Hydrological Responses to Land Use and Land Cover in Forest-Dominated Watershed Using SWAT Model

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Contents

Introduction and Purpose

What is?

- Land use and land cover (LULC):- refers to physical covers of basin which an operations can be carried out to obtain benefits for mankind.

Who does?

- Human activities have a significant impact to alter the land use and land covers of the region.
- The capital city of South Korea, Seoul, reside approximately 26 million individuals. While the study area allocate more than half million population.

How does?

- LULC change impact the ability of surfaces to retain water, affect the rate at which water moves across the landscape, and ultimately influence the overall water balance and hydrological processes within an area.

How to know?

- Hydrological models are frequently employed to estimate the effect of LULC change scenarios on hydrological water segments. SWAT model stands out as the most extensively exploited model to assess this kind of situation.
- The study region has encountered LULC transformation in the prior two decades, the purpose of this presentation is to display the groundwater recharge responses to the land use and land cover changes.

Study area description

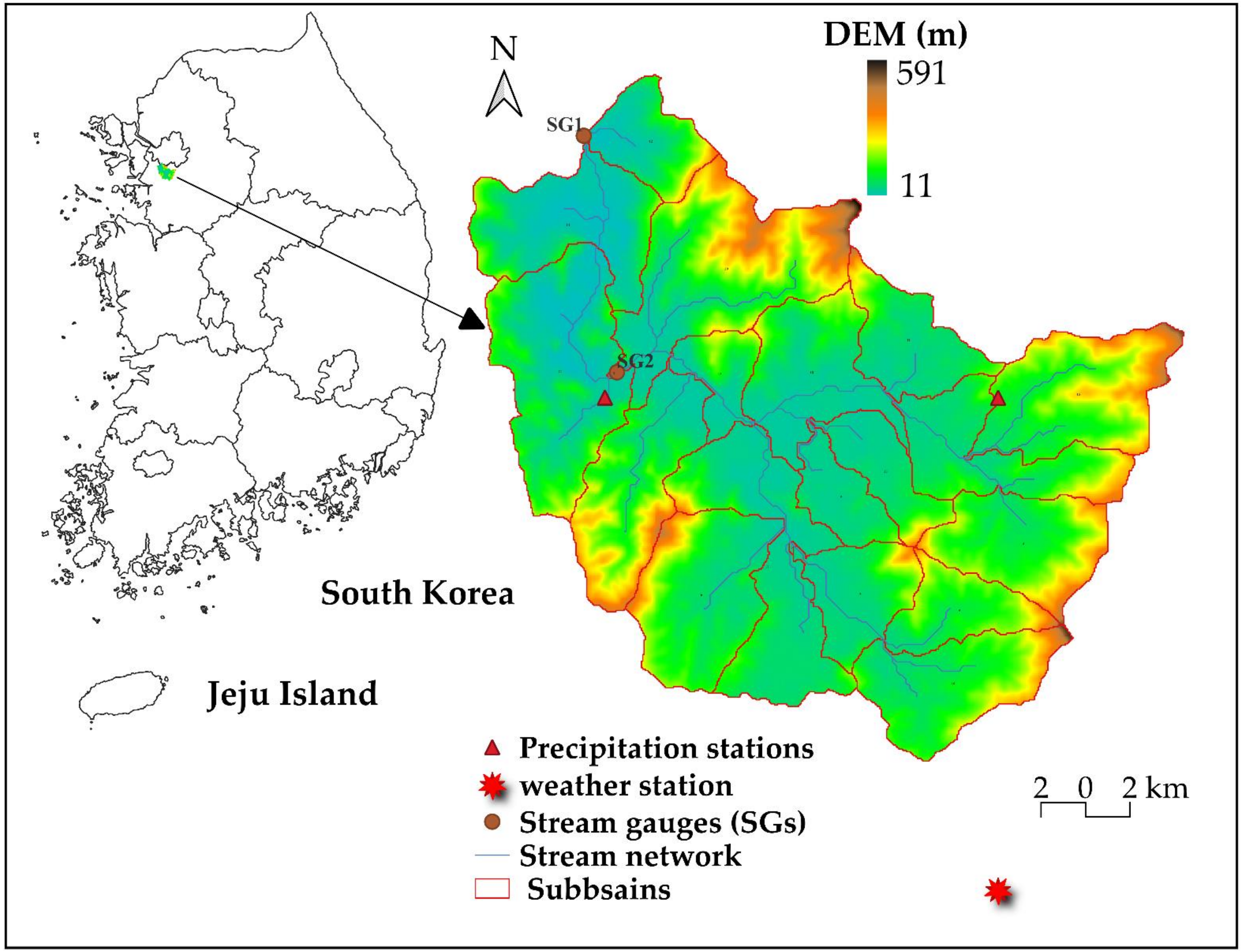

Fig 1. Anyang site map with digital elevation model (DEM) and others.

- Located in the Goyang province, southwest of Seoul, South Korea.
- The catchment enclose an area of 137 km^2, and its elevations vary from 11–591 m.
- The region experiences a humid climate, with mean daily temperatures ranging from 8.5–17.5 °C.
- The average annual rainfall in the watershed measured around 1266mm.
- The Coarse loamy soil series dominated (20.5%) the area.

Study area description

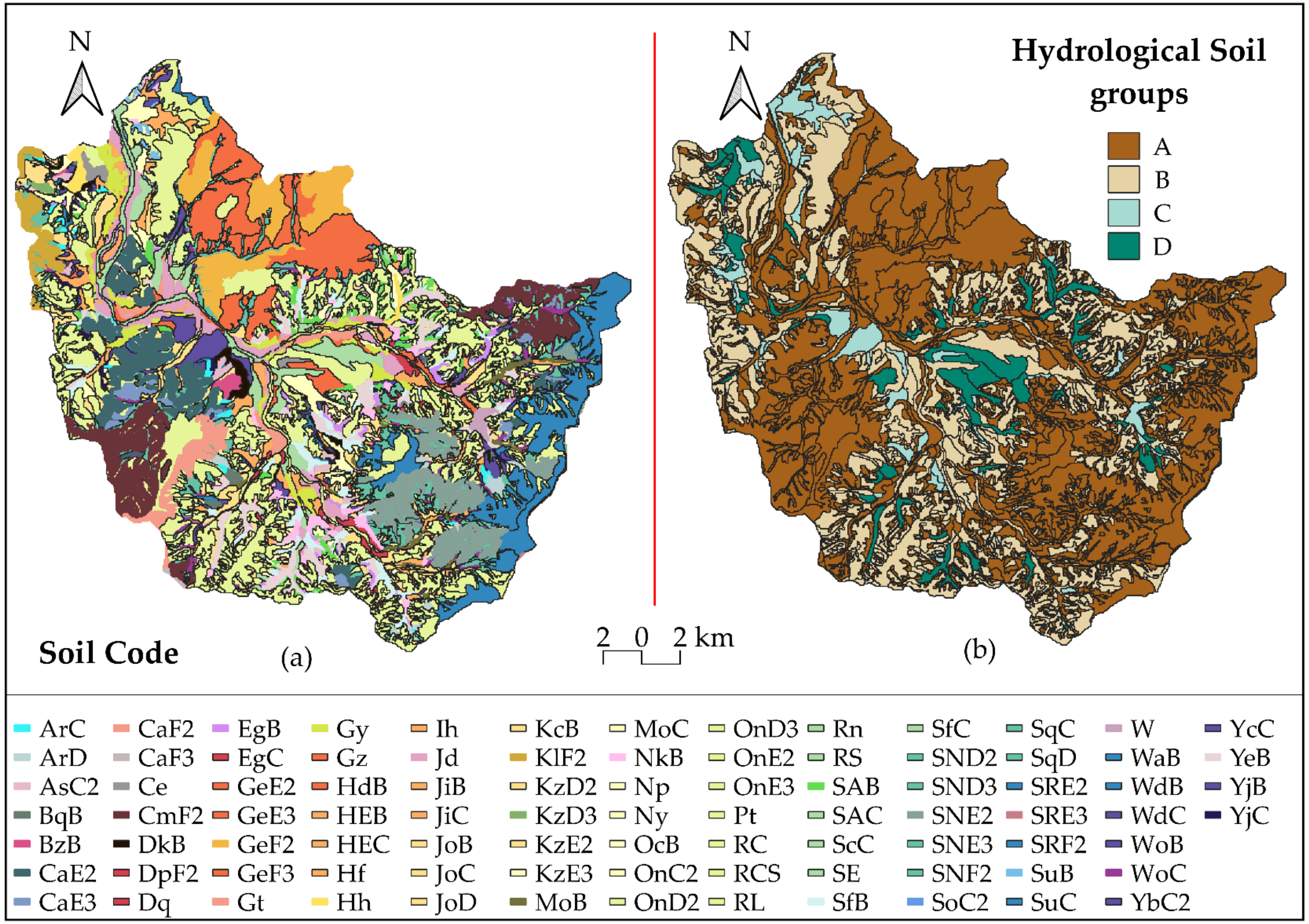

Fig 2. Anyang watershed soil types: (a) local soil classes used in the SWAT model; (b) hydrological soil group for soil types.

- The soil information was gathered from the National Institute of Agricultural Sciences of Korea.
- The study area have 88 soil classes.
- The hydrological soil group ‘A’ covers 67% of the region area.
- The soil group ‘A’ represents soil textures of sand and sandy loam with little possibility for runoff.
- Soil group ‘D’ covers 2.7% of the region area.

Study area description

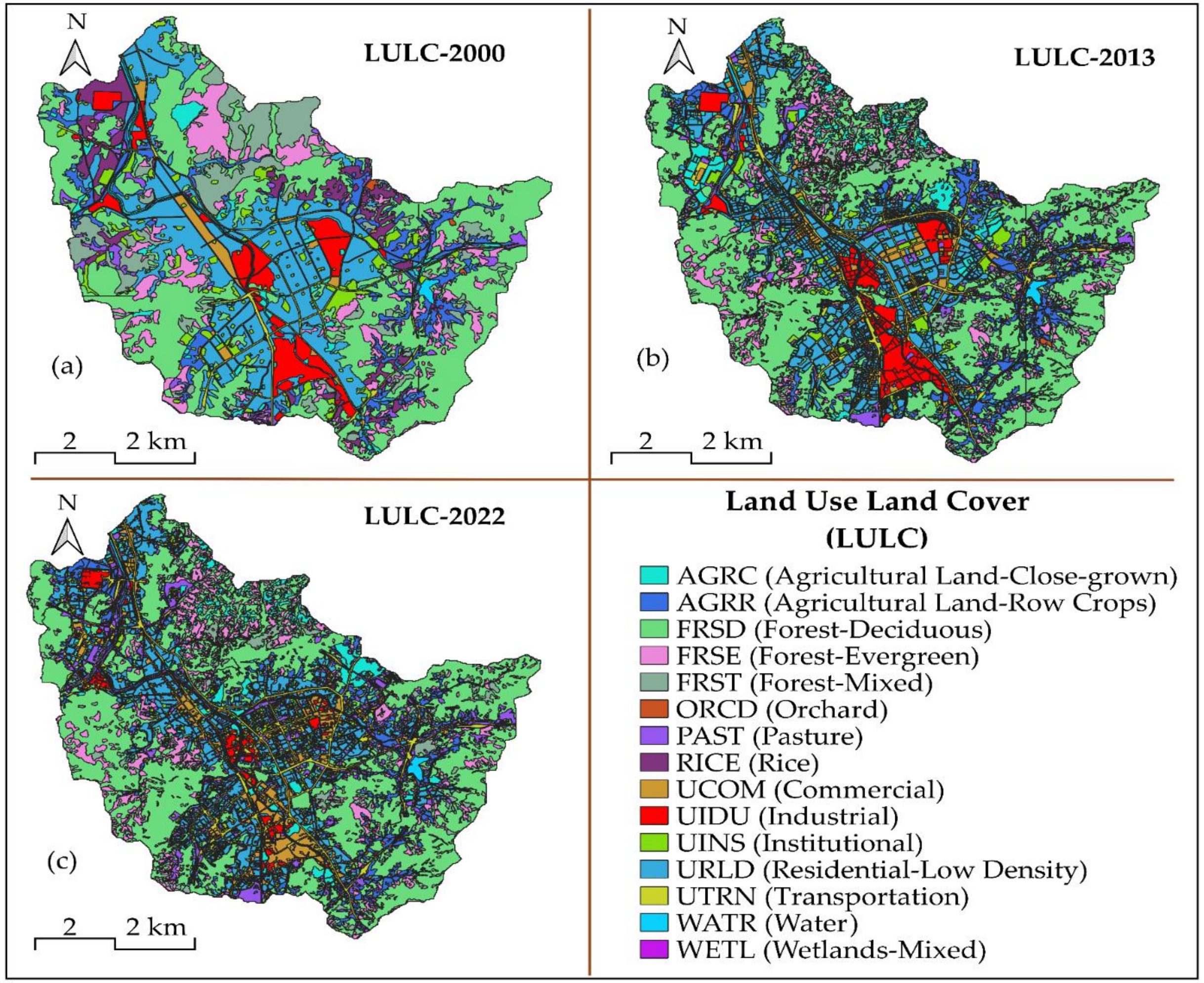

Fig 3. Watershed LULC types and their distribution for (a) 2000, (b) 2013, and (c) 2022.

- The LULC maps were obtained from Environmental Spatial Information Service.
- The watershed have 15 types of land use and land cover.
- Half of the study region covered by forest land area.
- While the urban area cover more than one-third of the watershed coverage

Table 1. LULC summary in the Anyang watershed

LULC area coverage in percent			
LULC Type	LULC-2000	LULC-2013	LULC-2022
Forest	50.50	50.71	50.66
Urban	36.74	33.17	30.35
Agriculture	11.11	10.17	8.64
Water bodies	1.04	1.33	1.07
Pasture	0.61	4.62	9.28

Agriculture= AGRR+RICE+AGRC+ORCD
Water bodies= WATR+WETL

Study area description

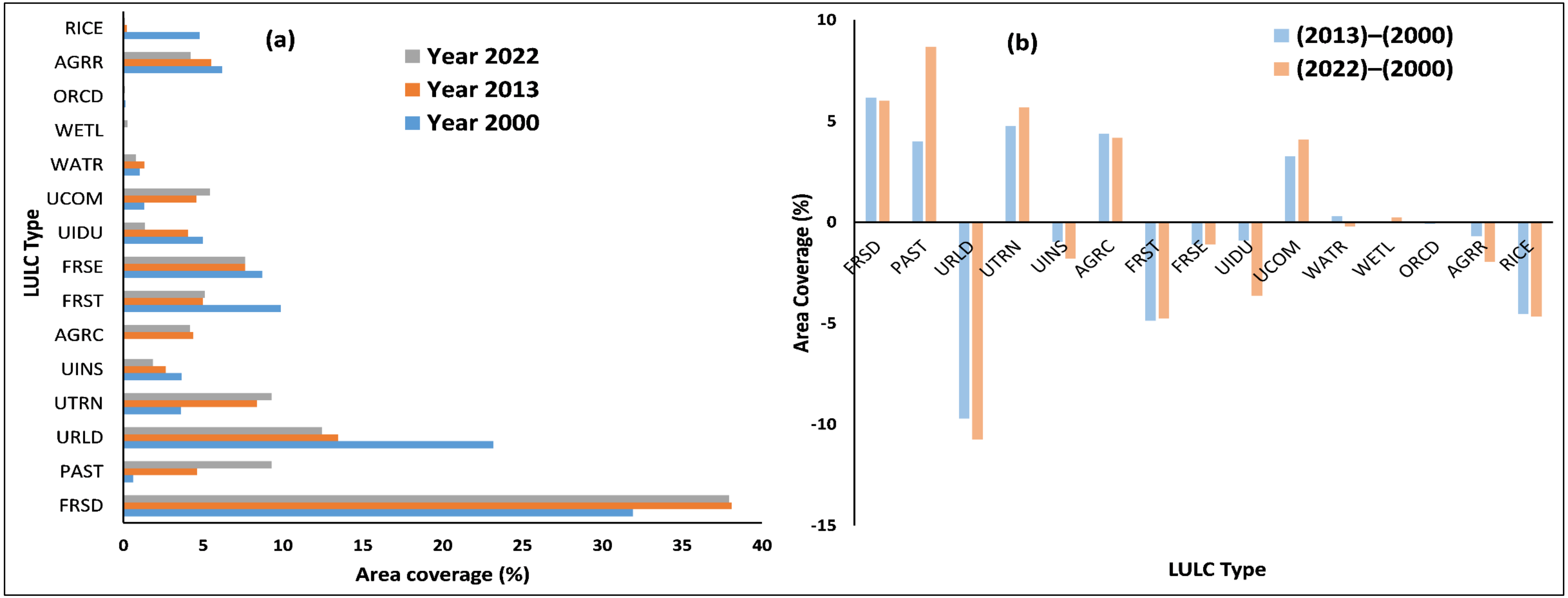

Fig 4. LULC types and area coverage in percent for study watershed.

- Year 2000–LULC is consider as the baseline.
- FRSD land use shows about 6% increase in coverage considering the baseline LULC. While, FRST and FRSE shows area coverage reduction.
- Pasture area increased by 4 and 8.6% for year 2013 and 2022 LULC.
- URLD shows significant reduction in area coverage, while UTRN and UCOM shows an increase in the study watershed
- Rice land also shows reduction in consistent pattern with LULC period.
- AGRC area shows an increase while AGRR shows a slight reduction considering the LULC baseline.

SWAT model description

$$SW_t = SW_o + \sum_{i=1}^{n}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad \text{Eq. 1}$$

$$w_{perc,ly} = SW_{ly,excess} \cdot \left(1 - \exp\left[\frac{-\Delta t}{TT_{perc}}\right]\right) \quad \text{Eq. 2}$$

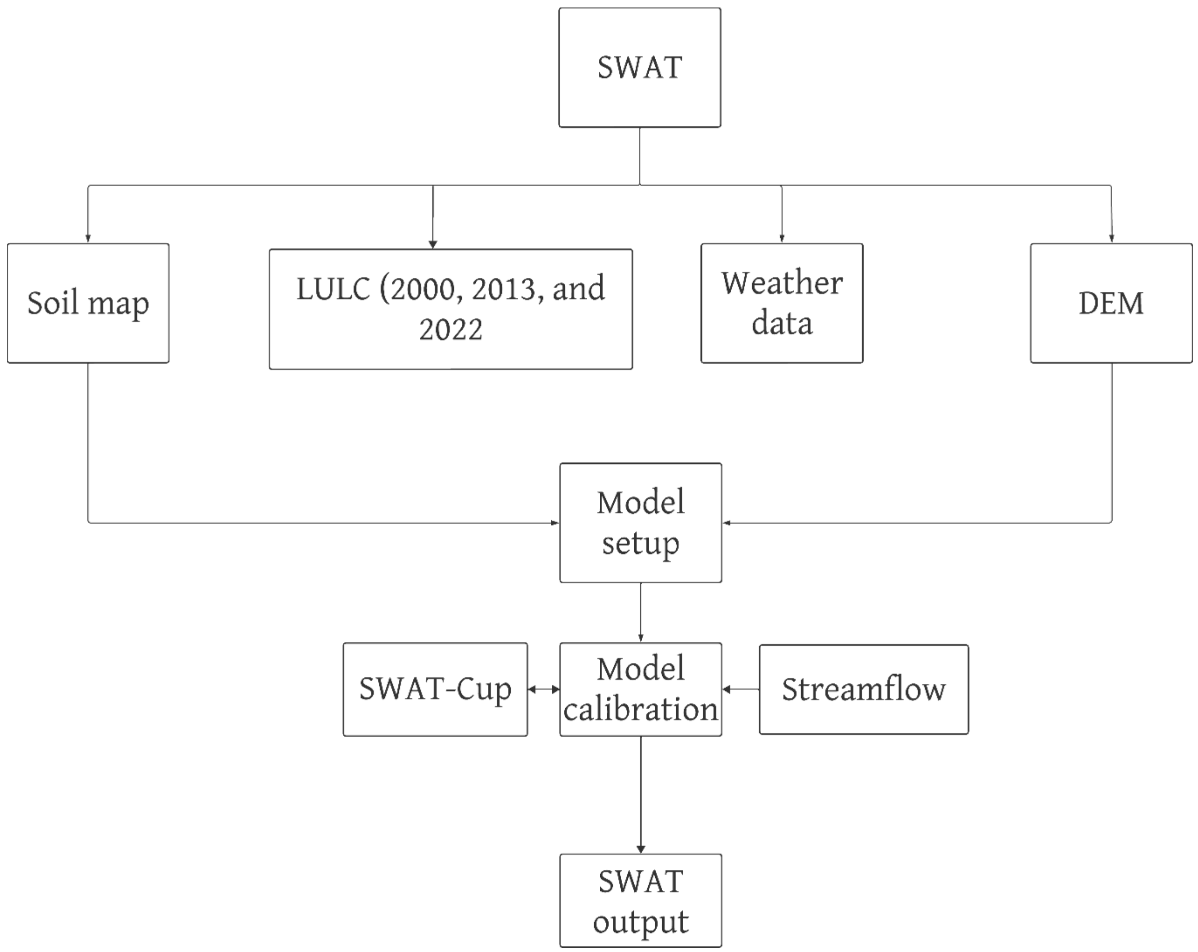

Fig 5. SWAT model flowchart.

- SWAT model water balance equation (eq.1) works at HRUs level.
- HRUs which created based the LULC maps were 3308, 3625, and 3806 for the year 2000, 2013, and 2022, respectively.
- The LULC change directly affect the amount of water reaching to the soil profile to percolate (which use equation 2).

Table 2. SWAT parameters used for calibration

Calibration Parameters	Descriptions	Calibrated Range Value	Fitted Value
r__CN2.mgt	Initial SCS runoff curve no. for moisture condition II	-0.2—0.2	-0.18
v__ALPHA_BF.gw	Baseflow alpha factor (days)	0—1	0.7
v__GW_DELAY.gw	Groundwater delay (days)	1—1	1
v__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0—1500	1141.5
v__GW_REVAP.gw	Groundwater "revap" coefficient	0.02—0.2	0.005
v__ESCO.hru	Soil evaporation compensation factor(-)	0—1	0.084
v__EPCO.hru	Plant uptake compensation factor(-)	0—1	0.173
r__SOL_AWC().sol	Available water capacity of the soil layer (mm mm^{-1})	-0.3—0.3	-0.23
v__RCHRG_DP.gw	Deep aquifer percolation fraction	0—1	0.57
r__SOL_K().sol	Saturated hydraulic conductivity (mm/h)	-0.2—0.2	-0.18
r__SOL_BD().sol	Moist bulk density	-0.2—0.3	-0.12
v__REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0—500	274.5
r__HRU_SLP.hru	Average slope steepness (m/m)	0—0.2	0.076
r__OV_N.hru	Manning's "n" value for overland flow	-0.2—0.2	-0.037
r__SLSUBBSN.hru	Surface runoff lag coefficient	-0.2—0.2	-0.02

Results and discussion

Table 3. Performance of statistical variable indicators for streamflow

Year	2000		2013		2022	
Statistical Variable	Calibration	Validation	Calibration	Validation	Calibration	Validation
R^2	0.91	0.86	0.90	0.85	0.90	0.86
NSE	0.90	0.82	0.89	0.78	0.89	0.80
PBIAS	11.3	-10.4	7.4	-17.6	8.3	-15.9

- Calibration period (2013–2017) and validation period (2006–2010).
- Calibration and validation statistical parameters showed great value for all LULC scenario.
- Simulated streamflow were underestimate during calibration period for all LULC map dataset. The opposite were displayed for validation period.

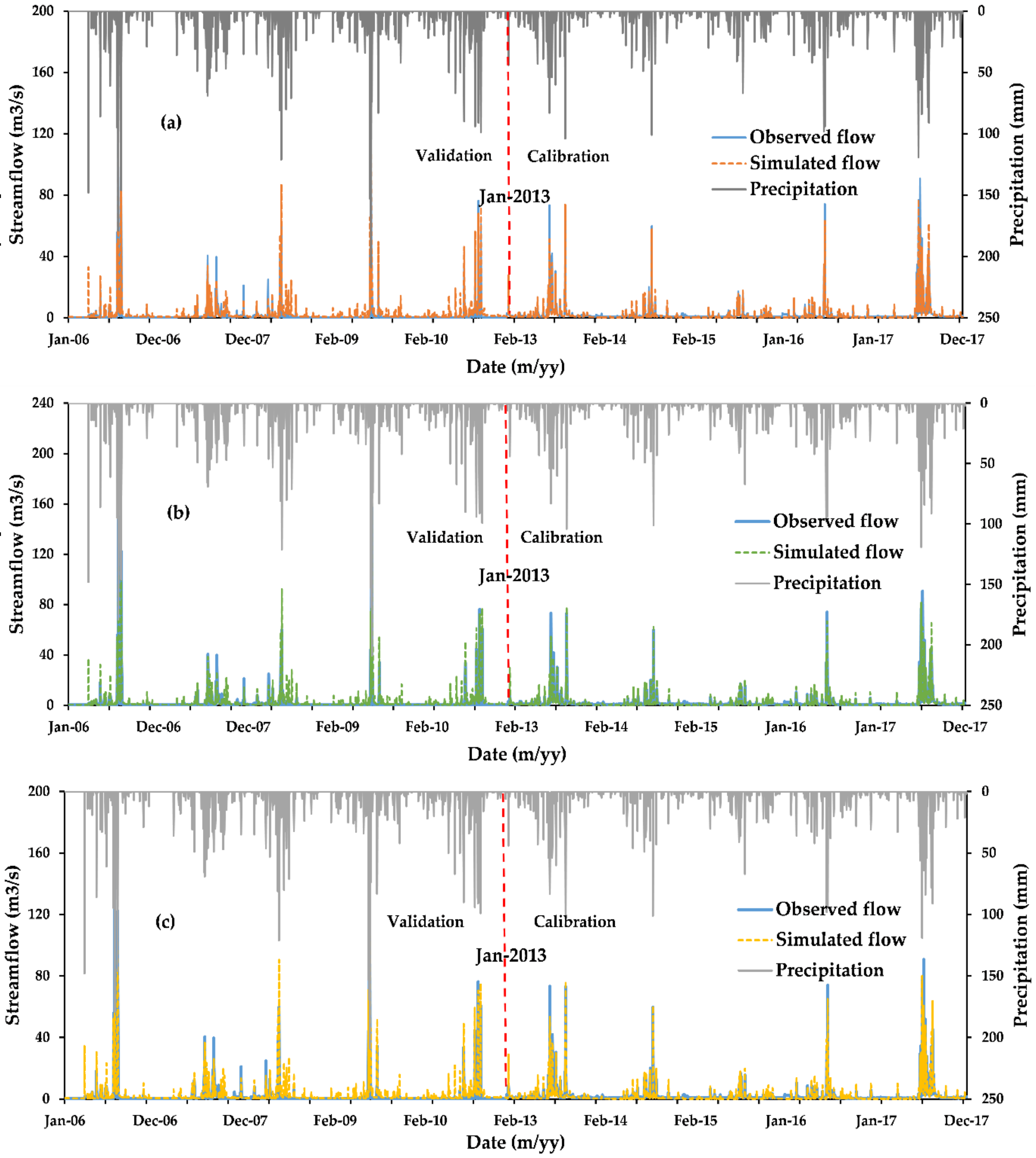

Fig 3. Observed vs. simulated streamflow hydrograph, including precipitation during calibration and validation for (a) 2000, (b) 2013, and (c) 2022 LULC changes.

Results and discussion

- Recharge accounted for 16.43, 14.59, and 15.28% of the annual precipitation in the years 2000, 2013, and 2022, respectively.
- The LULC change also impacts other hydrological components (see the table).
- Groundwater recharge distribution showed similar pattern in the southern part of the watershed for each LULC scenario .

Hydrological components	LULC-2000	LULC-2013	LULC-2022
Precipitation mm	1266.8	1266.8	1266.8
Surface runoff mm (%)	218.48 (17.25)	263.5 (20.80)	252.69 (19.96)
Lateral flow mm (%)	289.48 (22.85)	289.54 (22.86)	288.33 (22.76)
Water yield mm (%)	711.17 (56.14)	733.06 (57.87)	729.84 (57.61)
Recharge mm(%)	208.18 (16.43)	184.84 (14.59)	193.63 (15.28)
ET mm(%)	549.3 (43.36)	528.3 (41.70)	531.6 (41.96)

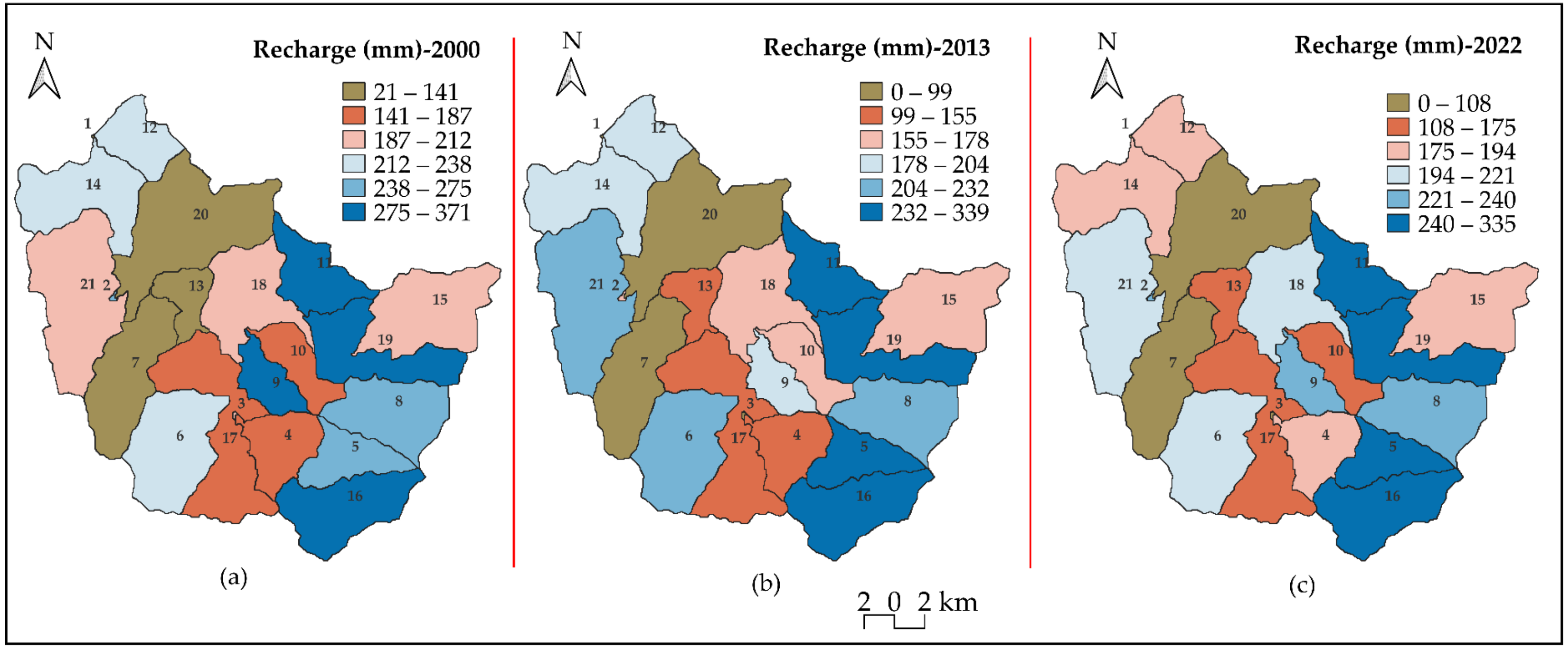

Fig 3. Mean annual groundwater recharge distribution across the years 2004—2018 for LULC in (a) 2000, (b) 2013, and (c) 2022.

Results and discussion

Table 3. selected LULC area coverage in the subbasin level

		Subbasin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
		LULC-2000 Perc (mm)	20.96	248.45	205.89	177.27	257.96	233.55	101.82	235.91	276.80	153.25	364.67	227.83	130.78	212.93	184.58	280.44	182.37	208.78	298.70	112.39	198.07
		LULC-2013 Perc (mm)	0.00	173.93	40.36	127.45	231.20	219.54	83.07	221.67	198.20	157.59	333.38	186.48	111.51	182.11	170.45	283.16	141.41	175.12	245.22	90.35	203.83
		LULC-2022 Perc (mm)	0.00	220.41	71.12	172.62	242.31	215.38	89.25	223.63	223.89	153.78	329.69	191.23	126.83	188.29	174.06	282.44	170.21	194.85	259.70	96.28	202.74
LULC Type	Year	Subbasin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Forestland	2000	LULC (ha)		0.09		167.13	286.2	457.2	592.74	572.4	38.52	80.37	221.04	182.43	127.53	313.47	734.58	522.36	242.91	242.91	359.82	1140.84	621.99
	2013	LULC (ha)		0.27		157.41	301.5	465.93	615.33	571.86	36.81	77.22	243.54	181.08	127.35	326.52	710.37	536.76	276.57	276.57	349.11	948.69	799.29
	2022	LULC (ha)		0.27		169.38	299.61	466.74	616.32	543.78	55.89	79.2	198.36	183.15	131.49	327.96	700.74	535.32	284.58	284.58	368.01	950.58	805.5
LULC Type	Year	Subbasin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Urban area	2000	LULC (ha)	0.9	4.14	2.07	316.62	76.23	424.44	306.09	33.12	291.87	298.8	101.25	259.47	155.97	351.54	89.46	148.77	805.95	475.92	221.94	261.09	413.01
	2013	LULC (ha)	0.54	2.61	1.89	312.3	64.8	422.73	247.5	33.21	261.27	265.68	88.2	229.68	135.63	377.73	93.87	104.22	764.19	430.02	221.94	235.08	256.95
	2022	LULC (ha)	0.54	2.52	1.89	256.86	57.06	363.06	228.6	63.27	221.67	245.25	114.75	221.58	97.65	344.79	86.22	86.76	694.26	382.14	209.88	203.13	280.98
LULC Type	Year	Subbasin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Water	2000	LULC (ha)		0.81	0.63	12.33	0.09	0.81		18.45	1.35		0.63		7.47	14.4	3.51	1.8	11.43	21.42	24.93	4.59	16.29
	2013	LULC (ha)		1.35	0.27	5.22	2.88	1.17	7.83	23.04	0.45		4.41		9.18	19.17	8.82	5.85	9.36	8.19	21.78	29.79	23.67
	2022	LULC (ha)		0.54	0.09	2.43	1.89	1.17	4.59	18.72	0.09		2.07		8.1	14.22	3.24	1.53	7.92	5.31	15.21	10.44	13.68
LULC Type	Year	Subbasin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Pasture	2000	LULC (ha)					3.15	7.65	1.62	3.42					0.63	0.36	21.6	12.69		5.76	12.6	0.63	13.59
	2013	LULC (ha)	0.27	0.81	0.27	18.99	16.65	34.11	18.99	19.89	22.5	27.9	16.2	14.4	14.13	47.79	69.93	30.69	73.71	31.14	43.11	50.76	81.81
	2022	LULC (ha)	0.27	1.53	0.27	41.04	25.29	111.33	35.1	66.06	27.45	49.95	81.09	22.23	31.32	104.04	108.36	61.02	132.93	63.27	88.56	93.06	128.88
		Subbasin Area (ha)	0.9	5.04	2.7	504.27	453.6	966.96	904.41	769.14	331.74	386.91	552.6	441.9	296.55	886.32	974.97	815.13	1117.44	801.81	760.77	1436.13	1306.71
		Total area (ha)-2000	0.9	5.04	2.7	496.08	365.67	890.1	900.45	627.39	331.74	379.17	322.92	441.9	291.6	679.77	849.15	685.62	1060.29	746.01	619.29	1407.15	1064.88
		Total area (ha)-2013	0.81	5.04	2.43	493.92	385.83	923.94	889.65	648	321.03	370.8	352.35	425.16	286.29	771.21	882.99	677.52	1123.83	745.92	635.94	1264.32	1161.72
		Total area (ha)-2022	0.81	4.86	2.25	469.71	383.85	942.3	884.61	691.83	305.1	374.4	396.27	426.96	268.56	791.01	898.56	684.63	1119.69	735.3	681.66	1257.21	1229.04

Percolation change (mm) for 2013 =78.6

Percolation change (mm) for 2022 = 52.9

Results and discussion

Subbasin-9 summary for year 2000

LULC	Area(ha)	Watershed(%)	Subbasin(%)
URLD	227.79	1.66	68.67
UTRN	31.5	0.23	9.5
UINS	32.22	0.23	9.71
UCOM	0.36	0	0.11
FRSD	22.86	0.17	6.89
WATR	1.35	0.01	0.41
FRSE	14.31	0.1	4.31
FRST	1.35	0.01	0.41

121 HRUs

166 HRUs

Subbasin-9 summary for 2022

LULC	Area(ha)	Watershed(%)	Subbasin(%)
PAST	27.45	0.2	8.27
URLD	95.31	0.69	28.73
UTRN	76.77	0.56	23.14
UCOM	34.74	0.25	10.47
UINS	14.85	0.11	4.48
AGRC	25.02	0.18	7.54
AGRR	1.62	0.01	0.49
FRSD	43.65	0.32	13.16
FRSE	4.41	0.03	1.33
FRST	7.83	0.06	2.36
WATR	0.09	0	0.03

Subbasin-9

- The URLD land cover percentage reduce significantly (30%) within two decade, which play for reduction of recharge amount .
- The increase in FRSD area and agricultural practices have a positive impact in groundwater recharge .
- The pasture may have a moderate impact in recharge of the subbasin

Summary and future works

- This study showed the impact of LULC on the groundwater recharge in the study watershed.

- The URLD land area plays a significant role in the groundwater recharge change, even the urban area coverage seems similar at the watershed level.

- These SWAT model with various LULC maps were used as input for SWAT-MODFLOW coupling model to see the surface and sub-surface interaction.

- The climate variation should also consider for further study including the projected future LULC.

THANK YOU FOR YOUR ATTENTION