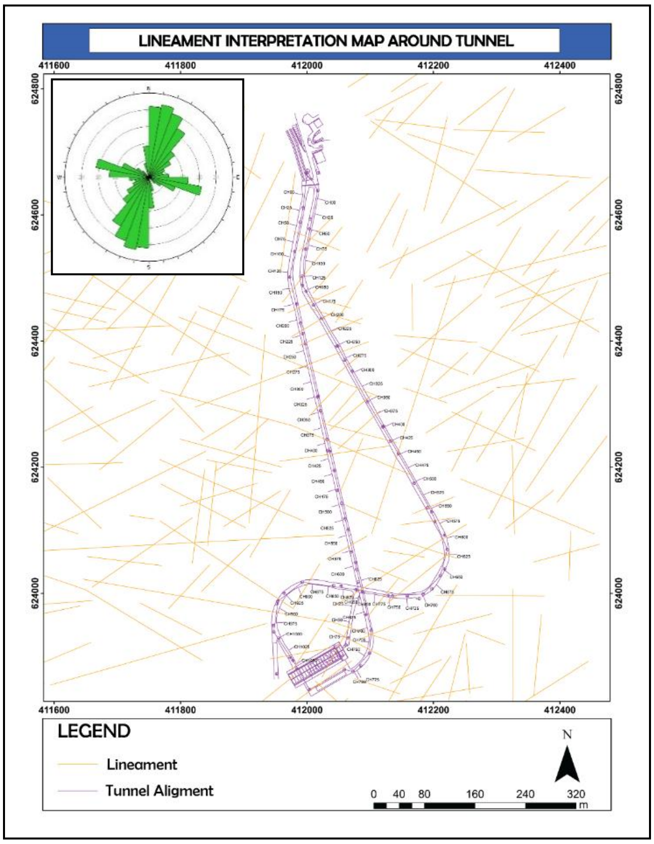

Fig. 4: Lineament interpretation map from satellite image. Four sets of lineaments oriented in NW-SE, NE-SW, E-W and N-S as shown in rose diagram

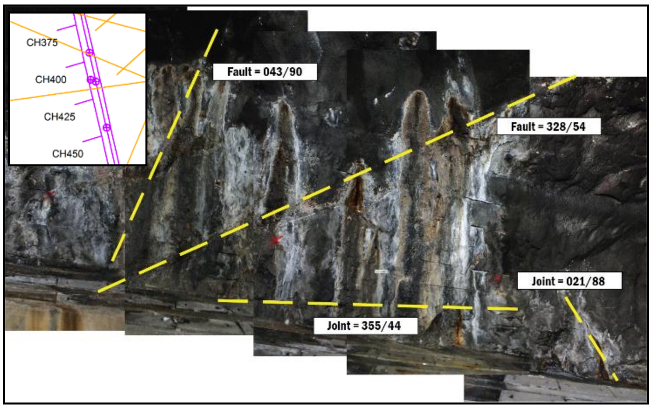

Fig. 5: Some fault structure measured in CH 420-425 in ventilation tunnel. These fault zones are represented in the lineament as interpreted in satellite image

4.2. Groundwater Intrusion

Groundwater intrusion into tunnel is a problematic situation in the study area. Multiple complications associated with groundwater intrusion are identified, examples being corrosion to tunnel support system (Fig. 6), deposition of secondary mineral and clog-up of installed drainage system. Field mapping, to sort and locate water seepages, was conducted from end to end inside the tunnel. Results of water intrusion mapping show significant locations of groundwater intrusion along tunnel. There are five conditions of water intrusion which are: past moisture, dump, standing drop, dripping and flowing (Fig. 7). Flowing and dripping were very common along tunnels, while dump and past moisture were not quite common. The meaning of terms used for groundwater intrusion is explained in Table 1. Calcite mineral deposit is a common feature that can observed at locations of groundwater intrusion. Almost 50% of total length of the tunnel is affected by groundwater intrusion. Intrusion is flowing out from both side of wall and crown (Fig. 8). Summary of groundwater intrusion locations along main and ventilation tunnels are shown in Fig. 9 and Table 2.

The distribution of groundwater intrusion is not concentrated at certain locations, but it is dispensed along tunnels from end to end. In main tunnel, the area most affected by groundwater is CH 0-80, while in ventilation tunnel, it is predominately at CH 650-780. Other areas affected by groundwater intrusion were the middle of tunnel, mainly at CH 250-275, CH 350-425 and CH 475-525. Groundwater is shown to be flowing along major geological structures, especially joints and faults. Some locations with high intensity of geological structures have excessive amount of groundwater and vice-versa. Other than geological structures, a few intrusions also occur via man-made holes, especially rock bolt and weep holes.

Although most part of tunnels are lined with shotcrete, installed as tunnel support system, groundwater still can seep into tunnels structure. Water present can be identified from wet conditions at shotcrete surface. The presence of groundwater inside rock mass will cause negative impact because it can accelerate chemical weathering processes and thusly influence engineering properties of rock material and rock mass [22–24].

Fig. 6: Heavily corroded rock bolt coated by secondary calcite

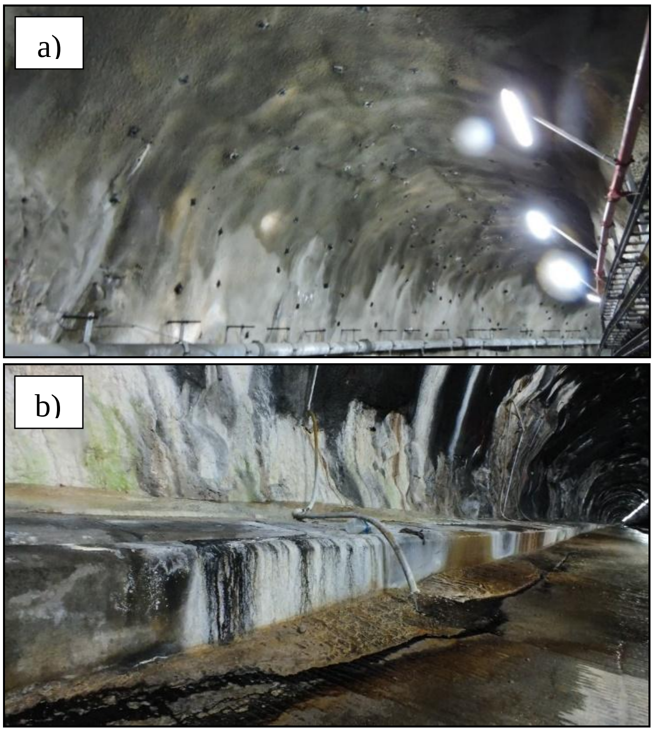

Fig. 7: Two different situations of groundwater intrusion, a) dumb, b) flow

Fig. 8: Groundwater intrusion can occur either at crown or wall of tunnel. Calcite mineral deposit is a typical feature that can observed at locations of groundwater intrusion

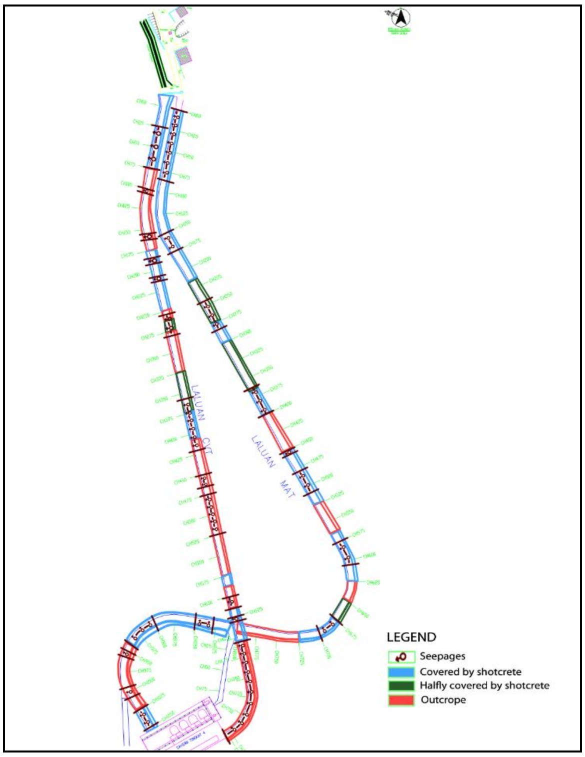

Fig. 9: Summary of water seepages/wet zones along main and ventilation tunnels

Table 1: Terms used to indicate amount of groundwater intrusion into tunnel

Term	Description
Damp	Slightly wet condition at surface of shotcrete or rock mass
Standing drop	Trickling of water with a gap between water drops
Dripping	Trickling or intermittent flow of small amount of water.
Continuous flow	Visible flow of water from weep holes
Past moisture	Dry but with signs of past damping or water marks, sometimes associated with dry calcite and/or rusty colorations

Table 2: Summary of types of groundwater intrusion in main and ventilation tunnels

	Main Tunnel			Ventilation Tunnel		
Types of Ground-water Intrusion	Location					
	Left Wall	Right Wall	Crown	Left Wall	Right Wall	Crown
Dump	CH 215 CH 450 CH 465 CH 525-CH 540 CH 580 CH 625-CH 635 CH675-CH700 CH 1025	CH 125 CH 400 CH 450 CH 520 CH 615-CH 640 CH 660-CH 690 CH 750	CH 650-CH 700 CH 780-CH 940 CH 1000-CH 1050	CH 0-CH 40 CH 55-CH 100 CH 125-CH 160 CH 190-CH 195 CH 210-CH 230 CH 240-CH 280 CH 310-CH 350 CH 430-CH 470 CH 480-CH 540 CH 570-CH 580 CH 600-CH 620 CH 660-CH 680 CH 690-CH 710 CH 735-CH 740 CH 760	CH 60-CH 80 CH 90-CH 120 CH 195-CH 200 CH 290 CH 405-CH 415 CH 425-CH 440 CH 680-CH 685 CH 690-CH 695 CH 730-CH 735 CH 760-CH 770	CH 290 CH 310-CH 350 CH 330-CH 335 CH 397-CH 400 CH 425-CH 470 CH 475-CH 500 CH 505-CH 530 CH 510-CH 530 CH 685-CH 690 CH 740-CH 745
Standing drop	CH 0-CH 10 CH 30-CH 50 CH 65-CH 90 CH 125-CH 130 CH 465 CH 500-CH 505 CH 530 CH 675-CH 690 CH 830 CH 900 CH 930 CH 980-CH 990	CH 0-CH 60 CH 100 CH 135-CH 145 CH 150-CH 160 CH 230 CH 255 CH 470 CH 490-CH 500 CH 780-CH 790 CH 830 CH 870 CH 890-CH 960	CH 60 CH 95-CH 100 CH 160-CH 170 CH 490 CH 520 CH 580 CH 710 CH 1005-CH 1020	CH 25-CH 40 CH 50-CH 70 CH 190-CH 215 CH 245-CH 250 CH 265-CH 270 CH 430-CH 435 CH 480-CH 490 CH 510 CH 520 CH 625-CH 630 CH 650-CH 660 CH 695-CH 705	CH 30-CH 35 CH 75-CH 80 CH 115 CH 185-CH 190 CH 200-CH 205 CH 210-CH 215 CH 225-CH 235 CH 255 CH 261 CH 265-CH 280 CH 313 CH 320-CH 335	CH 65 CH160 CH 270 CH 300-CH 308 CH 315 CH 340 CH 380-CH 382 CH 400 CH 415-CH 420 CH 455 CH 490-CH 505 CH 515

		CH 1010-CH 1040 CH 1030-CH 1050		CH 750-CH 755	CH 425-CH 430 CH 435-CH 440 CH 460-CH 465 CH 490-CH 505 CH 510-CH 520 CH 572 CH 602 CH 615 CH 650 CH 690 CH 705-CH 720	CH 560 CH 640 CH 685 CH 690-CH 700 CH 760
Dripping	CH 440 CH 90-CH 100 CH 140-CH 150 CH 160-CH 170 CH213 CH 250 CH 360-CH390 CH 590-CH 610 CH630 CH700-CH710 CH 1040-CH 1050	CH 170 CH 200 CH 370-CH 390 CH 440 CH 840-CH 860	CH 360-CH 370 CH 605-CH 615 C 1040-CH 1050	CH 30-CH 50 CH 50-CH 70 CH 100 CH 190-CH 220 CH 270 CH 340-CH 370 CH 380-CH 400 CH 410-CH 430 CH 470-CH 490 CH 510 CH 600-CH 605 CH 625 CH 710-CH 715 CH 755	CH 25 CH 50-CH 55 CH 475-CH 488 CH 578-CH 582 CH 665-CH 675	CH 155-CH 160 CH 380-CH 400 CH 455 CH 465 CH 602 CH 625 CH 695
Continuous flow	CH 70 CH 275 CH360-CH367 CH370-CH 390 CH 485-CH 495 CH820-CH840 CH845-CH875 CH1030-CH1050 CH 1000-CH 1010	CH 270 CH 900-CH 920 CH 1040-CH 1050	CH 275 CH 370 CH 440 CH 485 CH 1000-CH 1010 CH 1050	CH 190 CH 250 CH 275 CH 385-CH 400 CH 410-CH 430 CH 555-CH 585 CH 600-CH 615 CH 675 CH 705 CH 750-CH 780	CH 45 CH 230 CH 355-CH 360 CH 750-CH 780	CH 385 CH 395
Past Moisture	CH 0-CH 90 CH 100-CH 170 CH 220-CH 250 CH 360-CH 400 CH 425-CH 470 CH 480-CH 520 CH 575-CH 610 CH 660-CH 680 CH 710-CH 715 CH 780-CH 930 CH 1030-1050	CH 30-CH 40 CH 70-CH 160 CH 215-CH 230 CH 245-CH 255 CH 270-CH 280 CH 310-CH 325 CH 365-CH 390 CH 440-CH 450 CH 470-CH 530 CH 565-CH 580 CH 590-CH 620 CH 810-CH 820 CH 840-CH 870 CH 900-CH 960 CH 1005-CH 1050	CH 0-CH 90 CH 100-CH 175 CH 230-CH 250 CH 350-CH 390 CH 460-CH 475 CH 500-CH 530 CH 660-CH 680 CH 700-CH 710 CH 755-CH 765 CH 780-CH 800 CH 850-CH 900 CH 1000-CH 1050	CH 0-CH 70 CH 95-CH 105 CH 120-CH 150 CH 225-CH 240 CH 310-CH 320 CH 540-CH 560 CH 715 CH 765-CH 775	CH 220-CH 225 CH 445-CH 465 CH 505-CH 530 CH 570-CH 585 CH 620-CH 625 CH 635-CH 645	CH 105-CH 110 CH 120-CH 130 CH 193 CH 505-CH 530 CH 570-CH 585 CH 655-CH 650 CH 670-CH 675 CH 680-CH 685

4.3. Correlation between Lineament and Location of Groundwater Intrusion in Tunnel

Maps of lineament interpretation and groundwater intrusion are combined together, as shown in Fig. 10. The comparison between lineament and groundwater intrusion shows both data are related to each other. Each section or location where groundwater intrudes into tunnel, presence of lineament(s) can be noticed. Groundwater can flow efficiently through these geological structures, which are well-connected to each other, and thusly increases porosity and permeability. For example, at groundwater intrusion from CH 350-425 in ventilation tunnel, six lineaments are identified to be present. Similar setting also can be seen at other locations along tunnel, for instance from CH 475-525, CH 625-780 in ventilation tunnel and CH 150-175, CH 250-275 and CH 1025-1050 in main tunnel.

The number of lineaments differ from one location to another and it does not influence coverage area of groundwater intrusion into tunnel. For example, total groundwater affected are in main tunnel from CH 0-80 is 80m, but number of lineaments identified at that section are two. However, for 75m length of CH 350-425 in ventilation tunnel, identified lineaments are six. Therefore, it can be concluded that the amount of water flow inside each lineament differ.

Available data also suggests that rock mass that are not affected by lineaments do not have any issues with groundwater intrusion at any particular area. This situation happens in less fractured or massive rock mass. Comparison between these data also shows that not all identified lineaments form interpretation can cause groundwater intrusion into tunnel. This situation happens possibly because there is no groundwater flow regime occurring along that lineament.

5. Conclusion

Identifying lineament existence in major underground construction projects is important because its presence can control groundwater flow. Areas with excessive groundwater flow can cause multiple problems to tunnel support system or can trigger rock fall/landslide. This research concludes that groundwater intrusion into the tunnel is controlled by lineaments. Groundwater can freely flow along the lineament zone because it is highly permeable and porous.

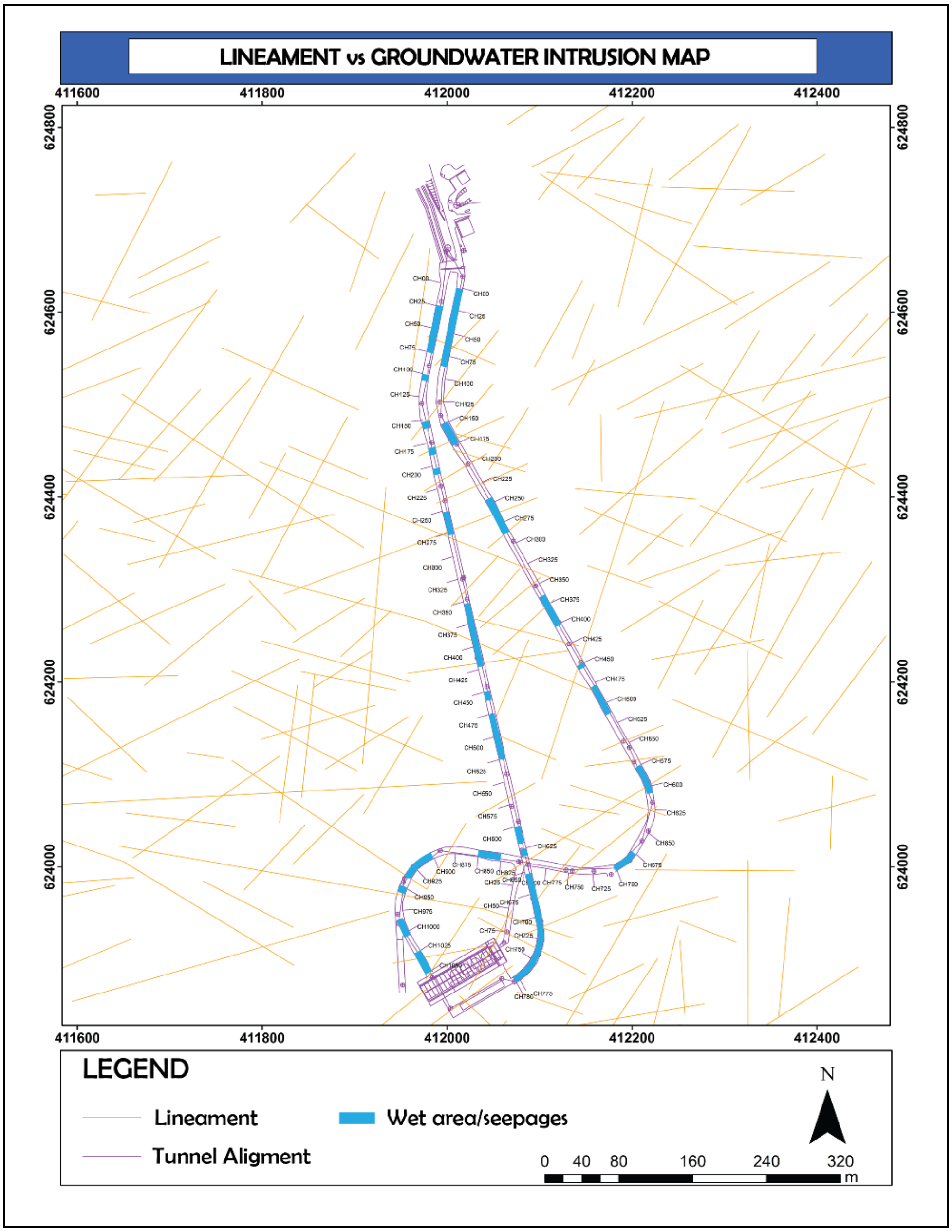

Fig. 10: Compilation of lineament and groundwater intrusion map

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