SEBARAN SPASIAL TINGKAT KARSTIFIKASI AREA PADA BEBERAPA MATAAIR DAN SUNGAI BAWAH TANAH KARST MENGGUNAKAN RUMUS RESESI HIDROGRAPH MALIK VOJTKOVA (2012)

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Latar Belakang

Tingkat perkembangan karst dari sisi tipe aliran yang dominan

Pendekatan Kualitatif vs Kuantitatif

Pendekatan Deduktif vs Induktif

Forward model vs invers model

Tujuan Penelitian

Mengetahui perbedaan tingkat perkembangan akuifer karst pada beberapa mataair dan sungai bawahtanah karst

Spasial

- **Kawasan Karst Gunung Sewu, DIY**
- **Kawasan Karst Rengel, Kab. Tuban, Jatim**

Daerah Penelitian

1 Juni 2014, Debit kecil, kondisi air jernih

25 Januari 2013, Debit kecil, kondisi air agak keruh

8 Maret 2014, Debit besar, kondisi air sangat keruh

6 Maret 2014, Debit Sedang, kondisi air keruh

Metode Penelitian

Data yang
Dibutuhkan

Data Tinggi Muka Air (TMA)

Direkam secara *time series* dg Interval
15 dan 30 menit menggunakan Hobo
Water Level

Pengukuran Debit

- Sudden Injection
- Velocity Area Methods
- Current Meter

Tahapan Analisis Penelitian

Karakteristik Umum

Hidrograf Banjir

Seropan

Gilap

Bribin

Ngerong

Toto

Petoyan

Beton

Ngreneng

Parameter Hidrograf Banjir

Mataair dan SBT	Periode	Debit (Q) <i>liter/detik</i>			Rerata Waktu (Jam)			% Baseflow Musim Hujan		
		<i>Q min</i>	<i>Q max</i>	<i>Q mean</i>	Tp	Tb	T event	Awal	Tengah	Akhir
Mataair Beton	Januari – September 2009	505.9	11111.7	1555.7	12.9	193.4	154	48.22	51.77	46.94
Mataair Petoyan	Oktober 2012- Agustus 2013	1.95	48.49	7.62	3.6	9.3	12.9	40.36	22.67	39.56
SBT Gilap	Mei 2006 – April 2007	3	380	-	3	36	37.56	52.78	55.68	72.12
SBT Ngreneng	Mei 2006 – April 2007	60	1905.3	-	4.5	16.8	56.12	45.10	48.75	-
SBT Seropan	Februari – Agustus 2009	812.4	1184.5	875.7	83.6	619.2	702.85	-	70.47	67.09
SBT Toto	November 2008- September 2009	124.5	943.5	153.5	14.4	910	924.28	73.09	66.64	72.65
SBT Bribin	Mei 2006 – April 2007	1630	2520	-	5.5	36	41.45	88.79	87.13	97.27
SBT Ngerong	Januari – Juli 2014	580.2	6407.9	968.5	10.25	20.54	30.77	50.46	57.26	48.14

Menghitung Derajat Karstifikasi (D_k)

Rumus MALIK VOJTKOVA (2012)

$$Q_t = Q_0 e^{-\alpha t} \quad \text{..... resesi aliran diffuse (laminer)}$$

$$Q_t = Q_0 (1 - \beta t) \quad \text{..... resesi aliran conduit (turbulen)}$$

Beberapa aliran **laminar** and **turbulent** bisa dijumpai pada satu mataair yang mencerminkan jenis perkembangan pelorongan di akuifer karst-nya

Kombinasi jenis aliran pada resesi banjir untuk penentuan perkembangan karst

Karstification degree	Groundwater flow sub-regimes type	Characteristic recession curve equation	Characteristics of recession-curve parameters	Characteristics of karstification degree
0.5 1.0	Single laminar sub-regime, lower values of α_1	$Q_t = Q_{o1}e^{-\alpha_1 t}$	$\alpha_1 < 0.001$ $\alpha_1 = 0.001-0.0025$	Usually tectonic faults and shear zones filled with crushed material, with high buffering capability in relation to discharge. Mainly deeper groundwater circulation
2.0 2.3	Single laminar sub-regime, higher values of α_1		$\alpha_1 = 0.0025-0.007$ $\alpha_1 > 0.007$	Tectonic faults filled with crushed material with higher permeability and lower buffering capability in relation to discharge. In some cases deeper groundwater circulation
2.5 2.7 3.0	Combination of two or more sub-regimes with merely laminar flow characterised by different discharge coefficients, lower values of α_1 and α_2	$Q_t = Q_{o1}e^{-\alpha_1 t} + Q_{o2}e^{-\alpha_2 t}$	$\alpha_1 < 0.0024$ and $\alpha_2 < 0.033$ $\alpha_1 < 0.0024$ or $\alpha_2 < 0.033$ $\alpha_1 = 0.0024-0.0045$; $\alpha_2 = 0.033-0.067$	Aquifer with dense, prevailingly regular fissure network, with majority of micro-fissures and small fissures. Increase of values α_1 and α_2 accompanies increasing permeability and also higher heterogeneity of fissured rock environment
3.5 3.7 4.0	Combination of two or more sub-regimes with merely laminar flow characterised by different discharge coefficients, higher values of α_1 and α_2		$\alpha_1 = 0.0024-0.0043$ and $\alpha_2 = 0.060-0.16$ $\alpha_1 > 0.0043$ and $\alpha_2 < 0.060$ $\alpha_1 = 0.0041-0.018$ and $\alpha_2 = 0.055-0.16$	Aquifer with irregularly developed fissure network, with majority of open macrofissures, also with possible presence of karst conduits of limited extent. In extreme cases, even short-term turbulent flow might occur in this type of rock environment
4.3 4.7 5.0	Discharge hydrogram is composed of a sub-regime with turbulent flow and a sub-regime with laminar flow. Substantial role in groundwater discharge plays the sub-regime with laminar flow	$Q_t = Q_{o1}e^{-\alpha_1 t} + Q_{o4}(1 - \beta_1 t)$	$\alpha_1 > 0.018$ or $\alpha_2 > 0.16$ $\alpha_1 > 0.018$ and $\alpha_2 > 0.16$ β and α low values	Aquifer with anticipated existence of crushed water-bearing zone (e.g., fault zone) or by dense network of open small fissures in combination with simple, partly (or occasionally) phreatic conduit system of considerable extent (e.g., with open karstified fault in the vadose zone)
5.5	Complex discharge regime, a combination of one sub-regime with turbulent flow and two sub-regimes with laminar groundwater flow. Discharge sub-regime with turbulent flow is of short-term influence in comparison with overall groundwater discharge	$Q_t = Q_{o1}e^{-\alpha_1 t} + Q_{o2}e^{-\alpha_2 t} + Q_{o4}(1 - \beta_1 t)$	$\alpha_1 > 0$ and $\alpha_2 > 0$ and $\beta_1 > 0$	Extensive disruption and disintegration of rock environment, with majority of open, medium size, both not karstified and karstified fissures in the phreatic zone of the fissure karst aquifer (according to α_1) and with smaller influence of connected conduits (groundwater of large karstic channels, according to β_1)
6.0	Very complex discharge regime, a combination of two sub-regimes with turbulent flow and two sub-regimes with laminar groundwater flow. Discharge sub-regimes with turbulent flow are of short-term influence in comparison with overall groundwater discharge	$Q_t = Q_{o1}e^{-\alpha_1 t} + Q_{o2}e^{-\alpha_2 t} + Q_{o4}(1 - \beta_1 t) + Q_{o5}(1 - \beta_2 t)$	β_2 , β_1 and α_1 , α_2 high values	Extensive disruption and disintegration of rock environment, with majority of open, medium size, both not karstified and karstified fissures in the phreatic zone of the fissure karst aquifer (according to α_1) and with smaller influence of connected conduits (groundwater of large karstic channels, according to β_1 and β_2)

Karstification degree	Groundwater flow sub-regimes type	Characteristic recession curve equation	Characteristics of recession-curve parameters	Characteristics of karstification degree
7.0	Discharge regime is a combination of one sub-regime with laminar flow with two to three sub-regimes with turbulent flow. Substantial role in groundwater discharge plays the sub-regime with laminar flow	$Q_t = Q_{01}e^{-\alpha_1 t} + Q_{04}(1 - \beta_1 t) + Q_{05}(1 - \beta_2 t) + Q_{06}(1 - \beta_3 t)$	$\beta_3, \beta_2, \beta_1$ and α high values, $\beta_1 > \beta_2$	Developed karstification of the aquifer, formed by large open tectonic faults and karstic channels, as well as by significant portion of karstified and non-karstified fissures and micro-fissures in rock blocks, generating phreatic zone with karstic groundwater table
8.0	Discharge regime is a combination of a sub-regime with laminar flow with two to three sub-regimes with turbulent flow. Substantial role in groundwater discharge is played by sub-regimes with turbulent flow. Sub-regime with laminar flow is less significant		$\beta_3, \beta_2, \beta_1$ and α high values	Highly developed karstification of the aquifer, formed by large open conduits (karst channels). Presence of open active small fissures and micro-fissures is reduced. Circulation of substantial part of groundwater is mainly via preferred pathways of channel systems. Phreatic zone is missing or its role is insignificant
8.5	Groundwater flow regime is represented merely by turbulent flow, with only one turbulent flow sub-regime present, which represents turbulent circulation in channel systems (conduits) without hydraulic connection to the groundwater in adjacent rock blocks. Groundwater circulation is mostly connected to vadose zone	$Q_t = Q_{04}(1 - \beta_1 t)$	$\alpha_1; \alpha_2 = 0$ and $\beta_1 > 0$	Karstic aquifer with well-developed conduit system, without any significant connection to open phreatic fissure systems in adjacent rock blocks. Extensively developed conduit system can ensure permanent groundwater replenishment
9.0	Groundwater flow regime is represented merely by turbulent flow, consisting of two turbulent flow sub-regimes. These represent turbulent circulation in channel systems (conduits) without hydraulic connection to the groundwater in adjacent rock blocks. Groundwater circulation is mostly connected to vadose zone	$Q_t = Q_{04}(1 - \beta_1 t) + Q_{05}(1 - \beta_2 t)$	β_1, β_2 low values	Karstic aquifer with well-developed conduit systems of karstic groundwater pathways, without any significant connection to open phreatic fissure systems in adjacent rock blocks. Replenishment of groundwater resources can still be ensured by extensively developed conduit system
10.0	Complex turbulent flow regime of groundwater discharge, consisting of three different turbulent flow sub-regimes. Probability of a very complex groundwater circulation by occasional flows in the vadose zone. Documented only in perennial flows	$Q_t = Q_{04}(1 - \beta_1 t) + Q_{05}(1 - \beta_2 t) + Q_{06}(1 - \beta_3 t)$	β_1, β_2 and β_3 high values	Karstic aquifer with extensive conduit system, without any significant connection to open phreatic fissure systems in adjacent rock blocks. In its spatial extent, the conduit system is bound only to the vadose zone, without enabling permanent groundwater replenishment

Banjir 30 Desember 2006

Jika karst sudah **berkembang dewasa-tua** (G. Bribin)

15 April 2014

Jika karst **muda menuju dewasa** (G. Ngerong-Tuban)

Banjir 10 Februari 2014

Jika karst **muda** (Mataair Petoyan)

Banjir 18 Desember 2014--Mataair Kakap

Mataair dan SBT	Derajat karstifikasi	Rumus kurva resesi
Mataair Beton	6,6	$Qt = 2.757^{-0.009t} + 3.372(1-0.006t) + 6.478(1-0.0005t)$
Mataair Petoyan	3,7	$Qt = 0.031^{0.0025t} + 0.032^{0.030t} + 0.034^{0.027t}$
SBT Gilap	5,8	$Qt = 0.103^{-0.0256t} + 0.183(1-0.145t)$
SBT Ngreneng	6,0	$Qt = 0.191^{0.0019t} + 0.260(1-0.851t) + 0.385(1-0.099t)$
SBT Seropan	5,2	$Qt = 0.218^{0.0045t} + 0.244^{0.0186t} + 0.424(1-0.0365t)$
SBT Toto	5,0	$Qt = 1.447^{-0.009t} + 1.639(1-0.000019t)$
SBT Bribin	7,7	$Qt = 1.847^{-0.0007t} + 1.911(1-0.0007t) + 1.936(1-0.0028t)$
SBT Ngerong	4,8	$Qt = 1.447^{-0.009t} + 1.639(1-0.000019t)$
Sumbersemen	4,0	$Qt = 0.6^{-0.007t} + 0.9^{-0.65t}$
Kakap	7,0	$Qt = 0.3^{-0.06t} + 0.5(1-0.923t) + 0.7(1-0.0112t)$

Mataair dan SBT	Dk	Kondisi
Beton	6,6	Karstifikasi tingkat dewasa karena pengaruh patahan dan saluran karst terbuka, dengan saluran conduit dan non-karst yang telah berkembang dan menuju pada perkembangan muka airtanah freatik secara wilayah
Petoyan dan Sumbersemen	3,7 – 4,0	Perkembangan jaringan fissure yang belum seragam, mayoritasnya adalah makrofissure terbuka dan minim adanya saluran karst (conduit). Saat periode banjir ada kemungkinan (langka) terjadi aliran turbulen dalam jangka pendek
Gilap	5,8	Mulai adanya karstifikasi dan pelarutan batuan karbonat, dengan pelorongan yang terbentuk mulai bersifat terbuka, berukuran sedang (fissure), baik dialami oleh batuan yang mudah atau sulit larut di zone freatik. Sifat aliran sedikit dipengaruhi oleh saluran terbuka (conduit) yang saling berhubungan
Ngreneng	6,0	Mulai adanya karstifikasi dan pelarutan batuan karbonat, dengan pelorongan yang terbentuk mulai bersifat terbuka, berukuran sedang (fissure), baik dialami oleh batuan yang mudah atau sulit larut di zone freatik. Sifat aliran sedikit dipengaruhi oleh saluran terbuka (conduit) yang saling berhubungan

Mataair dan SBT	Dk	Kondisi
Seropan	5,2	Akuifer dengan adanya masukan air dari zona sesar di daerah hulu (missal), dengan perkembangan jaringan saluran kecil (diffuse-fissure) yang cukup intensif, sebagiannya bersifat terbuka dan sudah mempunyai sistem air freatik yang bersifat terbuka
Toto	5,0	Akuifer dengan adanya masukan air dari zona sesar di daerah hulu (misal), dengan perkembangan jaringan saluran kecil (diffuse-fissure) yang cukup intensif, sebagiannya bersifat terbuka dan sudah mempunyai sistem air freatik yang bersifat terbuka
Bribin	7,7	Karstifikasi pada tingkat yang sangat berkembang, yang didominasi oleh saluran terbuka (conduit) yang besar. Peran dari saluran mengengah (fissure) dan jaringan saluran kecil (diffuse network) sudah sangat minim. Zona freatik sudah hilang atau perannya sudah tidak lagi signifikan. Hampir seluruh siklus airtanah telah bergabung pada sistem saluran terbuka.
Ngerong	4,8	Akuifer dengan adanya masukan air dari zona sesar di daerah hulu (misal), dengan perkembangan jaringan saluran kecil (diffuse-fissure) yang cukup intensif, sebagiannya bersifat terbuka dan sudah mempunyai sistem air freatik yang bersifat terbuka

Variasi Spasial Derajat Karstifikasi (*Dk*)

Kawasan Karst bagian Timur

$Dk = 5,2 - 7,7$ (dewasa hingga dewasa - tua)

Kawasan Karst bagian Barat

$Dk = 3,7$ (muda)

Kawasan Karst Rengel, Tuban

$Dk = 4,8$ (muda berkembang ke dewasa)

Kawasan Karst Rembang

$Dk = 4,0$ (muda)

Kawasan Karst Gunung Sewu

$Dk = 3,7 - 7,7$ (muda hingga dewasa - tua)

Masalah yang terbantu dengan klasifikasi perkembangan karst ini:

1. Identifikasi sifat dan jenis aliran yang dominan;
2. Untuk membantu menilai tingkat kerentanan terhadap pencemaran di daerah karst
3. Menjadi penengah ketika terjadi konflik pemanfaatan batugamping (misal: tambang semen)