Addis Ababa University
school of Graduate Studies,
Faculty of Science

LANDSLIDE ASSESSMENT AND HAZARD ZONATION IN MERSA & WURGESSA, NORTH WOLLO, ETHIOPIA

A Thesis Submitted to
The School of Graduate Studies of Addis Ababa University
In Partial Fulfillment of the Requirements for the
Degree of Master of Science in
Engineering Geology

By

Jemal Ibrahim

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Jemal Ibrahim

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Annex A Rating assigned to Individual facets for Intrinsic and external parameters.

Facets	Relative Relief	Slope Angle	slope material	Structural discontinuity	Land use Land cover	Ground water	Seismicity	Rain fall	Man made activities	Total Estimated Hazrd	Remark
1	0.6	2	1	2.46	1.2045	1.5	1.5	0.09	1.25	12.1045	HHZ
2	0.6	2	1	1.84	1.119	1.5	1.5	0.09	0	9.649	HHZ
3	0.8	1.7	1	2.04	1.203	1.5	1.5	0.225	0.075	10.043	HHZ
4	0.8	1.7	0.97	1.86	1.0875	0.928	1.5	0.213	0	9.0585	HHZ
5	0.8	1.7	0.974	1.76	0.806	0.798	1.5	0.214125	1	9.552125	HHZ
6	0.8	1	0.886	1.81	0.8665	1.023	1.5	0.43925	0	8.32475	HHZ
7	0.6	1	0.9	1.71	0.861	0.824	1.5	0.4375	0	7.5825	MHZ
8	0.6	2	1	2.46	1.23	1.5	1.5	0.09	1	11.38	HHZ
9	0.8	1.7	0.966	1.87	1.386	0.78	1.5	0.227125	0.075	9.304125	HHZ
10	0.2	1	1	1.87	1.302	1.5	1.5	0.425	0	8.797	HHZ
11	0.6	1	1	1.87	1.1985	0.6	1.5	0.45	0.075	8.2935	HHZ
12	0.6	1	1	1.82	1.182	0.952	1.5	0.425	0	8.479	HHZ
13	0.6	1	0.922	1.4	0.752	1.358	1.5	0.4645	0.25	8.2465	HHZ
14	0.8	1.7	1	1.61	0.8175	1	1.5	0.225	0	8.6525	HHZ
15	0.8	1.7	0.974	1.61	0.831	1.34	1.5	0.251625	0.25	9.256625	HHZ
16	0.6	1	0.988	1.66	0.9255	0.6	1.5	0.4265	0	7.7	MHZ
17	0.6	1	1	1.66	1.0875	0.6	1.5	0.425	0	7.8725	MHZ
18	0.8	1	0.984	1.66	0.93	0.6	1.5	0.427	0	7.901	MHZ
19	0.8	1	1	1.66	0.886	0.6	1.5	0.425	0	7.871	MHZ
20	0.6	1	0.97	1.66	1.1625	0.402	1.5	0.50375	0.075	7.97325	MHZ
21	0.6	1	0.92	1.69	1.158	0.62	1.5	0.50575	0.075	7.96375	MHZ
22	0.6	1.7	0.972	1.69	1.2	0.788	1.5	0.2125	0	8.9425	HHZ
23	0.8	1.7	1	1.71	0.855	1.33	1.5	0.250375	0.25	9.575375	HHZ
24	0.6	0.3	0.746	1.8	0.822	1.92	1.5	1.0185	0.25	8.9565	HHZ
25	0.2	0.3	0.816	1.8	0.8085	1.71	1.5	0.946	0.25	8.3305	HHZ
26	0.2	0.3	0.81	1.4	0.7725	1.466	1.5	0.9475	0.25	7.646	MHZ
27	0.2	0.3	0.8	1.8	0.638	2	1.5	1.05	0.25	8.538	HHZ
28	0.2	0.6	0.938	1.8	0.8375	1.88	1.5	0.761625	0.25	8.767125	HHZ
29	0.6	0.6	0.934	1.8	1.142	0.28	1.5	0.762375	0.075	7.693375	MHZ

30	0.6	0.6	0.926	1.8	1.23	0.366	1.5	0.763875	0.075	7.860875	MHZ
31	0.2	0.3	0.876	1.8	0.9685	0.132	1.5	1.031	0.075	6.8825	MHZ
32	0.6	0.6	0.84	1.8	1.204	0.124	1.5	0.78	0.075	7.523	MHZ
33	0.2	0.6	1	1.87	1.2165	0.27	1.5	0.6375	0.075	7.369	MHZ
34	0.2	0.3	0.82	1.8	1.3785	0.013	1.5	1.045	0.075	7.1315	MHZ
35	0.2	0.6	0.88	1.8	0.8145	1	1.5	0.7725	0	7.567	MHZ
36	0.2	0.3	0.902	1.8	1.1325	0.886	1.5	0.9245	0.075	7.72	MHZ
37	0.2	0.3	0.83	1.86		0.76	1.5	0.867	0	6.317	MHZ
38	1	2	0.845	2.485	0.735	2	1.5	0.128	0.075	10.768	HHZ
39	1	1	0.474	2.4735	1.08	2	1.5	0.64675	0.1875	10.36175	HHZ
40	1	2	0.728	2.455	0.714	1.94	1.5	0.12805	0.1125	10.57755	HHZ
41	1	0.3	0.3	1.4	0.47	1.35	1.5	1.253	0.25	7.823	MHZ
42	1	1	0.809	2.0795	1.1345	1.205	1.5	0.58575	0.1875	9.50125	HHZ
43	1	1	0.645	1.8595	1.064	1.84	1.5	0.57075	0	9.47925	HHZ
44	1	1.7	0.545	1.9155	0.602	2	1.5	0.323875	1	10.586375	HHZ
45	1	2	0.775	2.47	1.077	2	1.5	0.12755	1	12.11125	VHHZ
46	1	1.7	0.7	2.44	1.22	2	1.5	0.32925	1.1125	12.03875	VHHZ
47	1	1.7	0.815	2.47	1.087	2	1.5	0.2925	0.1125	12.004875	VHHZ
48	1	0.6	0.923	2.47	0.672	1.68	1.5	0.83325	0.075	9.75325	HHZ
49	1	1	0.845	2.451	0.817	1.84	1.5	0.6405	0	10.0935	HHZ
50	1	1.7	1	2.35	0.816	2	1.5	0.2955	0.15	10.8115	HHZ
51	1	2	0.712	1.95	0.725	2	1.5	0.13155	0.075	10.09355	HHZ
52	1	2	0.685	1.801	0.713	1.93	1.5	0.12815	0.075	9.83215	HHZ
53	1	2	0.66	1.804	0.751	1.93	1.5	0.1284	0.075	9.8484	HHZ
54	1	1	0.745	2.45	0.592	2	1.5	0.6465	0	9.9335	HHZ
55	0.8	0.3	1	1.8	0.4	2	1.5	1.2	0.15	9.15	HHZ
56	1	2	0.61	2.4	0.773	2	1.5	0.1204	0.1125	10.5159	HHZ
57	1	1.7	0.79	1.966	0.848	1.57	1.5	0.31775	0.1125	9.80425	HHZ
58	0.6	0.3	0.3	2.04	0.502	1	1.5	1.1	0.1875	7.5295	HHZ
59	0.6	0.3	0.5	2.44	0.825	2	1.5	1.2	1	10.365	VHHZ
60	0.2	0.6	0.5	2.44	0.487	2	1.5	0.9375	0.1125	8.777	HHZ
61	0.8	0.6	0.5	1.8	0.53	2	1.5	1.0065	0.1125	8.849	HHZ

ANNEXURE

Annex B Rating assigned for structural discontinuities of individual facets.

A	Relationship between dip of discontinuities and inclination of the slope
B	Parallelism between discontinuities dip direction and slope inclination
C	Dip of discontinuities
D	Soil cover depth
E	Structural discontinuities and rock mass condition
F	Continuity
G	Separation
H	Roughness
I	Infiling
J	Weathering

Facet	A	B	C	D	E	F	G	H	I	J	Total
1	0.5	0.4	0.4	0.5	0.25	0.02	0.15	0.07	0.07	0.1	2.46
2	0.1	0.15	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.1	1.84
3	0.3	0.15	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.1	2.04
4	0.2	0.1	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.86
5	0.1	0.1	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.76
6	0.1	0.1	0.5	0.5	0.25	0.02	0.12	0.03	0.12	0.07	1.81
7	0.1	0.1	0.4	0.5	0.25	0.02	0.12	0.03	0.12	0.07	1.71
8	0.5	0.4	0.4	0.5	0.25	0.02	0.15	0.07	0.07	0.1	2.46
9	0.1	0.1	0.5	0.5	0.25	0.02	0.15	0.03	0.12	0.1	1.87
10	0.1	0.1	0.5	0.5	0.25	0.02	0.15	0.03	0.12	0.1	1.87
11	0.1	0.1	0.5	0.5	0.25	0.02	0.15	0.03	0.12	0.1	1.87
12	0.1	0.1	0.5	0.5	0.2	0.02	0.15	0.03	0.12	0.1	1.82
13				1.4							1.4
14	0.1	0.1	0.5	0.5	0.2	0.02	0.07	0.03	0.02	0.07	1.61
15	0.1	0.1	0.5	0.5	0.2	0.02	0.07	0.03	0.02	0.07	1.61
16	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
17	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
18	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
19	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
20	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
21	0.1	0.1	0.4	0.5	0.2	0.02	0.15	0.03	0.12	0.07	1.69
22	0.1	0.1	0.4	0.5	0.2	0.02	0.15	0.03	0.12	0.07	1.69
23	0.1	0.1	0.5	0.5	0.25	0.02	0.12	0.03	0.02	0.07	1.71
24				1.8							1.8
25				1.8							1.8
26				1.4							1.4
27				1.8							1.8

28				1.8							1.8
29				1.8							1.8
30				1.8							1.8
31				1.8							1.8
32				1.8							1.8
33	0.1	0.1	0.5	0.5	0.25	0.02	0.15	0.03	0.12	0.1	1.87
34				1.4							1.4
35				1.4							1.4
36				1.4							1.4
37	0.2	0.1	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.86
38	0.4	0.4	0.4	0.5	0.225	0.04	0.15	0.15	0.12	0.1	2.485
39	0.4	0.4	0.4	0.5	0.244	0.04	0.12	0.15	0.12	0.1	2.4735
40	0.4	0.4	0.4	0.5	0.225	0.04	0.12	0.15	0.12	0.1	2.455
41				1.4							1.4
42	0.2	0.15	0.4	0.5	0.24	0.1	0.12	0.15	0.12	0.1	2.0795
43	0.1	0.15	0.4	0.5	0.24	0.1	0.12	0.03	0.12	0.1	1.8595
44	0.1	0.1	0.5	0.5	0.246	0.1	0.12	0.03	0.12	0.1	1.9155
45	0.5	0.2	0.4	0.5	0.25	0.1	0.15	0.15	0.12	0.1	2.47
46	0.5	0.2	0.4	0.5	0.25	0.1	0.15	0.15	0.12	0.1	2.47
47	0.5	0.2	0.4	0.5	0.25	0.1	0.15	0.15	0.12	0.1	2.47
48	0.5	0.2	0.4	0.5	0.2	0.15	0.15	0.15	0.12	0.1	2.47
49	0.5	0.4	0.25	0.5	0.231	0.15	0.15	0.15	0.02	0.1	2.451
50	0.5	0.1	0.5	0.5	0.25	0.1	0.15	0.03	0.12	0.1	2.35
51	0.1	0.1	0.5	0.5	0.25	0.1	0.15	0.03	0.12	0.1	1.95
52	0.1	0.1	0.5	0.5	0.231	0.1	0.12	0.03	0.02	0.1	1.801
53	0.1	0.1	0.5	0.5	0.234	0.1	0.12	0.03	0.02	0.1	1.804
54	0.5	0.5	0.25	0.5	0.25	0.15	0.15	0.03	0.02	0.1	2.45
55				1.8							1.8
56	0.5	0.5	0.25	0.5	0.2	0.15	0.15	0.03	0.02	0.1	2.4
57	0.1	0.5	0.25	0.5	0.246	0.1	0.12	0.03	0.02	0.1	1.966
58	0.5	0.1	0.4	0.5	0.25	0.02	0.12	0.03	0.02	0.1	2.04
59	0.4	0.1	0.4	1	0.25	0.02	0.12	0.03	0.02	0.1	2.44
60	0.4	0.1	0.4	1	0.25	0.02	0.12	0.03	0.02	0.1	2.44
61				1.8							1.8

Annex C Mersa Monthly Precipitation in mm (2000 – 2010).

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	57.5	49.7	12.2	258.2	386.1	106.3	116	36.5	38.7	1061.4
2001	2	18	206	3	80.5	24.8	303.3		124.5	25	2.4	5.5	795
2002	129.6	0	40.2	59.8	5.9	3.5	227.8	253.7	87.6	0	0	104.7	912.8
2003	43.4	18.1	43.6	167.8	0	40	121.8	284.9	124.2	1.8	8.2	45	898.8
2004	56.7	27.9	68.7	152.2	2.7	17	190	155.5	0.6	36.5	68.4	19.9	796.1
2005	0	0	54.5	84.3	143.2	27.8	214.1	322	32.6	18	0	0	896.5
2006	0	1.1	279.5	137	41.1	23.7	158.7	327.8	109.6	89.3	12.4	11.1	1191.3
2007	18	68.5	35.8	97.2	44.1	33.1	336.2	255.3	88.8	30.6	4.5	0	1012.1
2008	43.2	0	0	42.8	33.7	22.6	200.8	221.1	115.3	40.1	43.3	0	762.9
2009	35.1	6.4	52.7	137.6	3.2	9.5	233.8	268.5	0.8	28.8	3.8	127.8	908
2010	0		85.4	75.7	148.2	5.2	324.6	546.9					1186

Annex D Wurgessa Monthly Precipitation in mm (200 – 2003, & incomplete data of 2004, 2005, and 2010)

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	12.8	120.8	111.1	2.8	357.2	374.9	106	80.9	40.1	135.2	1341
2001	19.2	30.9	217.2	16	56.9	51.6	404.1	381.6	244	39.2	1.1	0	1462
2002	173.6	5.6	88.2	125	8.5	0.8	269.8	248.8	145	20.3	0	117	1203
2003	98.4	44.9	62.8	146.7	0	0	0	151.9	116	0	10.1	2.5	632.8
2004							32.3	203.7					
2005							312.9	276.9	41.6	35.2	64.6	0	
2010				117.1	75.4	0	451.5	587.2					

Annex E Wuchalle Monthly Precipitation in mm (2000 – 2009)

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	12.8	87.5	129.8	14	344.6	330.3	108.8	77.6	60.9	175.1	1341.4
2001	21.8	43.7	200.2	13.8	43.4	53.7	356.3	347.6	235.9	27.7	2.3	1.2	1347.6
2002	137.8	9.5	50	85.5	8.5	1	301	272.6	107.4	16.5	0	104.7	1094.5
2003	136.1	35.2	44.8	168.6	6.9	59.4	199.1	307.9	144.1	1.7	23.3	51.9	1179
2004	6.3	70.5	77.4	188.2	23	45.6	199	270.6	86.9	51.8	74.3	76.9	1170.5
2005	24.4	0	86.4	134.2	134.5	24.7	328.9	313.9	44.5	20.9	30.4	0	1142.8
2006	0	2.9	210.6	155.3	42.3	5.8	193	296.7	121.1	50.6	17.6		1095.9
2007	53.1	60.5	58.7	106.5	7.9	45.8	440.8	283	143.4	28.8	3	0	1231.5
2008	13.2	1.3	0	22.8	44.8	35.2	224.3	256.9	162.6	96.1	82		939.2
2009						33.9	212.7	268.6	30.5	10.8	47.7	70.4	674.6
2010			97.7	120.8									218.5

Annex F Dailly Rainfall (mm) of Mersa and Wurgessa for the month of April, May, June, July and August 2010.

Date	April		May		June		July		August	
	Mersa	Wurgessa	Mersa	Wurgessa	Mersa	Wurgessa	Mersa	Wurgessa	Mersa	Wurgessa
1	0.0	0.0	8.6	0.0	0.0	0.0	0.0	0.0	4.3	26.1
2	0.0	0.0	12.3	0.0	0.0	0.0	0.0	0.0	13.5	19.1
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.5	15.9
4	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	20.3	0.0
5	0.0	0.0	22.6	25.8	0.0	0.0	0.0	0.0	18.3	0.0
6	0.0	13.3	22.5	0.0	0.0	0.0	0.0	0.0	18.3	0.0
7	5.7	17.5	11.0	5.9	0.0	0.0	0.0	0.0	6.8	Tr
8	0.4	0.0	6.6	0.0	0.0	0.0	0.0	0.0	6.5	35.5
9	0.4	0.0	0.0	1.2	0.0	0.0	0.0	Tr	0.0	32.8
10	0.0	0.0	0.8	3.2	0.0	0.0	0.0	15.5	0.0	4.2
11	0.0	7.0	7.4	4.9	0.0	0.0	0.0	4.0	0.0	3.8
12	5.4	16.5	11.0	0.0	0.0	0.0	37.5	1.5	27.7	60.1
13	15.6	2.6	0.2	0.0	0.0	0.0	2.7	44.1	2.3	26.3
14	6.2	4.0	8.9	12.0	0.0	0.0	0.0	4.3	10.2	41.9
15	13.3	3.0	0.0	0.0	0.0	0.0	5.5	41.9	44.2	0.0
16	2.3	0.0	0.0	0.0	0.0	0.0	0.0	8.8	42.0	32.0
17	0.0	0.0	0.0	0.0	0.0	0.0	4.0	28.8	0.1	5.4
18	0.0	0.0	0.0	0.0	0.0	0.0	10.8	46.3	27.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	29.0	37.5	28.0	13.5
20	0.0	0.0	0.0	0.0	0.0	0.0	82.0	15.3	36.0	52.2
21	0.0	6.4	0.0	0.0	0.0	0.0	31.0	28.0	0.0	21.0
22	0.0	34.2	0.0	0.0	0.0	0.0	7.5	6.0	16.4	47.5
23	0.0	Tr	0.0	0.0	0.0	0.0	20.0	33.5	26.2	70.0
24	4.4	2.5	0.0	0.0	5.2	0.0	20.9	30.1	15.0	Tr
25	4.4	0.0	0.0	0.0	0.0	0.0	13.5	9.0	26.0	19.8
26	0.6	0.0	0.0	1.1	0.0	0.0	23.0	20.0	89.0	9. 8
27	0.0	0.0	0.0	0.0	0.0	0.0	21.3	7.1	0.0	1.2
28	0.0	10.1	36.3	18.1	0.0	0.0	9.4	32.9	19.5	37.0
29	17.0	0.0	0.0	0.0	0.0	0.0	5.5	25.0	8.2	12.1
30	0.0	0.0	0.0	0.0	0.0	0.0	1.0	19.3	16.0	0.0
31			0.0	0.0				41.0	9.5	0.0
Total	**75.7**	**117.1**	**148.2**	**75.4**	**5.2**	**0.0**	**324.6**	**451.5**	**546.9**	**587.2**

Annex G Sirinka – Monthly Precipitatation (mm) data (1966 – 2005)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1966	x	x	x	x	x	x	x	255.3	104.3	62.3	0.0	0.2	422.1
1967	0.0	1.0	19.0	125.1	188.3	23.0	313.6	224.6	47.4	74.4	152.6	1.0	1170.0
1968	11.0	38.8	36.4	109.0	53.5	34.0	243.0	147.0	81.0	61.0	55.0	23.0	892.7
1969	185.0	290.0	277.0	190.0	62.0	18.0	301.0	421.0	40.0	5.0	3.0	0.0	1792.0
1970	163.0	50.0	x	x	x	x	x	x	x	x	x	x	213.0
1980	x	x	x	x	x	x	95.5	242.2	x	63.2	0.0	4.0	404.9
1981	0.0	15.8	226.5	83.6	11.2	135.9	222.0	245.8	47.6	4.0	0.0	0.9	993.3
1982	52.9	165.9	89.2	54.7	44.5	0.0	78.3	178.6	78.8	147.6	60.8	17.0	968.3
1983	147.6	59.1	28.4	71.8	220.2	51.2	x	154.4	24.0	28.2	26.8	0.2	811.9
1984	x	24.7	26.2	53.2	147.6	10.5	25.7	45.5	68.8	0.0	14.8	65.8	482.8
1985	9.8	3.5	103.0	120.4	96.5	0.0	145.2	212.2	125.3	3.2	0.0	48.2	867.3
1986	0.0	94.8	48.9	181.7	0.0	75.2	130.1	178.2	177.7	7.0	1.2	66.7	961.5
1987	0.0	28.5	172.0	103.9	149.1	1.9	46.3	207.4	107.1	58.0	0.0	39.3	913.5
1988	21.4	208.5	5.8	155.1	12.2	11.0	299.2	250.2	110.4	30.7	0.0	0.5	1105.0
1989	15.2	68.0	173.4	133.0	64.4	7.6	132.5	x	92.4	x	x	x	686.5
1991	x	x	x	x	x	x	x	x	60.9	4.0	41.0	x	105.9
1992	75.3	75.2	52.6	17.8	34.2	0.0	159.4	281.5	86.8	48.9	59.0	211.1	1101.8
1993	29.4	87.3	29.2	152.4	64.0	0.0	152.2	134.2	140.5	93.3	0.0	11.4	893.9
1994	0.0	0.0	74.6	52.2	37.9	0.0	295.5	413.2	115.0	1.7	44.4	5.8	1040.3
1995	0.0	125.8	62.0	271.2	32.1	44.3	268.8	285.0	69.9	24.6	0.0	108.2	1291.9
1996	78.6	1.7	157.7	115.9	199.0	72.3	113.0	263.8	60.3	37.1	51.5	6.3	1157.2
1997	32.5	3.8	217.0	84.8	71.5	99.2	206.9	184.3	96.3	320.5	106.0	0.1	1422.9
1998	115.2	118.9	114.8	63.5	36.1	0.0	367.5	334.4	73.5	57.0	0.0	0.0	1280.9
1999	47.4	0.0	32.0	46.0	16.8	15.7	375.0	394.8	97.2	164.4	14.5	4.0	1207.8
2000	0.3	0.0	15.9	69.7	33.9	35.2	338.3	338.5	85.2	136.8	49.7	115.7	1219.2
2001	6.9	21.7	237.6	10.4	43.5	32.8	274.7	247.8	91.9	28.2	4.9	6.2	1006.6
2002	87.6	6.2	47.0	71.6	0.6	7.9	229.5	295.3	134.0	17.7	0.0	94.7	992.1
2003	65.2	60.4	68.4	115.5	4.9	36.9	166.6	274.2	103.2	0.0	10.7	48.3	954.3
2004	22.1	11	37.9	119.4	4.2	36.5	166.4	225.6	68.7	58.5	63.5	17.9	831.7
2005	32	7.8	99	116.7	114.6	26.7	283.8	323.3	55.6	36.3	71.1		1166.9

Annex H Maximum Temperature (Mersa)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	27.6	28.1	29.6	30.3	32.3	34.6	31.6	29.7	29.5	27.6	26.8	26.3
2001	23.8	26.4	26.6	31	32.2	32.7	31.2	29.9	29.7	28.8	27	27.1
2002	24.5	27.1	29.6	30.6	33.5	34.2	32.4	29.9	27	30.2	28.4	
2003			28.8	30.2	32.1	33.5	31.5	28.8	29.6	27.9	27.6	26.2
2004	26.3	26.7	28.7	29	33.2	34.8	30.7	30.4	32.4	30.8	26.8	25.9
2005			28.4	29.7	30	33.1	30.9	29.7	29.8	28.2		
2006	26.7	25.2	28.4	27.2	31	32.2	30.8	30	28	28.6	26	26
2007	24.3	24.4	29.6	29.3	33.1	32	29.4	29.2	28	28.4	27.1	26.7
2008	26.8	24.7	30.4	30	32.6	32	32	29	28	29	27	27
2009	27.6	25.3	30.4	29.4	33.4	34	30.2	30	28.7	29	27.5	26

Annex I Minimum Temperature (Mersa)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	5.4	5.4	8.7	12.2	13	15.3	15.5	12.5	13.6	12.2	11.7	7.3
2001	6.4	5.8	6	12.6	13.5		15.2	10.9	10.8	10.8	7.7	6.6
2002	11.8	12.4	11.6	12.6	13.1	12.7	12.5	9.3	8.5	10.3	9.4	11.2
2003	12.2	12.6	13.2	14.5	14.2	13.9	14.6	14.7	15	10.6	9.7	8.8
2004	11.5	10.9	11.2	14.7	13.9	14.4	10.1	10.5	10.5	9.2	9.5	10.9
2005			14.1	14.6	15.2	14.8	16.4	15.9	15	11.3		
2006	10.4	12	14.13	13.65	13.9	14.16	16.13	15.9	14.06	12.48	11.26	13.38
2007	12.94	12.31	12.31	14.66	15.47	15.95	16.24	15.88	14.35	11.18	9.16	7.06
2008	10.56	8.63	9.26	14.64	15.84	14.86	16.51	15.73	14.1	12.09	9.55	8.99
2009	12.44	9.55	13.39	14.46	15.86	15.56	16.21	16.03	14.97	12.78	9.48	13.41

Annex J Percentage Area coverage of slope material type for individual facets.

Facets	Very weak rock	Alluvial deposits	Poorly graded colluvial	Well graded colluvial	Total
Max	1.00	0.8	0.5	0.3	1.00
1	100% = 1.00				1.00
2	90% = 0.9	10% = 0.08			0.98
3	63% = 0.63	37% = 0.296			0.926
4	85% = 0.85	15% = 0.12			0.97
5	87% = 0.87	13% = 0.104			0.974
6	43% = 0.43	57% = 0.456			0.886
7	50% = 0.5	50% = 0.4			0.9
8	78% = 0.78	22% = 0.176			0.966
9	83 % = 0.83	17% = 0.136			0.94
10	100% = 1.00				1.00
11	100% = 1				1
12	100% = 1				1
13	42% = 0.42	58% = 0.464			0.884
14	100% = 1.00				1.00
15	87% = 0.87	13% = 0.104			0.974
16	94% = 0.94	6% = 0.048			0.988
17	100% = 1.00				1.00
18	92% = 0.92	8% = 0.064			0.984
19	100% = 1.00				1.00
20	85% = 0.85	15% = 0.12			0.97
21	60% = 0.6	40% = 0.32			0.92
22	100% = 1.00				1.00
23	100% = 1.00				1.00
24	13% = 0.13	77% = 0.616			0.746
25	8% = 0.08	92% = 0.736			0.816
26	5% = 0.05	95% = 0.76			0.81
27	100% = 0.8				0.8
28	69% = 0.69	31% = 0.248			0.938
29	67%=0.67	33%=0.246			0.94
30	63%= 0.63	37%=0.296			0.926
31	38%=0.38	62%=0.496			0.876
32	20%=0.2	80%=0.64			0.84
33	100% = 1				1.00
34	10%=0.1	90%=0.72			0.82
35	40% =0.4	60%=0.48			0.88
36	51%=0.51	49%=0.392			0.902
37	66%= 0.66	34%=0.34			0.83
38	49% = 0.49		51% = 0.255		0.745
39	13% = 0.13		61% = 0.305	26% = 0.078	0.513
40	50% = 0.5		39% = 0.195	11 % = 0.033	0.728
41			6% = 0.03	94% = 0.282	0.312
42	65% = 0.65		27% = 0.135	8%=0.024	0.809
43	37% = 0.37		43% = 0.215	20% = 0.06	0.645
44	9% = 0.09		91 % = 0.455	-	0.545
45	55 % = 0.55		45% =0.225		0.775
46	40 % = 0.3		60% = 0.35		0.7
47	63% = 0.63		37% = 0.185		0.815
48	89% = 0.89			11% = 0.033	0.923
49	69% = 0.69		31% = 0.155		0.845
50	86% = 0.86		14% = 0.07		0.93
51	22% = 0.22	34%= 0.272	44% = 0.22		0.712
52	37% = 0.37		63% = 0.315		0.685
53	32% = 0.32		68% = 0.34		0.66
54	49% = 0.49		51% = 0.255		0.745
55	100% = 1.00				1.00
56	42% = 0.42		8% = 0.04	50% = 0.15	0.61
57	58% = 0.58		42% = 0.21		0.79
58				100%	0.3
59				100%	0.5
60				100%	0.5
61			16%=0.08	84%=0.252	0.332

Annex K Percentage Area coverage of Land use land cover for individual facets.

Facets	Barren land	Sparsely vegetated	Moderately vegetated	Thickly vegetated forest area	Cultivated land with populated area	Total
Max	1.5	1.2	0.75	0.4	0.4	1.5
1	18% = 0.27	71% = 0.852	11% = 0.0825			1.2045
2		82% = 0.984	18% = 0.135			1.119
3		99% = 1.188	2% = 0.015			1.203
4		75% = 0.9	25% = 0.1875			1.0875
5		21% = 0.252	68% = 0.51	11% = 0.044		0.806
6	4% = 0.06	20% = 0.24	75% = 0.5625		1% = 0.004	0.8665
7		27% = 0.324	70% = 0.525		3% = 0.012	0.861
8	10% = 0.15	90% =1.08				1.23
9	7% = 0.315	83% = 0.996	10% = 0.075			1.386
10	34% = 0.51	66% = 0.792				1.302
11	25% = 0.375	58% = 0.696	17% = 0.1275			1.1985
12	6% = 0.09	86% = 1.032	8% =0.06			1.182
13		9% = 0.108	80% = 0.6		11% = 0.044	0.752
14		15% = 0.18	80% = 0.6		5% = 0.0375	0.8175
15		18% = 0.216	65% = 0.4875		17% = 0.1275	0.831
16		39% = 0.468	61% = 0.4575			0.9255
17		83% = 0.996	17% = 0.1275			1.1235
18		40% = 0.48	60% = 0.45			0.93
19	6% = 0.09	28% = 0.336	56% = 0.42		10% = 0.04	0.886
20	13% = 0.195	70% = 0.84	17% = 0.1275			1.1625
21	19% = 0.285	59% = 0.708	20% = 0.15		2% = 0.015	1.158
22		100% = 1.2				1.2
23		28% = 0.336	66% = 0.495		6% = 0.024	0.855
24		16% = 0.192	34% = 0.255		50% = 0.375	0.822
25		13% = 0.156	32% = 0.24		55% = 0.4125	0.8085
26		5% = 0.06	49% = 0.3675		46% =0.345	0.7725
27			68%=0.51		32%=0.128	0.638
28	4%=0.06	26%=0.312	53%=0.3975		17%=0.068	0.8375
29	35%=0.525	35%=0.42	22%=0.165		8%=0.032	1.142
30	28%=0.42	60%=0.72	12%=0.09			1.23
31	30%=0.45	4%=0.048	59%=0.4425		7%=0.028	0.9685
32	39%=0.585	39%=0.468	18%=0.135		4%=0.016	1.204
33	25%=0.375	62%=0.744	13%=0.0975			1.2165
34	82%=1.23	3%=0.036	15%=0.1125			1.3785
35	72%=1.08	26%=0.312			2%=0.008	1.4
36		19%=0.228	75%=0.5625		6%=0.024	0.8145
37		85%=1.02	15%=0.1125			1.1325
38	5% = 0.075	35% = 0.42			60% = 0.24	0.735
39	16% = 0.24	63% = 0.756			21% = 0.084	1.08
40	6% = 0.09	31% = 0.372			63% = 0.252	0.714
41	2% = 0.03	6% = 0.072			92% = 0.368	0.47
42	12% = 0.18	74% = 0.888	3% = 0.0225	3% = 0.012	8% = 0.032	1.1345
43	24% = 0.36	50% = 0.6		6% = 0.024	20% = 0.08	1.064
44	6% = 0.09	17% = 0.204		40% = 0.16	37% = 0.148	0.602
45	10% = 0.15	63% = 0.756	23% = 0.1725	1% = 0.004	3% = 0.012	1.2385
46	25% =0.375	70% = 0.84			5% = 0.02	1.235
47	16% = 0.24	67% = 0.804			17% = 0.068	1.112
48		34% = 0.408			66% = 0.264	0.672
49		25% = 0.3	62% = 0.465	13% = 0.052		0.817
50	8% = 0.12	41% = 0.492			51% = 0.204	0.816
51	7% = 0.105	31% = 0.372		2% = 0.008	60% = 0.24	0.725
52	3% = 0.045	35% = 0.42		34% = 0.136	28% = 0.112	0.713
53	5% = 0.075	37% = 0.444		25% = 0.1	33% = 0.132	0.751
54		17% = 0.204	16% = 0.12	67% = 0.268		0.592
55					100% = 0.4	0.4
56		44% = 0.528	6% = 0.045	11% = 0.044	39% = 0.156	0.773
57		56% = 0.672		8% = 0.032	36% = 0.144	0.848
58	2%=0.03	10%=0.12			88%=0.352	0.502
59	6%=0.09	45%=0.54			49%=0.195	0.825
60	5%=0.075	4%=0.048			91%=0.364	0.487
61	6%- 0.09	8%=0.096			86%=0.344	0.53

Annex L Percentage Area coverage of Ground water for individual facets.

Facets	Flowing	Dripping	Wet	Damp	Dry	Total
Max	2.0	1.5	1	0.6	0	2.00
1		100% = 1.5				1.5
2		100%=1.5				1.5
3		100%=1.5				1.5
4			79% = 0.79	23% = 0.138		0.928
5		22% = 0.33		78% = 0.468		0.798
6		47% = 0.705		53% = 0.318		1.023
7			56 % = 0.56	44% = 0.264		0.824
8		100 % = 1.5				1.5
9		52%=			48%	0.78
10		100%=1.5				1.5
11				100% = 0.6		0.6
12		24%=0.36	34%=0.34	42%=0.252		0.952
13	51% = 1.02		11%=0.11	38% = 0.228		1.358
14			100% = 1			0.6
15	34% = 0.68		66% = 0.66			1.34
16				100 % = 0.6		0.6
17				100 % = 0.6		0.6
18				100 % = 0.6		0.6
19				100 % = 0.6		0.6
20				67% = 0.402		0.402
21			29%=0.29	50% = 0.3		0.59
22			47% = 0.47	53% = 0.318		0.788
23	33 % = 0.66		67%= 0.67			1.33
24	92% = 1.84		8 % = 0.08			1.92
25	89% = 1.6		11% = 0.11			1.71
26	57% = 1.14		17%=0.17	26% = 0.156		1.466
27	100%=2.00					2.00
28	88%=1.76		12%=0.12			1.88
29				47%=0.28		0.28
30				61%=0.366		0.366
31				22%=0.132		0.132
32	2%=0.04			14%=0.084		0.124
33		18%=0.27				0.27
34	1.3%=0.013					0.013
35			100=1			1.00
36	6%=0.12	10%=0.15	28%=0.28	56%=0.336		0.886
37			40%=0.4	60%=0.36		0.76
38	60 % = 1.2			40%-0.4		1.6
39			100% = 1			1.00
40	94% = 1.88		6% = 0.06			1.94
41	35% = 0.7			65%=0.65		1.35
42	5% = 0.1	31%=0.465	64% = 0.64			1.205
43	84% = 1.68		16% = 0.16			1.84
44	100% = 2.00					2.00
45	25 % = 0.5	75% = 1.125				1.625
46	100%					2.00
47	100= 2.00					2.00
48	36% = 0.72	64% = 0.96				1.68
49	68% = 1.36	32% = 0.48				1.84
50	100% = 2.00					2.00
51	100% = 2.00					2.00
52	93% = 1.86		7% = 0.07			1.93
53	93% = 1.86		7% = 0.07			1.93
54	100% = 2.00					2.00
55	100% = 2.00					2.00
56	100% = 2.00					2.00
57	57% = 1.14		43% = 0.43			1.57
58			100%			1.00
59	100%=2.00					2.00
60	100%=2.00					2.00
61	100%=2.00					2.00

Annex M Percentage of area coverage for slope material as rain fall parameter.

Facets	Soil mass	Disintegrated	Blocky/Disturbed	Total
Max	0.25	0.2	0.15	
1		100% = 0.25		0.25
2		100% = 0.2		0.2
3		100% = 0.2		0.2
4	6% = 0.015	94% = 0.188		0.202
5	13% = 0.0325	87% = 0.174		0.2065
6	57% = 0.1425	43% = 0.086		0.2285
7	50% = 0.125	50% = 0.1		0.225
8		100% = 0.2		0.2
9	17% = 0.045	83 % = 0.166		0.2085
10		100% = 1.00		0.2
11		100% = 0.2		0.2
12		100% = 0.2		0.2
13	58% = 0.145	42% = 0.084		0.229
14		100% = 1.00		0.2
15	13% = 0.0325	87% = 0.174		0.2065
16	6% = 0.015	94% = 0.188		0.203
17		100% = 0.2		0.2
18	8% = 0.02	92% = 0.184		0.204
19		100% = 0.2		0.2
20	15% = 0.0375	85% = 0.17		0.2075
21	23% = 0.0575	77% = 0.154		0.2115
22		100% = 0.2		0.2
23	3% = 0.0075	97% = 0.194		0.2015
24	77% = 0.1925	13% = 0.026		0.2185
25	92% = 0.23	8% = 0.016		0.246
26	95% = 0.2375	5% = 0.01		0.2475
27	100%=0.25			0.25
28	31%=0.0775	69%=0.138		0.2155
29	33%=0.0825	67%=0.134		0.2165
30	37 %=0.0925	63%=0.126		0.2185
31	62 %=0.155	38%=0.076		0.231
32	80%=0.2	20%=0.04		0.24
33		100%=0.2		0.2
34	90%=0.225	10%=0.02		0.245
35	60%=0.15	40%=0.08		0.23
36	49%=0.1225	51%=0.102		0.2245
37	34%=0.085	66%=0.132		0.217
38	9% = 0.0225	42% = 0.084	49% = 0.0735	0.18
39	13% = 0.0325	61% = 0.122	13% = 0.039	0.1935
40	11% = 0.0275	39% = 0.078	50% = 0.0275	0.1805
41	94 % = 0.235	6% = 0.012		0.247
42	8% = 0.02	27%= 0.054	65% = 0.0975	0.1715
43	20% = 0.05	43% = 0.086	37% = 0.0555	0.1915
44		91% = 0.182	9% = 0.0135	0.1955
45		55 % = 0.11	45 % = 0.0675	0.1775
46		70% = 0.14	30% = 0.045	0.185
47		63% = 0.126	37% = 0.0555	0.1815
48	11% = 0.0275		89% = 0.1335	0.161
49		62% = 0.124	38% = 0.057	0.181
50		64% = 0.128	36% = 0.054	0.182
51	38% = 0.095	55% = 0.11	7% = 0.0105	0.2155
52		63% = 0.126	37% = 0.0555	0.1815
53		68% = 0.136	32% = 0.048	0.184
54	2% = 0.005	82% = 0.164	16% = 0.024	0.193
55	100% = 0.25			0.25
56	50% = 0.125	8% = 0.016	42% = 0.063	0.204
57		42% = 0.084	58% = 0.087	0.171
58	100%=0.25			0.25
59	100%=0.25			0.25
60	100%=0.25			0.25
61	84%=0.21	16%=0.032		0.242

Annex N Soil grain size analysis Laboratory anaysed data


CONSTRUCTION DESIGN SHARE SCo. OF/CDSCo./123
Grain Size Distribution — Page 1 of 1
Sample ID: Ge-6/03/1550
Project :- Land Slide Study On Murgessa And Mersa
Client :- Jemal Ibrahim
Location:- North wollo
Description:- Dark Gray Cilty Sand With Some Clay
Specific gravity 2.48

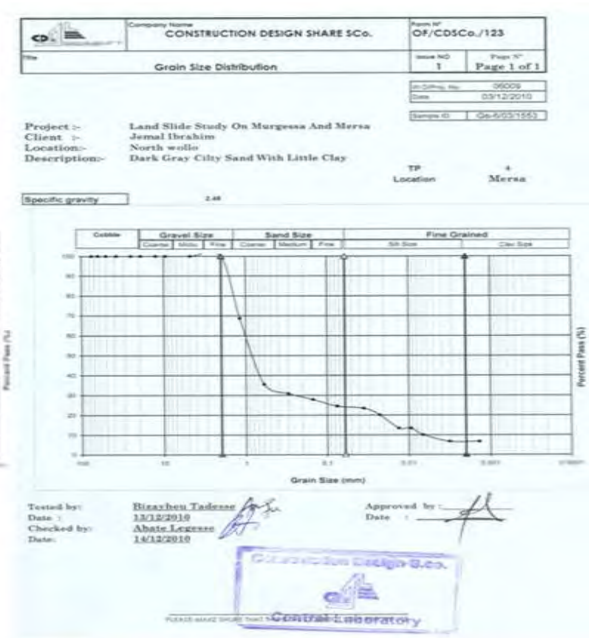
Tested by: Bizayhen Tadesse — Date: 13/12/2010
Checked by: Abate Legesse — Date: 14/12/2010
Approved by:
Construction Design S.co. Central Laboratory


CONSTRUCTION DESIGN SHARE SCo. OF/CDSCo./123
Grain Size Distribution — Issue NO 1 — Page 1 of 1
W.O/Proj. No. 06009 — Date 03/12/2010
Sample ID Ge-6/03/1551
Project :- Land Slide Study On Murgessa And Mersa
Client :- Jemal Ibrahim
Location:- North wollo
Description:- Dark Gray Cilty Sand With Some Clay
TP 2 — Location Murgessa
Specific gravity 2.48

Tested by: Bizayheu Tadesse — Date: 13/12/2010
Checked by: Abate Legesse — Date: 14/12/2010
Approved by: — Date:
Construction Design S.co. Central Laboratory


CONSTRUCTION DESIGN SHARE SCo. OF/CDSCo./123
Grain Size Distribution — Page 1 of 1
Sample ID Ge-6/03/1552
Project :- Land Slide Study On Murgessa And Mersa
Client :- Jemal Ibrahim
Location:- North wollo
Description:- Dark Gray Cilty Sand With Little Clay
TP 3 — Location Mersa
Specific gravity 2.48

Tested by: Bizayhen Tadesse — Date: 13/12/2010
Checked by: Abate Legesse — Date: 14/12/2010
Approved by:
Construction Design S.co. Central Laboratory


CONSTRUCTION DESIGN SHARE SCo. OF/CDSCo./123
Grain Size Distribution — Issue NO 1 — Page 1 of 1
W.O/Proj. No. 06009 — Date 03/12/2010
Sample ID Ge-6/03/1553
Project :- Land Slide Study On Murgessa And Mersa
Client :- Jemal Ibrahim
Location:- North wollo
Description:- Dark Gray Cilty Sand With Little Clay
TP 4 — Location Mersa
Specific gravity 2.48

Tested by: Bizayheu Tadesse — Date: 13/12/2010
Checked by: Abate Legesse — Date: 14/12/2010
Approved by: — Date:
Construction Design S.co. Central Laboratory

Annex N Cont………..

Company Name: CONSTRUCTION DESIGN SHARE CO. | Form No: OF/CDSCo./117

Title: LABORATORY TEST RESULT | Issue NO: 1 | Page N°: Page 1 of 1

W.O.No 06009
Date :- 03/12/2010

Project :- Land Slide Study On Murgessa And Mersa
Client :- Jemal Ibrahim
Location :- North Wollo
Object :- Soil Samples

1.Soil Sample

N°	TP No	Location	Moisture content (%)	Natural Unit Weight Kg/M³	Atterberig Limits LL (%)	PL (%)	PI (%)	Shear Strength C KN/m²	Ø Degree
1	1	Ninber	11.19	1650	39.65	31.52	8.13	-	-
2	2	Murgessa	7.38	1592	40.19	30.45	9.74	8	30
3	3	Mersa	7.20	1630	36.45	29.60	6.85	-	-
4	4	Mersa	7.70	1508	35.46	29.52	5.94	6	31

Note
1. Four graphs for grain size distribution test result are drawn and attached here with
2. Two graphs for Direct shear test result are drawn and attached here with

Tested by :- Bizayehu Taddese
Date :- '14/12/2010
Checked by :- Abate Legesse
Date :- 16/12/2010

Approved by :-
Date :-

Construction Design S.C. Central Laboratory

PLEASE MAKE SURE THAT THIS IS THE CORRECT ISSUE BEFORE USE

Annex O Remedial measures (

1. MODIFICATION OF SLOPE GEOMETRY	3. RETAINING STRUCTURES
1.1. Removing material from the area driving the landslide (with possible substitution by lightweight fill) 1.2. Adding material to the area maintaining stability (counterweight berm or fill) 1.3. Reducing general slope angle	3.1. Gravity retaining walls 3.2. Crib-block walls 3.3. Gabion walls 3.4. Passive piles, piers and caissons 3.5. Cast-in situ reinforced concrete walls 3.6. Reinforced earth retaining structures with strip/ sheet - polymer/metallic reinforcement elements 3.7. Buttress counterforts of coarse-grained material (mechanical effect) 3.8. Retention nets for rock slope faces 3.9. Rockfall attenuation or stopping systems (rocktrap ditches, benches,fences and walls) 3.10. Protective rock/concrete blocks against erosion
2. DRAINAGE	4. INTERNAL SLOPE REINFORCEMENT
2.1. Surface drains to divert water from flowing onto the slide area (collecting ditches and pipes) 2.2. Shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthetics) 2.3. Buttress counterforts of coarse-grained materials (hydrological effect) 2.4. Vertical (small diameter) boreholes with pumping or self draining 2.5. Vertical (large diameter) wells with gravity draining 2.6. Subhorizontal or subvertical boreholes 2.7. Drainage tunnels, galleries or adits 2.8. Vacuum dewatering 2.9. Drainage by siphoning 2.10. Electroosmotic dewatering 2.11. Vegetation planting (hydrological effect)	4.1. Rock bolts 4.2. Micropiles 4.3. Soil nailing 4.4. Anchors (prestressed or not) 4.5. Grouting 4.6. Stone or lime/cement columns 4.7. Heat treatment 4.8. Freezing 4.9. Electroosmotic anchors 4.10. Vegetation planting (root strength mechanical effect)

Annex P Report on damages resulted from Rainfall of 06/11/2002 to 17/12/2002 E.C. Habru Wereda Environmental Protection and Land Administration office, North Wollo, ANRS.

በሐብሩ ወረዳ የተከሰተውን አደጋ ስለማወቅ፣

በሐብሩ ወረዳ ከ06/11/2002-17/12/2002 ድረስ የጣለው ዝናብ ያደረሰው ጉዳት እንደሚከተለው ነው፡-

- የጉዳቱ ሰለባ " የሆኑት 15 ቀበሌወች 018፣019፣05፣07፣09፣020፣011፣06፣014፣015፣010፣013፣ውርጌሣ 01 መርሣ ከተማ ናቸው፡፡
- ከባድ ጉዳት የደረሰባቸው 7 ቀበሌዎች 019፣012፣013፣ ውርጌሣ 01፣ መርሣ ከተማ 09 ናቸው፡፡

የጉዳዩተ ዝርዝር ሁኔታ፣

1. አደጋው በማሣ ላይ ያስከተለው ጉዳት

   የወረዳችን የመኽር መሬታችን 24253 ሄ/ር ሲሆን በአሁኑ ሰአት 23540 ሄ/ር መሬት በተለያዩ ዘሮች የተሸፈነ ቢሆንም በጐርፍ የታጠበ በደለልና በትላልቅ ድንጋይ የተሞላ ሲሆን በአብዛኛው በጐርፍ የተጠቃው የአገዳ ሰብል /ማሽላና በቆሎ/ በመሆኑና በወረዳችንም በሰፊው የሚመረተው ማሽላና በቆሎ በመሆኑ ለ2002 /2003 ምርት ዘመን ከፍተኛ የሆነ የምርት ማነስ እንደሚገጥመንና በአጠቃላይ የጉዳት መጠኑ በአማካኝ 79 በመቶ እንደሚሆን በመስክ አረጋግጠናል፡፡

2. አደጋው በእንስሣት ላይ ያስከተለው ጉዳት

   በጐርፍ ሁኔታ ከቀን ወደ ቀን እየጨመረ ጉዳቱም እንደዚሁ እየጨመረ ይገኛል፡፡ በአጠቃላይ በእንስሣት ላይ ያደረሰው ጉዳት ስናይ 12 በሬ 6 ላም 6 በግና 1 ፍየል በጐርፍ የተወሰዱ ናቸው ከዚሁ ጋር በተያያዘ በ018 ቀበሌ 4.5 ሄ/ር የግጦሽ መሬት ሙሉ ለሙሉ በመንሸራተት ከጥቅም ውጭ የሆነ ሲሆን እንደዚሁም ለአርሶአደሩ ለወደፊት ለእንስሣቶቹ ብሎ ያስቀመጠው መኖ /አገዳ/ በጐርፍ በመወሰድ በቀጣይም በወረዳችን የእንስሣት ግጦሽ ቦታና መኖ ችግር እንደሚገጥመን ይገመታል፡፡

3. አደጋው በሰው ህይወት ላይ ያስከተለው ጉዳት፣

   በአጠቃላይ በጐርፍ ምክንያት 18 የሚሆኑ ቤቶች የፈረሱ ሲሆን ጐርፍ ቤታቸው በመግባት የቤት ንብረታቸውንና የሚበሉትን ከጥቅም ውጭ ያደረገባቸው 592 አባወራወች ከቀያቸው የተፈናቀሉበት ሁኔታ ቢኖርም አርሶአደሩ የራሱ የሆነ በአደጋ ወቅት እራሱን የመቋቋሚያ መንገዶች ያሉት ሲሆን ከእነዚህም ውስጥ አደጋ ሲፈጠር ከዘመድ አዝማድ መጠጋት ቤት በመከራየት ት/ቤት ውስጥ

በማረፍ ችግሩን ለመወጣት ትግል እያደረገ ቢሆንም ችግሩ ከቀን ወደ ቀን በመባባሱ የችግሩ ተጠቂ ሆነዋል።

በ16/12/2002 ሌሊት የጣለው ዝናብ በመርሣ ከተማ እና በ013 ቀበሌ በሰው ህይወት ላይ ከፍተኛ ጉዳት ያደረሰበት ሁኔታ ነበር። ይህም በአካባቢው ያለው ተራራ በመንሸራተቱ ወደ ግለሰቦች ቤት በመግባትና ሙሉ በሙሉ ቤቶቹን በመዋጥ ጉዳት አድርሷል። በመርሣ ከተማ 14 ሰዎች የሞቱ ሲሆን በ013 ቀበሌ 5 ሰዎች እንዲሁም 021 ቀበሌ 1 ሰው የምተ ሲሆን በውርጌሣ 1 ሰው በአጠቃላይ በሁለት ሌሊት 21 ሰው በአሰቃቂ ሁኔታ የሞተበት ክስተት ነበር። በመርሣ ከተማ የሞቱን ሰዎች ለማዳን የኔዱ 24 ሰዎች ላይ ጉዳት የደረሰ ሲሆን 11 በከባድ ጉዳት ወልዲያ ሆስፒታል ሲገኙ ቀሪዎቹ 13 ሰዎች ቀላል ጉዳት የደረሰባቸው ናቸው

4. አደጋው በመሰረተ ልማት ላይ ያስከተለው ጉዳት፣

- የሃብሩ ወረዳ በመስኖ ልማት ሃብት ትልቅ ድርሻ ቢኖረውም የዘንድሮው ጉርፍ ብዙ ዘመናዊና ባህላዊ መስኖ አውታሮችን ያበላሸበት ሁኔታ አለ በአጠቃላይ በሰንጠረዥ እንደቀረበው 14 መስኖወችን ካናላቸውን በመሰባበርና በደለል በመሙላት 2 ዘመናዊ 1 ባህላዊ መስኖ ሙሉ በሙሉ ከጥቅም ውጭ ሆኗል።
- ከ8 ቀበሌዎች ጋር የሚገናኝ ከሊብሶ ጊራና የሚወስደው ድልድል በጉርፍ ምክንያት ከጥቅም ውጭ ሆኗል።
- የውርጌሣ ከተማ ዋናው የአስፋልት ድልድይ ከአቅም በላይ በሆነ ሁኔታ ጉዳት ላይ መሆኑና ለጊዜያዊ መፍትሄ ተብሎ የመጣ ዶዘር ምንም ለውጥ ሊያመጣ አልቻለም።
- የወረዳውን በአጠቃላይ ክላይ ከተዘረዘሩት ችግሮች ምክንያት አሁንም በስጋት ያሉ ሰዎች ካሉበት ቦታ እንዲለቁ ጥሪ እየተደረገ ይገኛል በመሆኑም በስጋት ላይ ያሉ አባወራዎች በቀበሌ ደረጃ ስናይ

ቀበሌ	አባወራ
09	249
013	188
012	78
019	45
01/መርሣ/	257
015	40
ድምር	857

3

ተ/ቁ	ቀበሌ	በጐርፍ አደጋ ምክንያት የተጐዳ የመስኖ አውታሮች				
		የመስኖው ስም	የተጠቃሚ ብዛት	የመስኖ አይነት		የጉደት መጠን
				ባህላዊ	ዘመናዊ	
1	8	አጋምሣ	285		√	መሰራት የማይችል
2	8	ደሃና	90	√		መጠነኛ ጉዳት
3	8	እርግቦ	213		√	መጠነኛ ጉዳት
4	9	ወደይ	98		√	መጠነኛ ጉዳት
5	15	ጉኒ	240	√		መሰራት የማይችል
6	12	ለይማን	263		√	መጠነኛ ጉዳት
7	18	ገላና	630		√	መጠነኛ ጉዳት
8	18	ጐቱ	354		√	መጠነኛ ጉዳት
9	18	ወይመል	494	√		መጠነኛ ጉዳት
10	20	ኢማን አብድ	640		√	መሰራት የማይችል
11	15	መደኑ	273		√	መጠነኛ ጉዳት
12	15	አጋፋሪ	207		√	መጠነኛ ጉዳት
13	5	ጨረቲ	400		√	መጠነኛ ጉዳት
14	10	መገናኛ	385		√	መጠነኛ ጉዳት

4

Annex Q Report of (Habru Wereda Disaster Prevention & Preparedness Agency).

በሐብሩ ወረዳ ከሃምሌ 6- ነሃሴ 17/2002 ዓ.ም የጣለው ዝናብ ያስከተለው አደጋ

ቀበሌ	የተጎዳው አባወራ ብዛት	ቤተሰብ	የተጎዳው ማሣ በሄ/ር	የጠፋ የምግብ እህል በኩ/ል	የጠፋው ንብረት በብር ሲተመን	የተጎዱ ቤቶች			የተጎዱ መሰረተ ልማቶች					የውሃ ተቋማት			የሰብል ጉዳት መጠን	የእንስሳት
						የፈረሰ	የተሰቀቀ	ቤተሰብ	FTC	የጤና ተቋም	መጋዘን	ት/ቤት	ድልድይ	ምንጭ	የእጅ ጉድጓድ	የተጎዱ የመስኖ አውታሮች		
18	830	4150	616	247	1823335	5	110	651	1	1	1	0	0	0	0	3	83%	2ላም 2 በሬ
19	399	2394	255	20	8240	3	11	42	0	0	0	0	1	1	2	0	80%	4ላም 1በሬ 1 ፍየል
12	314	1884	1145	96	112127	2	96	401	0	1	0	0	0	1	0	1	81%	1 በሬ
5	395	2370	23625	0	0	0	20	117	0	0	0	1	0	0	0	1	73%	
7	150	901	111	29	52000	0	0	0	0	0	0	0	0	0	0	0	67%	
20	393	2358	127.9	0	0	0	0	0	0	0	0	0	0	0	0	1	59%	
11	400	2410	413	0	0	0	0	0	0	0	0	0	0	0	0	0	66%	
6	177	796	97	0	0	0	0	0	0	0	0	0	0	0	0	0	65%	
9	511	2146	174	0	0	0	21	67	0	0	0	0	0	0	0	1	100%	2 በሬ
17	239	1147	174	0	0	0	0	0	0	0	0	0	0	0	0	0	71%	
14	578	2014	192	0	0	0	10	47	0	0	0	0	0	0	0	0	79%	6 በግ 4 በሬ
15	250	1025	289.75	0	0	0	0	0	0	0	0	0	0	0	0	3	81%	
10	621	2910	327	0	0	0	0	0	0	0	0	0	0	0	0	1	87%	
13	569	2258	452	0	0	2	184	719	0	0	0	1	0	0	0	0	80%	
01 ወርጌሣ	88	186	0	0	0	2	88	186	0	0	0	0	1	0	0	0	0%	
21	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1%	
01 መርሣ	45	160	0	0	0	4	46	160	0	0	0	0	0	0	0	0	0%	
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0%	
ድ	5960	29109	3692.4	392	354702	18	592	2390	1	2	1	2	2	2	2	14		6 ላም 12 በሬ 6 በግ 1 ፍየል

Annex R Landslide related questionnaire

1. Have you ever known before a landslide to happen in these area

   a) Yes b) No

2. Have you observed tilting of trees and cracks before the landslide happened?

   a) Yes b) No

3. Please explain if there were signs and symptoms before the incidence?________________

   ____

   ____

4. How were the rains then as compared to the rains before?

   A) Highest B) Lower C) Similar

5. How was the pace of the landslide?

   A) Gradual B) Fast C) Can't be noticed

6. When was it witnessed?____

7. How long did it stay devastating the area?____

8. Have you felt tremors during the occurrence of landslide?__________________________

   ____

   ____

9. What do you think was the causes of a landslide in the order of importance?

   A) ______________________ B) ____________________C) ____________________

   D) _____________________ E) ___________________F) ______________________

10. What would be the remedial measure in response of the 2010 landslide disasters?_______

    ____

11. How were the 2010 rains as compared to the rains 3-4 years before?

    A) Highest B) Lower C) Similar D) can't be recognize

12. How was the extent of damage in your house?

    A) Completely destroyed B) Partially affected

13. Were there hot springs emerged with the occurrence of the 2010 landslides?

A) Yes B) No

14. In opinion what can you say about the future regarding the occurrence of landslides in this area?

A) It will never happen again B) It can be reactivated C) It is god all Knows.

15) How was the vegetation cover change as compared with the previous times?

____

16) Do you think deforestation will cause landslide?

____

17. Have you felt earthquake in this area for the last years? If yes when? & have you observed landslide at that time?

____

<u>Questionnaire to the focus group</u>

1. Have you ever known or heard of before a landslide to happen in this area?

   A) Yes b) No
2. What is /was the name of the localities where landslide was witnessed before 2010?

   ____

   ____
3. When was it occurred?____

   ____
4. What was the damage /loss attributed by the previous landslides?____________________

   ____
5. Have you felt/heard of tremors with the time range of the previous landslide?__________

   ____
6. What do you think was the causes of a landslide in the order of importance?

   B) ______________________ B) ____________________C) _____________________

D) ______________________ E) ____________________F) ______________________

7. How were the rains then as compared to the rains before?

B) Highest B) Lower C) Similar

8. When it was exactly started?____

____

9. What other localities are affected by the 2010 landslides?___________________

____

____

10. How long did it stay devastating the area?____________________________________

____

11. What was the damage /loss attributed by the 2005 landslides?__________________

____

____

12. Have you felt/heard of tremors with the time range of the 2005 landslide?__________

____

____

13. What do you think was the causes of the landslide in the order of importance?

C) ______________________ B) ____________________C) ______________________

D) ______________________ E) ____________________F) ______________________

14. How were the rains of 2005 as compared with the rains before 3 to 4 years?

A) Highest B) Lower C) Similar

15. Is there deforestation around the area?

ANNEXURE

Annex B Rating assigned for structural discontinuities of individual facets.

A	Relationship between dip of discontinuities and inclination of the slope
B	Parallelism between discontinuities dip direction and slope inclination
C	Dip of discontinuities
D	Soil cover depth
E	Structural discontinuities and rock mass condition
F	Continuity
G	Separation
H	Roughness
I	Infiling
J	Weathering

Facet	A	B	C	D	E	F	G	H	I	J	Total
1	0.5	0.4	0.4	0.5	0.25	0.02	0.15	0.07	0.07	0.1	2.46
2	0.1	0.15	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.1	1.84
3	0.3	0.15	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.1	2.04
4	0.2	0.1	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.86
5	0.1	0.1	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.76
6	0.1	0.1	0.5	0.5	0.25	0.02	0.12	0.03	0.12	0.07	1.81
7	0.1	0.1	0.4	0.5	0.25	0.02	0.12	0.03	0.12	0.07	1.71
8	0.5	0.4	0.4	0.5	0.25	0.02	0.15	0.07	0.07	0.1	2.46
9	0.1	0.1	0.5	0.5	0.25	0.02	0.15	0.03	0.12	0.1	1.87
10	0.1	0.1	0.5	0.5	0.25	0.02	0.15	0.03	0.12	0.1	1.87
11	0.1	0.1	0.5	0.5	0.25	0.02	0.15	0.03	0.12	0.1	1.87
12	0.1	0.1	0.5	0.5	0.2	0.02	0.15	0.03	0.12	0.1	1.82
13				1.4							1.4
14	0.1	0.1	0.5	0.5	0.2	0.02	0.07	0.03	0.02	0.07	1.61
15	0.1	0.1	0.5	0.5	0.2	0.02	0.07	0.03	0.02	0.07	1.61
16	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
17	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
18	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
19	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
20	0.1	0.1	0.4	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.66
21	0.1	0.1	0.4	0.5	0.2	0.02	0.15	0.03	0.12	0.07	1.69
22	0.1	0.1	0.4	0.5	0.2	0.02	0.15	0.03	0.12	0.07	1.69
23	0.1	0.1	0.5	0.5	0.25	0.02	0.12	0.03	0.02	0.07	1.71
24				1.8							1.8
25				1.8							1.8
26				1.4							1.4
27				1.8							1.8
28				1.8							1.8
29				1.8							1.8
30				1.8							1.8
31				1.8							1.8
32				1.8							1.8

33	0.1	0.1	0.5	0.5	0.25	0.02	0.15	0.03	0.12	0.1	1.87
34				1.4							1.4
35				1.4							1.4
36				1.4							1.4
37	0.2	0.1	0.5	0.5	0.2	0.02	0.12	0.03	0.12	0.07	1.86
38	0.4	0.4	0.4	0.5	0.225	0.04	0.15	0.15	0.12	0.1	2.485
39	0.4	0.4	0.4	0.5	0.244	0.04	0.12	0.15	0.12	0.1	2.4735
40	0.4	0.4	0.4	0.5	0.225	0.04	0.12	0.15	0.12	0.1	2.455
41				1.4							1.4
42	0.2	0.15	0.4	0.5	0.24	0.1	0.12	0.15	0.12	0.1	2.0795
43	0.1	0.15	0.4	0.5	0.24	0.1	0.12	0.03	0.12	0.1	1.8595
44	0.1	0.1	0.5	0.5	0.246	0.1	0.12	0.03	0.12	0.1	1.9155
45	0.5	0.2	0.4	0.5	0.25	0.1	0.15	0.15	0.12	0.1	2.47
46	0.5	0.2	0.4	0.5	0.25	0.1	0.15	0.15	0.12	0.1	2.47
47	0.5	0.2	0.4	0.5	0.25	0.1	0.15	0.15	0.12	0.1	2.47
48	0.5	0.2	0.4	0.5	0.2	0.15	0.15	0.15	0.12	0.1	2.47
49	0.5	0.4	0.25	0.5	0.231	0.15	0.15	0.15	0.02	0.1	2.451
50	0.5	0.1	0.5	0.5	0.25	0.1	0.15	0.03	0.12	0.1	2.35
51	0.1	0.1	0.5	0.5	0.25	0.1	0.15	0.03	0.12	0.1	1.95
52	0.1	0.1	0.5	0.5	0.231	0.1	0.12	0.03	0.02	0.1	1.801
53	0.1	0.1	0.5	0.5	0.234	0.1	0.12	0.03	0.02	0.1	1.804
54	0.5	0.5	0.25	0.5	0.25	0.15	0.15	0.03	0.02	0.1	2.45
55				1.8							1.8
56	0.5	0.5	0.25	0.5	0.2	0.15	0.15	0.03	0.02	0.1	2.4
57	0.1	0.5	0.25	0.5	0.246	0.1	0.12	0.03	0.02	0.1	1.966
58	0.5	0.1	0.4	0.5	0.25	0.02	0.12	0.03	0.02	0.1	2.04
59	0.4	0.1	0.4	1	0.25	0.02	0.12	0.03	0.02	0.1	2.44
60	0.4	0.1	0.4	1	0.25	0.02	0.12	0.03	0.02	0.1	2.44
61				1.8							1.8

Annex C Mersa Monthly Precipitation in mm (2000 – 2010).

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	57.5	49.7	12.2	258.2	386.1	106.3	116	36.5	38.7	1061.4
2001	2	18	206	3	80.5	24.8	303.3		124.5	25	2.4	5.5	795
2002	129.6	0	40.2	59.8	5.9	3.5	227.8	253.7	87.6	0	0	104.7	912.8
2003	43.4	18.1	43.6	167.8	0	40	121.8	284.9	124.2	1.8	8.2	45	898.8
2004	56.7	27.9	68.7	152.2	2.7	17	190	155.5	0.6	36.5	68.4	19.9	796.1
2005	0	0	54.5	84.3	143.2	27.8	214.1	322	32.6	18	0	0	896.5
2006	0	1.1	279.5	137	41.1	23.7	158.7	327.8	109.6	89.3	12.4	11.1	1191.3
2007	18	68.5	35.8	97.2	44.1	33.1	336.2	255.3	88.8	30.6	4.5	0	1012.1
2008	43.2	0	0	42.8	33.7	22.6	200.8	221.1	115.3	40.1	43.3	0	762.9
2009	35.1	6.4	52.7	137.6	3.2	9.5	233.8	268.5	0.8	28.8	3.8	127.8	908
													1186
2010	0		85.4	75.7	148.2	5.2	324.6	546.9					

Annex D Wurgessa Monthly Precipitation in mm (200 – 2003, & incomplete data of 2004, 2005, and 2010)

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	12.8	120.8	111.1	2.8	357.2	374.9	106	80.9	40.1	135.2	1341
2001	19.2	30.9	217.2	16	56.9	51.6	404.1	381.6	244	39.2	1.1	0	1462
2002	173.6	5.6	88.2	125	8.5	0.8	269.8	248.8	145	20.3	0	117	1203
2003	98.4	44.9	62.8	146.7	0	0	0	151.9	116	0	10.1	2.5	632.8
2004							32.3	203.7					
2005							312.9	276.9	41.6	35.2	64.6	0	
2010				117.1	75.4	0	451.5	587.2					

Annex E Wuchalle Monthly Precipitation in mm (2000 – 2009)

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	12.8	87.5	129.8	14	344.6	330.3	108.8	77.6	60.9	175.1	1341.4
2001	21.8	43.7	200.2	13.8	43.4	53.7	356.3	347.6	235.9	27.7	2.3	1.2	1347.6
2002	137.8	9.5	50	85.5	8.5	1	301	272.6	107.4	16.5	0	104.7	1094.5
2003	136.1	35.2	44.8	168.6	6.9	59.4	199.1	307.9	144.1	1.7	23.3	51.9	1179
2004	6.3	70.5	77.4	188.2	23	45.6	199	270.6	86.9	51.8	74.3	76.9	1170.5
2005	24.4	0	86.4	134.2	134.5	24.7	328.9	313.9	44.5	20.9	30.4	0	1142.8
2006	0	2.9	210.6	155.3	42.3	5.8	193	296.7	121.1	50.6	17.6		1095.9
2007	53.1	60.5	58.7	106.5	7.9	45.8	440.8	283	143.4	28.8	3	0	1231.5
2008	13.2	1.3	0	22.8	44.8	35.2	224.3	256.9	162.6	96.1	82		939.2
2009						33.9	212.7	268.6	30.5	10.8	47.7	70.4	674.6
2010			97.7	120.8									218.5

Annex F Dailly Rainfall (mm) of Mersa and Wurgessa for the month of April, May, June, July and August 2010.

Date	April		May		June		July		August	
	Mersa	Wurgessa	Mersa	Wurgessa	Mersa	Wurgessa	Mersa	Wurgessa	Mersa	Wurgessa
1	0.0	0.0	8.6	0.0	0.0	0.0	0.0	0.0	4.3	26.1
2	0.0	0.0	12.3	0.0	0.0	0.0	0.0	0.0	13.5	19.1
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.5	15.9
4	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	20.3	0.0
5	0.0	0.0	22.6	25.8	0.0	0.0	0.0	0.0	18.3	0.0
6	0.0	13.3	22.5	0.0	0.0	0.0	0.0	0.0	18.3	0.0
7	5.7	17.5	11.0	5.9	0.0	0.0	0.0	0.0	6.8	Tr
8	0.4	0.0	6.6	0.0	0.0	0.0	0.0	0.0	6.5	35.5
9	0.4	0.0	0.0	1.2	0.0	0.0	0.0	Tr	0.0	32.8
10	0.0	0.0	0.8	3.2	0.0	0.0	0.0	15.5	0.0	4.2
11	0.0	7.0	7.4	4.9	0.0	0.0	0.0	4.0	0.0	3.8
12	5.4	16.5	11.0	0.0	0.0	0.0	37.5	1.5	27.7	60.1
13	15.6	2.6	0.2	0.0	0.0	0.0	2.7	44.1	2.3	26.3
14	6.2	4.0	8.9	12.0	0.0	0.0	0.0	4.3	10.2	41.9
15	13.3	3.0	0.0	0.0	0.0	0.0	5.5	41.9	44.2	0.0

16	2.3	0.0	0.0	0.0	0.0	0.0	0.0	8.8	42.0	32.0
17	0.0	0.0	0.0	0.0	0.0	0.0	4.0	28.8	0.1	5.4
18	0.0	0.0	0.0	0.0	0.0	0.0	10.8	46.3	27.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	29.0	37.5	28.0	13.5
20	0.0	0.0	0.0	0.0	0.0	0.0	82.0	15.3	36.0	52.2
21	0.0	6.4	0.0	0.0	0.0	0.0	31.0	28.0	0.0	21.0
22	0.0	34.2	0.0	0.0	0.0	0.0	7.5	6.0	16.4	47.5
23	0.0	Tr	0.0	0.0	0.0	0.0	20.0	33.5	26.2	70.0
24	4.4	2.5	0.0	0.0	5.2	0.0	20.9	30.1	15.0	Tr
25	4.4	0.0	0.0	0.0	0.0	0.0	13.5	9.0	26.0	19.8
26	0.6	0.0	0.0	1.1	0.0	0.0	23.0	20.0	89.0	9. 8
27	0.0	0.0	0.0	0.0	0.0	0.0	21.3	7.1	0.0	1.2
28	0.0	10.1	36.3	18.1	0.0	0.0	9.4	32.9	19.5	37.0
29	17.0	0.0	0.0	0.0	0.0	0.0	5.5	25.0	8.2	12.1
30	0.0	0.0	0.0	0.0	0.0	0.0	1.0	19.3	16.0	0.0
31			0.0	0.0				41.0	9.5	0.0
Total	**75.7**	**117.1**	**148.2**	**75.4**	**5.2**	**0.0**	**324.6**	**451.5**	**546.9**	**587.2**

Annex G Sirinka – Monthly Precipitatation (mm) data (1966 – 2005)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1966	x	x	x	x	x	x	x	255.3	104.3	62.3	0.0	0.2	422.1
1967	0.0	1.0	19.0	125.1	188.3	23.0	313.6	224.6	47.4	74.4	152.6	1.0	1170.0
1968	11.0	38.8	36.4	109.0	53.5	34.0	243.0	147.0	81.0	61.0	55.0	23.0	892.7
1969	185.0	290.0	277.0	190.0	62.0	18.0	301.0	421.0	40.0	5.0	3.0	0.0	1792.0
1970	163.0	50.0	x	x	x	x	x	x	x	x	x	x	213.0
1980	x	x	x	x	x	x	95.5	242.2	x	63.2	0.0	4.0	404.9
1981	0.0	15.8	226.5	83.6	11.2	135.9	222.0	245.8	47.6	4.0	0.0	0.9	993.3
1982	52.9	165.9	89.2	54.7	44.5	0.0	78.3	178.6	78.8	147.6	60.8	17.0	968.3
1983	147.6	59.1	28.4	71.8	220.2	51.2	x	154.4	24.0	28.2	26.8	0.2	811.9
1984	x	24.7	26.2	53.2	147.6	10.5	25.7	45.5	68.8	0.0	14.8	65.8	482.8
1985	9.8	3.5	103.0	120.4	96.5	0.0	145.2	212.2	125.3	3.2	0.0	48.2	867.3
1986	0.0	94.8	48.9	181.7	0.0	75.2	130.1	178.2	177.7	7.0	1.2	66.7	961.5
1987	0.0	28.5	172.0	103.9	149.1	1.9	46.3	207.4	107.1	58.0	0.0	39.3	913.5
1988	21.4	208.5	5.8	155.1	12.2	11.0	299.2	250.2	110.4	30.7	0.0	0.5	1105.0
1989	15.2	68.0	173.4	133.0	64.4	7.6	132.5	x	92.4	x	x	x	686.5
1991	x	x	x	x	x	x	x	x	60.9	4.0	41.0	x	105.9
1992	75.3	75.2	52.6	17.8	34.2	0.0	159.4	281.5	86.8	48.9	59.0	211.1	1101.8
1993	29.4	87.3	29.2	152.4	64.0	0.0	152.2	134.2	140.5	93.3	0.0	11.4	893.9
1994	0.0	0.0	74.6	52.2	37.9	0.0	295.5	413.2	115.0	1.7	44.4	5.8	1040.3
1995	0.0	125.8	62.0	271.2	32.1	44.3	268.8	285.0	69.9	24.6	0.0	108.2	1291.9
1996	78.6	1.7	157.7	115.9	199.0	72.3	113.0	263.8	60.3	37.1	51.5	6.3	1157.2
1997	32.5	3.8	217.0	84.8	71.5	99.2	206.9	184.3	96.3	320.5	106.0	0.1	1422.9
1998	115.2	118.9	114.8	63.5	36.1	0.0	367.5	334.4	73.5	57.0	0.0	0.0	1280.9
1999	47.4	0.0	32.0	46.0	16.8	15.7	375.0	394.8	97.2	164.4	14.5	4.0	1207.8
2000	0.3	0.0	15.9	69.7	33.9	35.2	338.3	338.5	85.2	136.8	49.7	115.7	1219.2
2001	6.9	21.7	237.6	10.4	43.5	32.8	274.7	247.8	91.9	28.2	4.9	6.2	1006.6
2002	87.6	6.2	47.0	71.6	0.6	7.9	229.5	295.3	134.0	17.7	0.0	94.7	992.1
2003	65.2	60.4	68.4	115.5	4.9	36.9	166.6	274.2	103.2	0.0	10.7	48.3	954.3
2004	22.1	11	37.9	119.4	4.2	36.5	166.4	225.6	68.7	58.5	63.5	17.9	831.7
2005	32	7.8	99	116.7	114.6	26.7	283.8	323.3	55.6	36.3	71.1		1166.9

Annex H Maximum Temperature (Mersa)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	27.6	28.1	29.6	30.3	32.3	34.6	31.6	29.7	29.5	27.6	26.8	26.3
2001	23.8	26.4	26.6	31	32.2	32.7	31.2	29.9	29.7	28.8	27	27.1
2002	24.5	27.1	29.6	30.6	33.5	34.2	32.4	29.9	27	30.2	28.4	
2003			28.8	30.2	32.1	33.5	31.5	28.8	29.6	27.9	27.6	26.2
2004	26.3	26.7	28.7	29	33.2	34.8	30.7	30.4	32.4	30.8	26.8	25.9
2005			28.4	29.7	30	33.1	30.9	29.7	29.8	28.2		
2006	26.7	25.2	28.4	27.2	31	32.2	30.8	30	28	28.6	26	26
2007	24.3	24.4	29.6	29.3	33.1	32	29.4	29.2	28	28.4	27.1	26.7
2008	26.8	24.7	30.4	30	32.6	32	32	29	28	29	27	27
2009	27.6	25.3	30.4	29.4	33.4	34	30.2	30	28.7	29	27.5	26

Annex I Minimum Temperature (Mersa)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	5.4	5.4	8.7	12.2	13	15.3	15.5	12.5	13.6	12.2	11.7	7.3
2001	6.4	5.8	6	12.6	13.5		15.2	10.9	10.8	10.8	7.7	6.6
2002	11.8	12.4	11.6	12.6	13.1	12.7	12.5	9.3	8.5	10.3	9.4	11.2
2003	12.2	12.6	13.2	14.5	14.2	13.9	14.6	14.7	15	10.6	9.7	8.8
2004	11.5	10.9	11.2	14.7	13.9	14.4	10.1	10.5	10.5	9.2	9.5	10.9
2005			14.1	14.6	15.2	14.8	16.4	15.9	15	11.3		
2006	10.4	12	14.13	13.65	13.9	14.16	16.13	15.9	14.06	12.48	11.26	13.38
2007	12.94	12.31	12.31	14.66	15.47	15.95	16.24	15.88	14.35	11.18	9.16	7.06
2008	10.56	8.63	9.26	14.64	15.84	14.86	16.51	15.73	14.1	12.09	9.55	8.99
2009	12.44	9.55	13.39	14.46	15.86	15.56	16.21	16.03	14.97	12.78	9.48	13.41

Annex J Percentage Area coverage of slope material type for individual facets.

Facets	Very weak rock	Alluvial deposits	Poorly graded colluvial	Well graded colluvial	Total
Max	1.00	0.8	0.5	0.3	1.00
1	100% = 1.00				1.00
2	90% = 0.9	10% = 0.08			0.98
3	63% = 0.63	37% = 0.296			0.926
4	85% = 0.85	15% = 0.12			0.97
5	87% = 0.87	13% = 0.104			0.974
6	43% = 0.43	57% = 0.456			0.886
7	50% = 0.5	50% = 0.4			0.9
8	78% = 0.78	22% = 0.176			0.966
9	83 % = 0.83	17% = 0.136			0.94
10	100% = 1.00				1.00
11	100% = 1				1
12	100% = 1				1
13	42% = 0.42	58% = 0.464			0.884
14	100% = 1.00				1.00
15	87% = 0.87	13% = 0.104			0.974
16	94% = 0.94	6% = 0.048			0.988
17	100% = 1.00				1.00
18	92% = 0.92	8% = 0.064			0.984
19	100% = 1.00				1.00
20	85% = 0.85	15% = 0.12			0.97
21	60% = 0.6	40% = 0.32			0.92
22	100% = 1.00				1.00
23	100% = 1.00				1.00
24	13% = 0.13	77% = 0.616			0.746
25	8% = 0.08	92% = 0.736			0.816
26	5% = 0.05	95% = 0.76			0.81
27	100% = 0.8				0.8
28	69% = 0.69	31% = 0.248			0.938
29	67%=0.67	33%=0.246			0.94
30	63%= 0.63	37%=0.296			0.926
31	38%=0.38	62%=0.496			0.876
32	20%=0.2	80%=0.64			0.84
33	100% = 1				1.00
34	10%=0.1	90%=0.72			0.82
35	40% =0.4	60%=0.48			0.88
36	51%=0.51	49%=0.392			0.902
37	66%= 0.66	34%=0.34			0.83
38	49% = 0.49		51% = 0.255		0.745
39	13% = 0.13		61% = 0.305	26% = 0.078	0.513
40	50% = 0.5		39% = 0.195	11 % = 0.033	0.728
41			6% = 0.03	94% = 0.282	0.312
42	65% = 0.65		27% = 0.135	8%=0.024	0.809
43	37% = 0.37		43% = 0.215	20% = 0.06	0.645
44	9% = 0.09		91 % = 0.455	-	0.545
45	55 % = 0.55		45% =0.225		0.775
46	40 % = 0.3		60% = 0.35		0.7
47	63% = 0.63		37% = 0.185		0.815
48	89% = 0.89			11% = 0.033	0.923
49	69% = 0.69		31% = 0.155		0.845
50	86% = 0.86		14% = 0.07		0.93
51	22% = 0.22	34%= 0.272	44% = 0.22		0.712
52	37% = 0.37		63% = 0.315		0.685
53	32% = 0.32		68% = 0.34		0.66
54	49% = 0.49		51% = 0.255		0.745
55	100% = 1.00				1.00
56	42% = 0.42		8% = 0.04	50% = 0.15	0.61
57	58% = 0.58		42% = 0.21		0.79
58				100%	0.3
59				100%	0.5
60				100%	0.5
61			16%=0.08	84%=0.252	0.332

Annex K Percentage Area coverage of Land use land cover for individual facets.

Facets	Barren land	Sparsely vegetated	Moderately vegetated	Thickly vegetated forest area	Cultivated land with populated area	Total
Max	1.5	1.2	0.75	0.4	0.4	1.5
1	18% = 0.27	71% = 0.852	11% = 0.0825			1.2045
2		82% = 0.984	18% = 0.135			1.119
3		99% = 1.188	2% = 0.015			1.203
4		75% = 0.9	25% = 0.1875			1.0875
5		21% = 0.252	68% = 0.51	11% = 0.044		0.806
6	4% = 0.06	20% = 0.24	75% = 0.5625		1% = 0.004	0.8665
7		27% = 0.324	70% = 0.525		3% = 0.012	0.861
8	10% = 0.15	90% =1.08				1.23
9	7% = 0.315	83% = 0.996	10% = 0.075			1.386
10	34% = 0.51	66% = 0.792				1.302
11	25% = 0.375	58% = 0.696	17% = 0.1275			1.1985
12	6% = 0.09	86% = 1.032	8% =0.06			1.182
13		9% = 0.108	80% = 0.6		11% = 0.044	0.752
14		15% = 0.18	80% = 0.6		5% = 0.0375	0.8175
15		18% = 0.216	65% = 0.4875		17% = 0.1275	0.831
16		39% = 0.468	61% = 0.4575			0.9255
17		83% = 0.996	17% = 0.1275			1.1235
18		40% = 0.48	60% = 0.45			0.93
19	6% = 0.09	28% = 0.336	56% = 0.42		10% = 0.04	0.886
20	13% = 0.195	70% = 0.84	17% = 0.1275			1.1625
21	19% = 0.285	59% = 0.708	20% = 0.15		2% = 0.015	1.158
22		100% = 1.2				1.2
23		28% = 0.336	66% = 0.495		6% = 0.024	0.855
24		16% = 0.192	34% = 0.255		50% = 0.375	0.822
25		13% = 0.156	32% = 0.24		55% = 0.4125	0.8085
26		5% = 0.06	49% = 0.3675		46% =0.345	0.7725
27			68%=0.51		32%=0.128	0.638
28	4%=0.06	26%=0.312	53%=0.3975		17%=0.068	0.8375
29	35%=0.525	35%=0.42	22%=0.165		8%=0.032	1.142
30	28%=0.42	60%=0.72	12%=0.09			1.23
31	30%=0.45	4%=0.048	59%=0.4425		7%=0.028	0.9685
32	39%=0.585	39%=0.468	18%=0.135		4%=0.016	1.204
33	25%=0.375	62%=0.744	13%=0.0975			1.2165
34	82%=1.23	3%=0.036	15%=0.1125			1.3785
35	72%=1.08	26%=0.312			2%=0.008	1.4
36		19%=0.228	75%=0.5625		6%=0.024	0.8145
37		85%=1.02	15%=0.1125			1.1325
38	5% = 0.075	35% = 0.42			60% = 0.24	0.735
39	16% = 0.24	63% = 0.756			21% = 0.084	1.08
40	6% = 0.09	31% = 0.372			63% = 0.252	0.714
41	2% = 0.03	6% = 0.072			92% = 0.368	0.47
42	12% = 0.18	74% = 0.888	3% = 0.0225	3% = 0.012	8% = 0.032	1.1345
43	24% = 0.36	50% = 0.6		6% = 0.024	20% = 0.08	1.064
44	6% = 0.09	17% = 0.204		40% = 0.16	37% = 0.148	0.602
45	10% = 0.15	63% = 0.756	23% = 0.1725	1% = 0.004	3% = 0.012	1.2385
46	25% =0.375	70% = 0.84			5% = 0.02	1.235
47	16% = 0.24	67% = 0.804			17% = 0.068	1.112
48		34% = 0.408			66% = 0.264	0.672
49		25% = 0.3	62% = 0.465	13% = 0.052		0.817
50	8% = 0.12	41% = 0.492			51% = 0.204	0.816
51	7% = 0.105	31% = 0.372		2% = 0.008	60% = 0.24	0.725
52	3% = 0.045	35% = 0.42		34% = 0.136	28% = 0.112	0.713
53	5% = 0.075	37% = 0.444		25% = 0.1	33% = 0.132	0.751
54		17% = 0.204	16% = 0.12	67% = 0.268		0.592
55					100% = 0.4	0.4
56		44% = 0.528	6% = 0.045	11% = 0.044	39% = 0.156	0.773
57		56% = 0.672		8% = 0.032	36% = 0.144	0.848
58	2%=0.03	10%=0.12			88%=0.352	0.502
59	6%=0.09	45%=0.54			49%=0.195	0.825
60	5%=0.075	4%=0.048			91%=0.364	0.487
61	6%- 0.09	8%=0.096			86%=0.344	0.53

Annex L Percentage Area coverage of Ground water for individual facets.

Facets	Flowing	Dripping	Wet	Damp	Dry	Total
Max	2.0	1.5	1	0.6	0	2.00
1		100% = 1.5				1.5
2		100%=1.5				1.5
3		100%=1.5				1.5
4			79% = 0.79	23% = 0.138		0.928
5		22% = 0.33		78% = 0.468		0.798
6		47% = 0.705		53% = 0.318		1.023
7			56 % = 0.56	44% = 0.264		0.824
8		100 % = 1.5				1.5
9		52%=			48%	0.78
10		100%=1.5				1.5
11				100% = 0.6		0.6
12		24%=0.36	34%=0.34	42%=0.252		0.952
13	51% = 1.02		11%=0.11	38% = 0.228		1.358
14			100% = 1			0.6
15	34% = 0.68		66% = 0.66			1.34
16				100 % = 0.6		0.6
17				100 % = 0.6		0.6
18				100 % = 0.6		0.6
19				100 % = 0.6		0.6
20				67% = 0.402		0.402
21			29%=0.29	50% = 0.3		0.59
22			47% = 0.47	53% = 0.318		0.788
23	33 % = 0.66		67%= 0.67			1.33
24	92% = 1.84		8 % = 0.08			1.92
25	89% = 1.6		11% = 0.11			1.71
26	57% = 1.14		17%=0.17	26% = 0.156		1.466
27	100%=2.00					2.00
28	88%=1.76		12%=0.12			1.88
29				47%=0.28		0.28
30				61%=0.366		0.366
31				22%=0.132		0.132
32	2%=0.04			14%=0.084		0.124
33		18%=0.27				0.27
34	1.3%=0.013					0.013
35			100=1			1.00
36	6%=0.12	10%=0.15	28%=0.28	56%=0.336		0.886
37			40%=0.4	60%=0.36		0.76
38	60 % = 1.2			40%-0.4		1.6
39			100% = 1			1.00
40	94% = 1.88		6% = 0.06			1.94
41	35% = 0.7			65%=0.65		1.35
42	5% = 0.1	31%=0.465	64% = 0.64			1.205
43	84% = 1.68		16% = 0.16			1.84
44	100% = 2.00					2.00
45	25 % = 0.5	75% = 1.125				1.625
46	100%					2.00
47	100= 2.00					2.00
48	36% = 0.72	64% = 0.96				1.68
49	68% = 1.36	32% = 0.48				1.84
50	100% = 2.00					2.00
51	100% = 2.00					2.00
52	93% = 1.86		7% = 0.07			1.93
53	93% = 1.86		7% = 0.07			1.93
54	100% = 2.00					2.00
55	100% = 2.00					2.00
56	100% = 2.00					2.00
57	57% = 1.14		43% = 0.43			1.57
58			100%			1.00
59	100%=2.00					2.00
60	100%=2.00					2.00
61	100%=2.00					2.00

Annex M Percentage of area coverage for slope material as rain fall parameter.

Facets	Soil mass	Disintegrated	Blocky/Disturbed	Total
Max	0.25	0.2	0.15	
1		100% = 0.25		0.25
2		100% = 0.2		0.2
3		100% = 0.2		0.2
4	6% = 0.015	94% = 0.188		0.202
5	13% = 0.0325	87% = 0.174		0.2065
6	57% = 0.1425	43% = 0.086		0.2285
7	50% = 0.125	50% = 0.1		0.225
8		100% = 0.2		0.2
9	17% = 0.045	83 % = 0.166		0.2085
10		100% = 1.00		0.2
11		100% = 0.2		0.2
12		100% = 0.2		0.2
13	58% = 0.145	42% = 0.084		0.229
14		100% = 1.00		0.2
15	13% = 0.0325	87% = 0.174		0.2065
16	6% = 0.015	94% = 0.188		0.203
17		100% = 0.2		0.2
18	8% = 0.02	92% = 0.184		0.204
19		100% = 0.2		0.2
20	15% = 0.0375	85% = 0.17		0.2075
21	23% = 0.0575	77% = 0.154		0.2115
22		100% = 0.2		0.2
23	3% = 0.0075	97% = 0.194		0.2015
24	77% = 0.1925	13% = 0.026		0.2185
25	92% = 0.23	8% = 0.016		0.246
26	95% = 0.2375	5% = 0.01		0.2475
27	100%=0.25			0.25
28	31%=0.0775	69%=0.138		0.2155
29	33%=0.0825	67%=0.134		0.2165
30	37 %=0.0925	63%=0.126		0.2185
31	62 %=0.155	38%=0.076		0.231
32	80%=0.2	20%=0.04		0.24
33		100%=0.2		0.2
34	90%=0.225	10%=0.02		0.245
35	60%=0.15	40%=0.08		0.23
36	49%=0.1225	51%=0.102		0.2245
37	34%=0.085	66%=0.132		0.217
38	9% = 0.0225	42% = 0.084	49% = 0.0735	0.18
39	13% = 0.0325	61% = 0.122	13% = 0.039	0.1935
40	11% = 0.0275	39% = 0.078	50% = 0.0275	0.1805
41	94 % = 0.235	6% = 0.012		0.247
42	8% = 0.02	27%= 0.054	65% = 0.0975	0.1715
43	20% = 0.05	43% = 0.086	37% = 0.0555	0.1915
44		91% = 0.182	9% = 0.0135	0.1955
45		55 % = 0.11	45 % = 0.0675	0.1775
46		70% = 0.14	30% = 0.045	0.185
47		63% = 0.126	37% = 0.0555	0.1815
48	11% = 0.0275		89% = 0.1335	0.161
49		62% = 0.124	38% = 0.057	0.181
50		64% = 0.128	36% = 0.054	0.182
51	38% = 0.095	55% = 0.11	7% = 0.0105	0.2155
52		63% = 0.126	37% = 0.0555	0.1815
53		68% = 0.136	32% = 0.048	0.184
54	2% = 0.005	82% = 0.164	16% = 0.024	0.193
55	100% = 0.25			0.25
56	50% = 0.125	8% = 0.016	42% = 0.063	0.204
57		42% = 0.084	58% = 0.087	0.171
58	100%=0.25			0.25
59	100%=0.25			0.25
60	100%=0.25			0.25
61	84%=0.21	16%=0.032		0.242

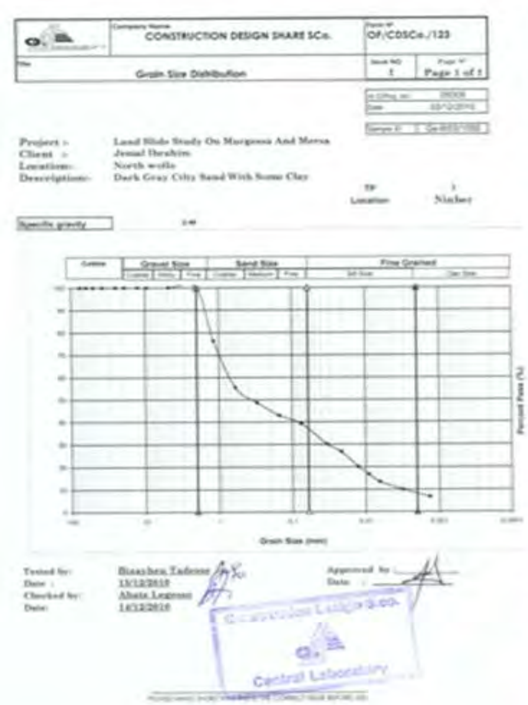
Annex N Rating values assigned to Rainfall parameters.

A	**Mean annua Rainfall**
B	Rain induced manifestation on slope
C	Slope material
D	Discontinuities orrientation with respect to the slope
E	Rainfall adjustment factors for slope morphometry
F	Total values assigned for Rainfall

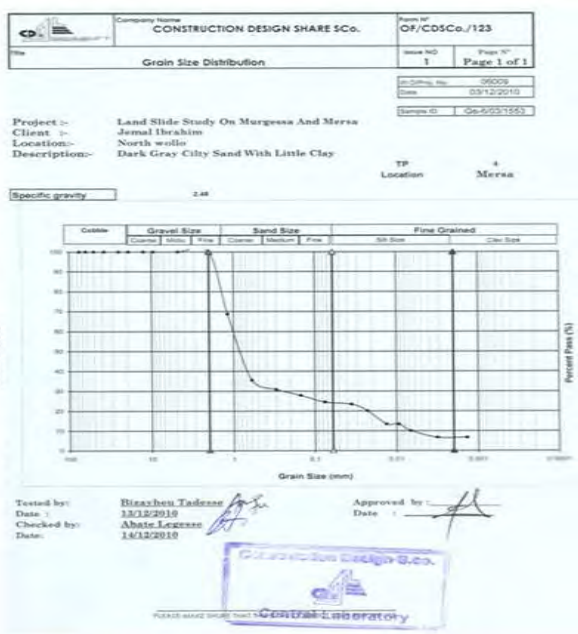
Facets	A	B	C	D	E	F
1	0.3	0.1	0.25	0.25	0.1	0.09
2	0.3	0.15	0.2	0.25	0.1	0.09
3	0.3	0.15	0.2	0.25	0.25	0.225
4	0.3	0.1	0.202	0.25	0.25	0.213
5	0.3	0.1	0.2065	0.25	0.25	0.214125
6	0.3	0.1	0.2285	0.25	0.5	0.43925
7	0.3	0.1	0.225	0.25	0.5	0.4375
8	0.3	0.15	0.2	0.25	0.1	0.09
9	0.3	0.15	0.2085	0.25	0.25	0.227125
10	0.3	0.1	0.2	0.25	0.5	0.425
11	0.3	0.15	0.2	0.25	0.5	0.45
12	0.3	0.1	0.2	0.25	0.5	0.425
13	0.3	0.15	0.229	0.25	0.5	0.4645
14	0.3	0.15	0.2	0.25	0.25	0.225
15	0.3	0.25	0.2065	0.25	0.25	0.251625
16	0.3	0.1	0.203	0.25	0.5	0.4265
17	0.3	0.1	0.2	0.25	0.5	0.425
18	0.3	0.1	0.204	0.25	0.5	0.427
19	0.3	0.1	0.2	0.25	0.5	0.425
20	0.3	0.25	0.2075	0.25	0.5	0.50375
21	0.3	0.25	0.2115	0.25	0.5	0.50575
22	0.3	0.1	0.2	0.25	0.25	0.2125
23	0.3	0.25	0.2015	0.25	0.25	0.250375
24	0.3	0.25	0.2185	0.25	1	1.0185
25	0.3	0.15	0.246	0.25	1	0.946
26	0.3	0.15	0.2475	0.25	1	0.9475
27	0.3	0.25	0.25	0.25	1	1.05
28	0.3	0.25	0.2155	0.25	0.75	0.761625
29	0.3	0.25	0.2165	0.25	0.75	0.762375
30	0.3	0.25	0.2185	0.25	0.75	0.763875
31	0.3	0.25	0.231	0.25	1	1.031
32	0.3	0.25	0.24	0.25	0.75	0.78
33	0.3	0.1	0.2	0.25	0.75	0.6375
34	0.3	0.25	0.245	0.25	1	1.045
35	0.3	0.25	0.23	0.25	0.75	0.7725
36	0.3	0.15	0.2245	0.25	1	0.9245
37	0.3	0.1	0.217	0.25	1	0.867
38	0.6	0.25	0.18	0.25	0.1	0.128

39	0.6	0.25	0.1935	0.25	0.5	0.64675
40	0.6	0.25	0.1805	0.25	0.1	0.12805
41	0.6	0.25	0.153	0.25	1	1.253
42	0.6	0.15	0.1715	0.25	0.5	0.58575
43	0.6	0.1	0.1915	0.25	0.5	0.57075
44	0.6	0.25	0.1955	0.25	0.25	0.323875
45	0.6	0.25	0.1775	0.25	0.1	0.12775
46	0.6	0.25	0.185	0.25	0.25	0.32125
47	0.6	0.15	0.1815	0.25	0.25	0.295375
48	0.6	0.1	0.161	0.25	0.75	0.83325
49	0.6	0.25	0.181	0.25	0.5	0.6405
50	0.6	0.15	0.182	0.25	0.25	0.2955
51	0.6	0.25	0.2155	0.25	0.1	0.13155
52	0.6	0.25	0.1815	0.25	0.1	0.12815
53	0.6	0.25	0.184	0.25	0.1	0.1284
54	0.6	0.25	0.193	0.25	0.5	0.6465
55	0.6	0.1	0.25	0.25	1	1.2
56	0.6	0.15	0.204	0.25	0.1	0.1204
57	0.6	0.25	0.171	0.25	0.25	0.31775
58	0.6	0.1	0.25	0.25	1	1.2
59	0.6	0.1	0.25	0.25	1	1.2
60	0.6	0.15	0.25	0.25	0.75	0.9375
61	0.6	0.25	0.242	0.25	0.75	1.0065

Annex O Soil grain size analysis Laboratory anaysed data



Annex O continue…



Company Name: CONSTRUCTION DESIGN SHARE CO.	Form No: OF/CDSCo./117	
Title: LABORATORY TEST RESULT	Issue NO: 1	Page N°: Page 1 of 1

W.O.No 06009
Date :- 03/12/2010

Project :- Land Slide Study On Murgessa And Mersa
Client :- Jemal Ibrahim
Location :- North Wollo
Object :- Soil Samples

1.Soil Sample

N°	TP No	Location	Moisture content (%)	Natural Unit Weight Kg/M³	Atterberig Limits LL (%)	PL (%)	PI (%)	Shear Strength C KN/m²	Ø Degree
1	1	Ninber	11.19	1650	39.65	31.52	8.13	-	-
2	2	Murgessa	7.38	1592	40.19	30.45	9.74	8	30
3	3	Mersa	7.20	1630	36.45	29.60	6.85	-	-
4	4	Mersa	7.70	1508	35.46	29.52	5.94	6	31

Note
1. Four graphs for grain size distribution test result are drawn and attached here with
2. Two graphs for Direct shear test result are drawn and attached here with

Tested by :- Bizayehu Taddese
Date :- '14/12/2010
Checked by :- Abate Legesse
Date :- 16/12/2010

Approved by :-
Date :-

Construction Design S.Co.
Central Laboratory

PLEASE MAKE SURE THAT THIS IS THE CORRECT ISSUE BEFORE USE

Annex P Remedial measures (Popescuss , 2002).

1. MODIFICATION OF SLOPE GEOMETRY	3. RETAINING STRUCTURES
1.1. Removing material from the area driving the landslide (with possible substitution by lightweight fill) 1.2. Adding material to the area maintaining stability (counterweight berm or fill) 1.3. Reducing general slope angle	3.1. Gravity retaining walls 3.2. Crib-block walls 3.3. Gabion walls 3.4. Passive piles, piers and caissons 3.5. Cast-in situ reinforced concrete walls 3.6. Reinforced earth retaining structures with strip/ sheet - polymer/metallic reinforcement elements 3.7. Buttress counterforts of coarse-grained material (mechanical effect) 3.8. Retention nets for rock slope faces 3.9. Rockfall attenuation or stopping systems (rocktrap ditches, benches,fences and walls) 3.10. Protective rock/concrete blocks against erosion
2. DRAINAGE	4. INTERNAL SLOPE REINFORCEMENT
2.1. Surface drains to divert water from flowing onto the slide area (collecting ditches and pipes) 2.2. Shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthetics) 2.3. Buttress counterforts of coarse-grained materials (hydrological effect) 2.4. Vertical (small diameter) boreholes with pumping or self draining 2.5. Vertical (large diameter) wells with gravity draining 2.6. Subhorizontal or subvertical boreholes 2.7. Drainage tunnels, galleries or adits 2.8. Vacuum dewatering 2.9. Drainage by siphoning 2.10. Electroosmotic dewatering 2.11. Vegetation planting (hydrological effect)	4.1. Rock bolts 4.2. Micropiles 4.3. Soil nailing 4.4. Anchors (prestressed or not) 4.5. Grouting 4.6. Stone or lime/cement columns 4.7. Heat treatment 4.8. Freezing 4.9. Electroosmotic anchors 4.10. Vegetation planting (root strength mechanical effect)

Annex Q Report on damages resulted from Rainfall of 06/11/2002 to 17/12/2002 E.C. Habru Wereda Environmental Protection and Land Administration office, North Wollo, ANRS.

በሐብሩ ወረዳ የተከሰተውን አደጋ ስለማወቅ፣

በሐብሩ ወረዳ ከ06/11/2002-17/12/2002 ድረስ የጣለው ዝናብ ያደረሰው ጉዳት እንደሚከተለው ነው፡-

- የጉዳቱ ሰለባ የሆኑት 15 ቀበሌወች 018፣019፣05፣07፣09፣020፣011፣06፣014፣015፣010፣013፣ውርጌሣ 01 መርሣ ከተማ ናቸው።
- ከባድ ጉዳት የደረሰባቸው 7 ቀበሌዎች 019፣012፣013፣ ውርጌሣ 01፣ መርሣ ከተማ 09 ናቸው።

የጉዳዩቱ ዝርዝር ሁኔታ፣

1. አደጋው በማሣ ላይ ያስከተለው ጉዳት

   የወረዳችን የመኽር መሬታችን 24253 ሄ/ር ሲሆን በአሁኑ ሰአት 23540 ሄ/ር መሬት በተለያዩ ዘሮች የተሸፈነ ቢሆንም በጎርፍ የታጠበ በደለልና በትላልቅ ድንጋይ የተሞላ ሲሆን በአብዛኛው በጎርፍ የተጠቃው የአገዳ ሰብል /ማሽላና በቆሎ/ በመሆኑና በወረዳችንም በሰፊው የሚመረተው ማሽላና በቆሎ በመሆኑ ለ2002 /2003 ምርት ዘመን ከፍተኛ የሆነ የምርት ማነስ እንደሚገጥመንና በአጠቃላይ የጉዳት መጠኑ በአማካኝ 79 በመቶ እንደሚሆን በመስክ አረጋግጠናል።

2. አደጋው በእንስሣት ላይ ያስከተለው ጉዳት

   በጎርፍ ሁኔታ ከቀን ወደ ቀን እየጨመረ ጉዳቱም እንደዚሁ እየጨመረ ይገኛል።
   በአጠቃላይ በእንስሣት ላይ ያደረሰው ጉዳት ስናይ 12 በሬ 6 ላም 6 በግና 1 ፍየል በጎርፍ የተወሰዱ ናቸው ከዚሁ ጋር በተያያዘ በ018 ቀበሌ 4.5 ሄ/ር የግጦሽ መሬት ሙሉ ለሙሉ በመንሸራተት ከጥቅም ውጭ የሆነ ሲሆን እንደዚሁም ለአርሶአደሩ ለወደፊት ለእንስሣቶቹ ብሎ ያስቀመጠው መኖ /አገዳ/ በጎርፍ በመወሰድ በቀጣይም በወረዳችን የእንስሣት ግጦሽ ቦታና መኖ ችግር እንደሚገጥመን ይገመታል።

3. አደጋው በሰው ህይወት ላይ ያስከተለው ጉዳት፣

   በአጠቃላይ በጎርፍ ምክንያት 18 የሚሆኑ ቤቶች የፈረሱ ሲሆን ጎርፍ ቤታቸው በመግባት የቤት ንብረታቸውንና የሚበሉትን ከጥቅም ውጭ ያደረገባቸው 592 አባወራወች ከቀያቸው የተፈናቀሉበት ሁኔታ ቢኖርም አርሶአደሩ የራሱ የሆነ በአደጋ ወቅት እራሱን የመቋቋሚያ መንገዶች ያሉት ሲሆን ከእነዚህም ውስጥ አደጋ ሲፈጠር ከዘመድ አዝማድ መጠጋት ቤት በመከራየት ት/ቤት ውስጥ

2

በማረፍ ችግሩን ለመወጣት ትግል እያደረገ ቢሆንም ችግሩ ከቀን ወደ ቀን በመባባሱ የችግሩ ተጠቂ ሆነዋል።

በ16/12/2002 ሌሊት የጣለው ዝናብ በመርሣ ከተማ እና በ013 ቀበሌ በሰው ህይወት ላይ ከፍተኛ ጉዳት ያደረሰበት ሁኔታ ነበር። ይህም በአካባቢው ያለው ተራራ በመንሸራተቱ ወደ ግለሰቦች ቤት በመግባትና ሙሉ በሙሉ ቤቶቹን በመዋጥ ጉዳት አድርሷል። በመርሣ ከተማ 14 ሰዎች የሞቱ ሲሆን በ013 ቀበሌ 5 ሰዎች እንዲሁም 021 ቀበሌ 1 ሰው የምተ ሲሆን በውርጌሣ 1 ሰው በአጠቃላይ በሁለት ሌሊት 21 ሰው በአሰቃቂ ሁኔታ የሞተበት ክስተት ነበር። በመርሣ ከተማ የሞቱን ሰዎች ለማዳን የኄዱ 24 ሰዎች ላይ ጉዳት የደረሰ ሲሆን 11 በከባድ ጉዳት ወልዲያ ሆስፒታል ሲገኙ ቀሪዎቹ 13 ሰዎች ቀላል ጉዳት የደረሰባቸው ናቸው

4. አደጋው በመሰረተ ልማት ላይ ያስከተለው ጉዳት፣

- የሃብሩ ወረዳ በመስኖ ልማት ሃብት ትልቅ ድርሻ ቢኖረውም የዘንድሮው ጉርፍ ብዙ ዘመናዊና ባህላዊ መስኖ አውታሮችን ያበላሸበት ሁኔታ አለ በአጠቃላይ በሰንጠረዥ እንደቀረበው 14 መስኖወችን ካናላቸውን በመሰባበርና በደለል በመሙላት 2 ዘመናዊ 1 ባህላዊ መስኖ ሙሉ በሙሉ ከጥቅም ውጭ ሆኗል።
- ከ8 ቀበሌዎች ጋር የሚገናኝ ከሲብሶ ጊራና የሚወስደው ድልድል በጉርፍ ምክንያት ከጥቅም ውጭ ሆኗል።
- የውርጌሣ ከተማ ዋናው የአስፋልት ድልድይ ከአቅም በላይ በሆነ ሁኔታ ጉዳት ላይ መሆኑና ለጊዜያዊ መፍትሄ ተብሎ የመጣ ዶዘር ምንም ለውጥ ሊያመጣ አልቻለም።
- የወረዳውን በአጠቃላይ ክላይ ከተዘረዘሩት ችግሮች ምክንያት አሁንም በስጋት ያሉ ሰዎች ካሉበት ቦታ እንዲለቁ ጥሪ እየተደረገ ይገኛል በመሆኑም በስጋት ላይ ያሉ አባወራዎች በቀበሌ ደረጃ ስናይ

ቀበሌ	አባወራ
09	249
013	188
012	78
019	45
01/መርሣ/	257
015	40
ድምር	857

3

ተ/ቁ	ቀበሌ	በጐርፍ አደጋ ምክንያት የተጐዱ የመስኖ አውታሮች				
		የመስኖው ስም	የተጠቃሚ ብዛት	የመስኖ አይነት		የጉደት መጠን
				ባህላዊ	ዘመናዊ	
1	8	አጋምሣ	285		√	መሰራት የማይችል
2	8	ደሃና	90	√		መጠነኛ ጉዳት
3	8	እርግቦ	213		√	መጠነኛ ጉዳት
4	9	ወደይ	98		√	መጠነኛ ጉዳት
5	15	ጉኒ	240	√		መሰራት የማይችል
6	12	ለይማን	263		√	መጠነኛ ጉዳት
7	18	ገላና	630		√	መጠነኛ ጉዳት
8	18	ጐቱ	354		√	መጠነኛ ጉዳት
9	18	ወይመል	494	√		መጠነኛ ጉዳት
10	20	ኢማን አብድ	640		√	መሰራት የማይችል
11	15	መደኑ	273		√	መጠነኛ ጉዳት
12	15	አጋፋሪ	207		√	መጠነኛ ጉዳት
13	5	ጨረቲ	400		√	መጠነኛ ጉዳት
14	10	መገናኛ	385		√	መጠነኛ ጉዳት

4

Annex R Report of (Habru Wereda Disaster Prevention & Preparedness Agency).

በሐብሩ ወረዳ ከሃምሌ 6- ነሃሴ 17/2002 ዓ.ም የጣለው ዝናብ ያስከተለው አደጋ

ቀበሌ	የተጎዳው አባወራ ብዛት	ቤተሰብ	የተጎዳው ማሣ በሄ/ር	የጠፋ የምግብ እህል በኩ/ል	የጠፋው ንብረት በብር ሲተመን	የተጎዱ ቤቶች			የተጎዱ መሰረተ ልማቶች					የውሃ ተቋማት			የሰብል ጉዳት መጠን	የእንስሣት
						የፈረሰ	የተሰቀቀ	ቤተሰብ	FTC	የጤና ተቋም	መጋዘን	ት/ቤት	ድልድይ	ምንጭ	የእጅ ጉድጓድ	የተጎዱ የመስኖ አውታሮች		
18	830	4150	616	247	1823335	5	110	651	1	1	1	0	0	0	0	3	83%	2ላም 2 በሬ
19	399	2394	255	20	8240	3	11	42	0	0	0	0	1	1	2	0	80%	4ላም 1በሬ 1 ፍየል
12	314	1884	1145	96	112127	2	96	401	0	1	0	0	0	1	0	1	81%	1 በሬ
5	395	2370	23625	0	0	0	20	117	0	0	0	1	0	0	0	1	73%	
7	150	901	111	29	52000	0	0	0	0	0	0	0	0	0	0	0	67%	
20	393	2358	127.9	0	0	0	0	0	0	0	0	0	0	0	0	1	59%	
11	400	2410	413	0	0	0	0	0	0	0	0	0	0	0	0	0	66%	
6	177	796	97	0	0	0	0	0	0	0	0	0	0	0	0	0	65%	
9	511	2146	174	0	0	0	21	67	0	0	0	0	0	0	0	1	100%	2 በሬ
17	239	1147	174	0	0	0	0	0	0	0	0	0	0	0	0	0	71%	
14	578	2014	192	0	0	0	10	47	0	0	0	0	0	0	0	0	79%	6 በግ 4 በሬ
15	250	1025	289.75	0	0	0	0	0	0	0	0	0	0	0	0	3	81%	
10	621	2910	327	0	0	0	0	0	0	0	0	0	0	0	0	1	87%	
13	569	2258	452	0	0	2	184	719	0	0	0	1	0	0	0	0	80%	
01 ወርጌሣ	88	186	0	0	0	2	88	186	0	0	0	0	1	0	0	0	0%	
21	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1%	
01 መርሣ	45	160	0	0	0	4	46	160	0	0	0	0	0	0	0	0	0%	
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0%	
ድ	5960	29109	3692.4	392	354702	18	592	2390	1	2	1	2	2	2	2	14		6 ላም 12 በሬ 6 በግ 1 ፍየል

Annex S Landslide related questionnaire

1. Have you ever known before a landslide to happen in these area

    a) Yes b) No

2. Have you observed tilting of trees and cracks before the landslide happened?

    a) Yes b) No

3. Please explain if there were signs and symptoms before the incidence?________________

    ____

    ____

4. How were the rains then as compared to the rains before?

    A) Highest B) Lower C) Similar

5. How was the pace of the landslide?

    A) Gradual B) Fast C) Can't be noticed

6. When was it witnessed?____
7. How long did it stay devastating the area?____
8. Have you felt tremors during the occurrence of landslide?___________________________

    ____

    ____

9. What do you think was the causes of a landslide in the order of importance?

    A) ______________________ B) ____________________C) ____________________

    D) _____________________ E) __________________F) ______________________

10. What would be the remedial measure in response of the 2010 landslide disasters?_______

    ____

11. How were the 2010 rains as compared to the rains 3-4 years before?

    A) Highest B) Lower C) Similar D) can't be recognize

12. How was the extent of damage in your house?

    A) Completely destroyed B) Partially affected

13. Were there hot springs emerged with the occurrence of the 2010 landslides?

A) Yes B) No

14. In opinion what can you say about the future regarding the occurrence of landslides in this area?

A) It will never happen again B) It can be reactivated C) It is god all Knows.

15) How was the vegetation cover change as compared with the previous times?

____

16) Do you think deforestation will cause landslide?

____

17. Have you felt earthquake in this area for the last years? If yes when? & have you observed landslide at that time?

____

<u>Questionnaire to the focus group</u>

1. Have you ever known or heard of before a landslide to happen in this area?

   A) Yes b) No

2. What is /was the name of the localities where landslide was witnessed before 2010?

   ____

   ____

3. When was it occurred?____

   ____

4. What was the damage /loss attributed by the previous landslides?_____________________

   ____

5. Have you felt/heard of tremors with the time range of the previous landslide?___________

   ____

6. What do you think was the causes of a landslide in the order of importance?

   B) ______________________ B) ____________________C) _____________________

D) ______________________ E) ____________________ F) ______________________

7. How were the rains then as compared to the rains before?

B) Highest B) Lower C) Similar

8. When it was exactly started?____

____

9. What other localities are affected by the 2010 landslides?_________________________

____

____

10. How long did it stay devastating the area?_____________________________________

____

11. What was the damage /loss attributed by the 2010 landslides?_____________________

____

____

12. Have you felt/heard of tremors with the time range of the 2010 landslide?____________

____

____

13. What do you think was the causes of the landslide in the order of importance?

C) ______________________ B) ____________________ C) ______________________

D) ______________________ E) ____________________ F) ______________________

14. How were the rains of 2010 as compared with the rains before 3 to 4 years?

A) Highest B) Lower C) Similar

15. Is there deforestation around the area?

ACRONYMS

Acronyms

ADSWE	Amhara Design Supervision Works Enterprise.
ANN	Artificial Neural Network
CFB	Continental Flood Basalt
DEM	Digital Elevation Model
EIGS	Ethiopian Institute of Geological Survey
ELH	Evaluated Landslide Hazard
ERA	Ethiopian Road Authority
ERDAS	Earth Resources Data Analysis System
GIS	Geographic Information System
GPS	Geographic Positioning System
GSE	Geological Survey of Ethiopia
HWDP&PA	Habru Wereda Disaster Protection and Preparedness Agency
HWEP & LAO	Habru Wereda Environmental Protection and Land Administration Office
LHEF	Landslide Hazard Evaluation Factor
LHZ	Landslide Hazard Zonation
LSZ	Landslide Susceptibility Zonation
MOWR-KGVPIP	Ministry of Water Resource- Kobo Girana Vally Pressurized Irrigation Project
MCE .	Metaferia Consulting Engineers.
MM	Modified Meracali
SSEP	Slope Susceptibility Evaluation Parameter
TEHD	Total Estimated Hazard
UNESCO	United Nation Educational, Scientific and Cultural Organization
US	United States
USGS	United States Geological Survey
WP/WLI	Working Party for World Landslide Inventory

Abstract

On August 22, 2010, after a period of prolonged rainfall catastrophic and devastating landslides have been triggered around Mersa and Wurgessa towns, Habru Wereda of North Wollo Zonal Administration, Amhara National Regional State in northern Ethiopia, some 490 km and 465 km respectively from Addis Ababa. These Landslides have caused twenty three causalities, destruction of property and infrastructures, disrupting traffic movement on roads, loss and damage to agricultural lands, and a general degradation of natural environment. The dominant type of slides which triggered was soil slips, translational slides and debris flows. Thus, looking into the severity of such devastating landslide hazard in the area the present research study was conceived, mainly to evaluate the various possible causes which were responsible for the triggering of such landslide hazard in the said area. Besides, to identify those areas which have possible potential for future landslide activities, Landslide hazard zonation of the present study area was delineated.

In order to meet out the objectives of the present study a systematic methodology was executed. To develop a conceptual framework of the problem a thorough literature review was carried out. As a part of methodology field trip was made where various kinds of observations and assessments were made pertaining to the causative and triggering factors which might be responsible for the instability of the area. An inventory on various past landslide activities and the potential instability zones in the area was prepared. In order to delineate the Landslide hazard zonation of the area expert evaluation technique was adopted. The technique for Landslide Hazard Zonation (LHZ) proposed by Anbalagan (1992) and modified by Raghuvanshi (2011) has been followed for the present study. This modified technique includes inherent causative factors such as; slope material, slope morphometry, relative relief, landuse/ landcover and groundwater condition. Besides, it considers triggering factors such as; rainfall, seismicity and manmade activities. Based on these inherent causative and triggering factors landslide hazard was evaluated for the present study area.

From the field observations and the data analysis on various aspects it was found that the possible cause of past landslide activities is a combination of inherent causative and triggering factors. The inherent causative factors responsible for past activities are; mainly slope morphometry, incompetent slope material and structural discontinuities, whereas the triggering factor was mainly prolonged intensive rainfall and for some slopes the construction activities which has made the slopes steeper locally. The LHZ performed during the present study reveals that 25% of the present study area falls under very high hazard, 69% falls into high hazard, and 6% falls in moderate hazard zone. Further, in order to validate the LHZ map prepared during the present study, past landslide activities and potential instability areas, delineated through inventory mapping, was overlain on it. All past landslide activities and potential instability areas fall within very high and high hazard zone. Thus, the satisfactory agreement confirms the rationality of the considered governing parameters, the adopted methodology, tools and procedures in developing the landslide hazard map of the study area. Further, to avoid/ reduce the hazard in the susceptible zones various remedial measures have been proposed, which include proper drainage of the area and resettlement of residents from high and very high hazard zone to other stable areas.

Key words: *Landslide, Causative factors, Triggering factors, Landslide hazard zonation.*

CHAPTER ONE INTRODUCTION

1.1 Preamble

Landslide is defined as the mass movement of rock, debris or earth along a sliding plane. The term “Landslide” comprises almost all varieties of mass movements on slopes, including some, such as rock-falls, topples, and debris flow (Varnes, 1984).

Landslide causes substantial human life, economic and farm land losses throughout the world. Only from 1995 up to 2005 over 12,730 causalities have been reported due to landslide worldwide (World Bank, 2010). From 1900 to 2011 a total of 54,020 peoples have been killed, 6,848,109,000 US dollars have been lost by Landslides excluding Subsidence and Avalanches (www.em-dat.net).

It is also common occurrences and recurring hazards in Ethiopia. Absolute mortality risk by landslide is highest in countries such as Ethiopia (http://www.preventionweb.net.). The highlands and mountainous area of Ethiopia; like Blue Nile Gorge, Tarmaber, Kombolcha – Dessie road, Wondogenet area and many other parts of Ethiopia are repeatedly facing problems associated with landslides. These landslides have caused human fatalities as well as significant economic losses. From 1993 to 1998 alone, about 300 lives have been lost, more than 200 houses demolished, over 100 km long road damaged and in excess of 500 ha of land devastated (Lulseged Ayalew, 1999).

In August 2010, following prolonged precipitation, which has fallen throughout summer; Landslides have been triggered in many parts of Ethiopia. Wurgessa, Mersa, Wuchalle and the southern margin of Girana basin, which are called Wefacho ridge and Gorarba – Abey Terara, are among those which have been affected by landslides in August, 2010.

These landslides which claimed many casualties have also affected much of the farm lands and damaged the economy of the poor farmers. This led to considerable concern among the local Authorities as well as the population about the stability of the slopes in the area.

Along Combolcha – Woldiya road at localities; Tita, Baso-Mile, Tis–Abalima, Wuchalle, Wurgessa, and Nene–Ber; distress, and deformation of road occurred due to the road slide near to bridges and road side slides on the main road body. During rainy period, on August 2010, the slide debris accumulated on the road has posed difficulty for normal traffic movements. Since there is no emergency plan in the area either for human fatalities or for the infrastructure damage there was no immediate response to reduce the risks.

The types of landslide which occurred in the area were dominantly shallow soil slips, Debris flow, translational and rotational sliding and at a place rock and soil fall.

1.2 Statement of the problem

Landslide problem has been causing lots of causalities, economic and social problems to societies especially to those that are living in the mountainous area (Larson, 2008).

Most of the people of the countryside in the study area are living at the toe and sloppy side of mountain leaving the plain land for agricultural purpose. In towns also due to the shortage of suitable lands for building construction as a result of increasing number of population in alarming rate, and increased cost of land, peoples are forced to live in mountainous area. This has increased the risk of Landslide by increasing vulnerability, which means the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomena of a given magnitude (Varnes, 1984).

After prolonged rainfall of summer, on August 22, 2010, devastating landslide had occurred in the town of Mersa, Wurgesssa, and at locality called Limo and Berebiyu, Habru Woreda of Amhara National Regional State, which are 70 and100 km, respectively from Dessie town (Fig. 1.1). The Mersa landslide killed 14 people, damaged three homes completely, six homes were partially damaged and twenty three additional homes were evacuated by the local administration. While the Berebiyu and Limo landslides killed five and four people respectively those are buried inside their homes.

In Habru Woreda of Amhara National Regional State, a large area of farm land which were used for the cultivation of crops, cereals and vegetables degraded by these landslides. In many parts of the road, along Combolcha – Woldiya road, distress and deformation occurred due to this phenomenon. The rock falls, debris flows and slides hindered the traffic along these road sections. Due to this problem Ethiopian Road construction Authority has been spending unnecessary external expenses for temporary remedial measures.

In this study, various causes of slope instability which includes both causative and triggering factors will be identified and thereby various remedial measures will be proposed. Landslide hazard zonation map of the study area will be prepared.

Therefore local administration and concerned government bodies will take appropriate measures for local residents, who are living in a state of anxiety for any future landslide hazard, according to the hazard map.

1.3 The study area

1.3.1 Location and accessibility

The study area is located in Mersa and Wurgessa towns, Habru Woreda of North Wollo Zonal Administration, Amhara National Regional State. The Woreda Administration headquarter is situated in Mersa town along Combolcha – Woldiya road 490 km from Addis Ababa and 30 km from Woldiya to South (Fig 1.1).

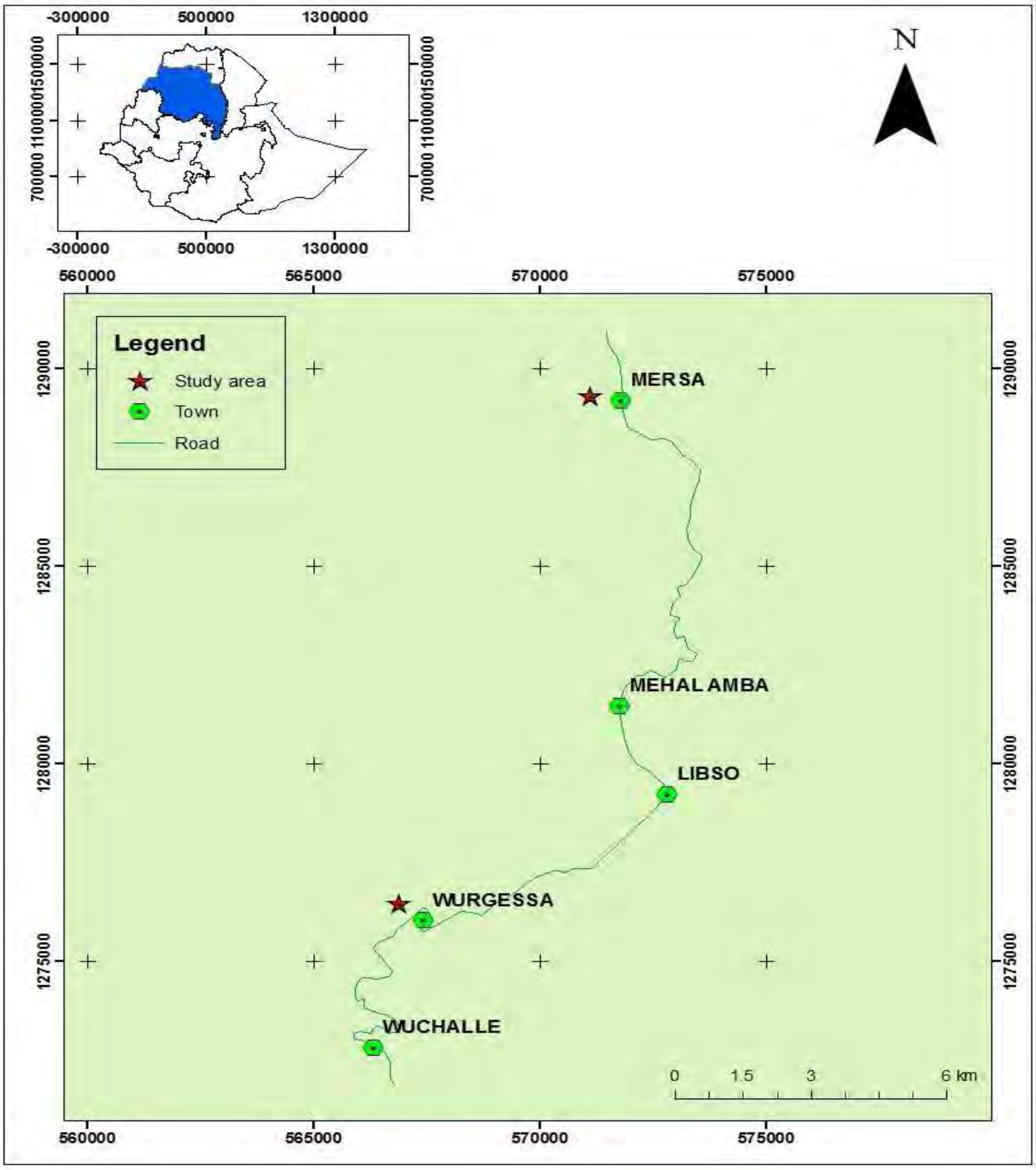


Fig.1.1 Location of the study areas

Wurgessa is located along same road which is 465 km from Addis Ababa and 5 km from Wuchalle, which is a historical town (Fig.1.1).

Geographically the study area (one part towards Mersa) is bounded by UTM (Zone 37 N) coordinates (1287 000 N; 568 000 E) to (1 290 000 N; 568 000 E) and (1 291 000N; 572 000 E) to (1287 000 N; 572 000 E) and for the other part towards Wurgessa it is bounded by UTM coordinates (1275 000 N; 563 000 E) to (1278 000 N; 565 500 E) and (1276 500 N; 567 500 E) to (1273 000 N; 565 000E).

The study area can be accessed by Combolcha – Woldiya asphalt road which links Addis Ababa, the Afar region and the northern part of Ethiopia. Most of the study area is found towards the sides of the main road which can be accessed by foot trails on rugged topography.

1.3.2 Climatic condition of the study area

There is one principal Metrological station at Sirinka, located near to the study area which is 10 km from Mersa. Rain gage Metrological stations are located at Mersa, Wurgesa and Wuchalle. Wuchale is located about 3 km from Wurgessa (the study area). According to the Metrological data from these stations, the main rainy season in the area is from June to September and a short rainy period from March to April (Fig. 1.2).

Mersa and Wurgessa area receive annual average rainfall about 962 mm (Year 2000 to 2009) and 1188 mm (Year 2000 to 2005), respectively. Maximum Temperature of the study area is 33 ^{0}c in the month of June and minimum temperature of 9 ^{0}c in the month of November (year 2000 to 2009) (Annex H & I).

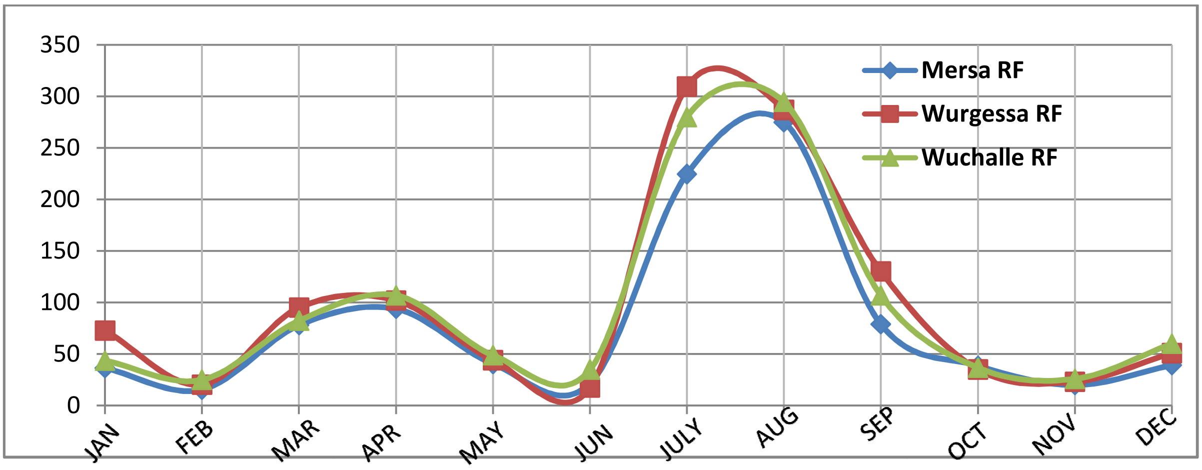


Fig 1.2 Monthly Average Rain fall for Mersa, Wuchalle (2000 -2009) and Wurgessa (2000 – 2005)

1.3.3 Physiography and drainage pattern of the study area

The study area is located in the Afar rift marginal escarpment. It is part of the western escarpment and western boundary of the Mersa and Girana marginal basins. The maximum elevation within the study area is 1950 m at the top of Abey Terara Mountain for Mersa and 2938 m at Bahiritu Lake for Wurgessa (Fig.1.3). The minimum elevation is 1620 m in the town of Mersa and 1900 m at road side near to Golo River for Wurgessa. The drainage network of the study area is dendritic and parallel. Structurally controlled streams are dominant in the study area.

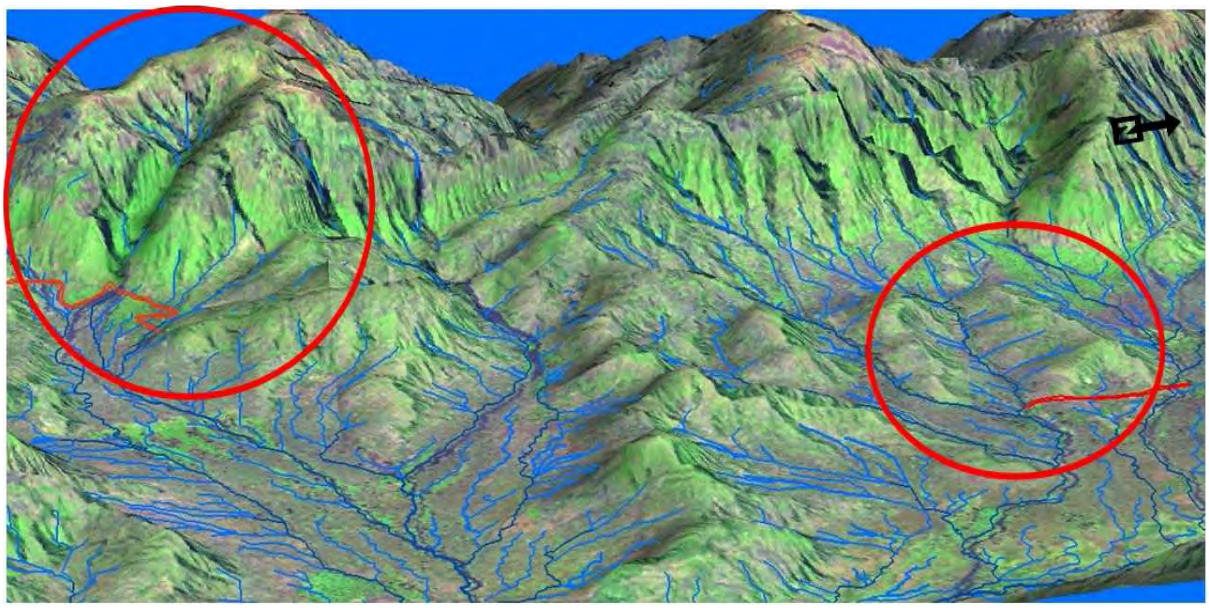


Fig 1.3 General Physiography of the study area

1.3.4 Seismicity of the study area

The study area is located in the western Afar escarpment, which is part of the rift marginal basin. It is found at a range of 150 km in air distance from Debaho active volcanic areas and seismicity is situated. This indicates that the study area is in great proximity to active seismic zones. It falls in the seismic Zone 4 which has a ground acceleration of 0.1g (Chapter 6; Fig. 6.10) on the map of seismic zonation of Ethiopia which is produced by Laike Mariam Asfaw (1986).

1.3.5 Vegetation cover

The vegetation cover in the study area can be categorized as sparsely and moderately vegetated.

Some trees, scattered bushes and wild grass are the types of vegetation which cover most parts of the ridges in the study area.

The gorges are relatively densely vegetated, the steeper parts are sparsely vegetated and foot of the mountain is cultivated by different kinds of crops and vegetables. The dominant crop production in the area is sorghum, Maize, Tef, and vegetables like onions. In the highest elevated portion of the study area in Wurgessa, wheat is also cultivated.

1.4 Objective of the study

1.4.1 General Objective

The impact of landslides in Mersa town and around Wurgessa, along Kombolcha – Woldiya road, has caused many causalities and severe distress and deformation on roads. Therefore, the general objective of the present research is to identify the factors responsible for these failures and to understand the exact mechanism of the landslides. Besides, it was also intended to work out the landslide hazard zonation of the area. Further, based on the results of the present study, possible general remedial measures for critical slope sections will be suggested.

1.4.2 Specific Objectives

- To assess the causative and triggering factors responsible for landslides in the area.
- To determine the engineering geological characterization of soils and rocks of the study area and to assess their potential for landslide.
- To know the possible failure mechanism of the landslides.
- To prepare the landslide hazard zonation (LHZ) map by integrating geological, slope morphometry, Relative relief, vegetation cover, ground water condition, seismicity, Rain fall and manmade activities. Later, to validate the LHZ map with prepared general inventory of past landslide activities and demarcated areas of possible potential instability.
- To suggest possible general remedial measures.

1.5 Importance of the study

The past damage resulted from the landslides in the study area was very devastating. Many casualties, demolished houses, damaged roads and bridges, were recorded by these incidents. These landslides left destruction marks in the study area as; tension cracks, cracked lands and inclined trees, which are the indications for potential slope instability. People who are living at the toe of steep slopes near to the catastrophic landslides of August, 2010, are anxious and suspecting reoccurrence of similar Landslide activity which may bury them like their neighbors. The road which takes from Dessie to Woldiya, which is at great risk of landslides, is an important corridor which links many important cities in the North from the central Ethiopia. Therefore, the present study is very important from the point of view of identifying and understanding the possible causes of the past landslide activities and delineating the areas which are susceptible for future landslide activities. Besides, the present study is also forwarding the general remedial measures which may be adopted to minimize or to eliminate the possible hazard caused by these landslides.

1.6 Methodology and Materials Used

1.6.1 Materials used

- Topographic map (1: 50,000) was used for base map preparation and delineation of facet map of the study area.
- To prepare different thematic and landslide hazard zonation maps different softwares such as; ARCGIS, AUTOCAD (MAP), ERDAS IMAGINE and GLOBBAL MAPPER softwares were utilized.
- To determine engineering properties of soil laboratory test has been conducted.
- GPS was also used to mark the various locations.

1.6.2 Methods

For successful completion of the research office work, field work and laboratory analysis has been done;

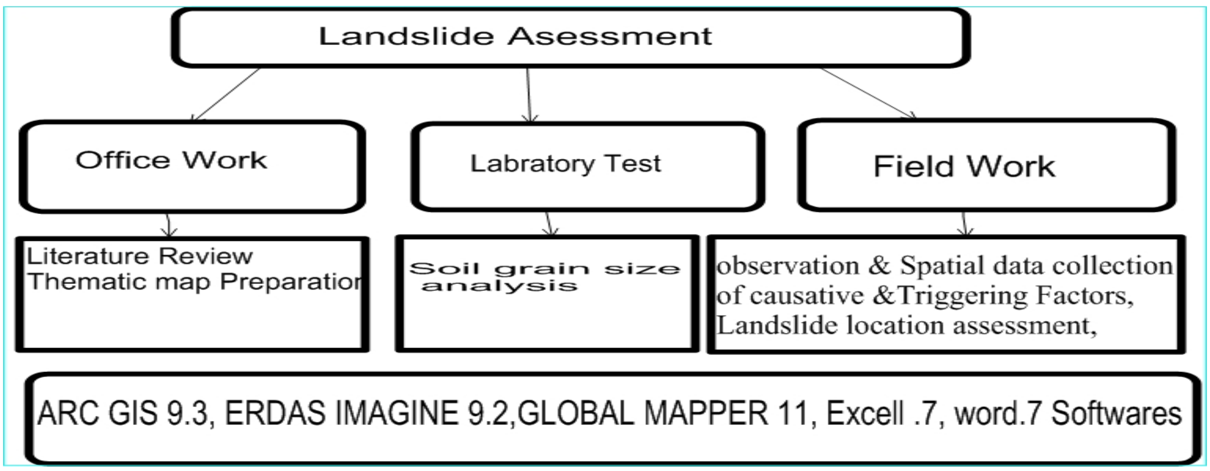


Fig 1.4 Flow chart of the Methodology followed.

- Desk study; includes review of relevant literature and maps, technical research papers and thesis so as to develop preliminary conceptual framework and to prepare base map.
- Inventory mapping survey using GPS to obtain detailed map of landslide activities in the area and the surface manifestations of instability.
- Field observation on geology, structural discontinuities, slope geometry, land use land cover and ground water condition, rain induced manifestation on slopes and manmade activities of the study area.
- Field data analysis and causative factors map preparation.
- Computation and analysis for estimated total hazard for the study area.
- Rain fall data analysis to understand the triggering factors.
- Sub surface investigation using trial pits, to investigate soil type for its vertical depth variations and sample collection for laboratory testing.
- Determination of, index properties and particle size distribution of the material using laboratory analysis to characterize the soils involved in landslide.
- Preparation of Landslide Hazard Zonation Map based on the primary and secondary data.
- Validation of Landslide Hazard Zonation map with inventory data.
- To workout suitable remedial measures for critical slope sections.

1.7 Outcomes of the study

In the present study firstly, it was intended to identify the various causative and triggering slope instability factors and secondly, to prepare the landslide hazard zonation map of the study area. Understanding the causative and triggering factors responsible for slope instability may give an insight into the possible mechanism of landslide in the area which may probably be helpful in evolving the possible remedial measures. The Landslide hazard zonation map of the present study area may further help the administrators and planners to take decisions on safety of local people and property. Besides, it may also guide them to locate safe sites for any future developmental activities.

Ethiopian Roads Authorities are spending much of their resource for temporary remedial measures to mitigate the threat and damage caused by slope stability problems. The recommendation made through the present study may help in deciding permanent remedial measures. Thus, these may help in alleviating the reoccurring traffic obstacles during rainy season. Moreover, the present study may be helpful to researchers, individuals or agencies/

organizations, who are intending to carry out similar type of studies in the other parts of the country.

1.8 Future studies and extension of the research work

This study is the first research work on landslide in the study area. It provides valuable information on possible causes of landslide, susceptible landslide areas and possible remedial measures to be considered. The present research study was attempted mainly to delineate the areas which are susceptible for landslide activities. Thus, based on the degree of landslide hazard different areas in the study area have been delineated. The present study may be continued in future and detailed slope stability studies could be carried out for all critical slope sections falling within very high hazard or high hazard landslide zones, as delineated during the present study.

1.7 Limitation of the study

No historical landslide records were available in the area which may be used to correlate with these active landslide occurrences. Due to its rugged and steep topography accessibility was difficult in some part of the study area. The present research also faced limitations on finance and resources.

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CHAPTER TWO LITERATURE REVIEW AND PREVIOUS STUDIES

2.1 Preamble

Landslide is a worldwide problem which causes much casualties and economic losses. It is also recurrent and devastating hazard in the highlands of Ethiopia. Therefore, many research studies have been conducted on landslide related issues in the world as well as in Ethiopia.

In this chapter literature review about the causes of slope instability, classification and types of landslide, different techniques of landslide hazard zonation mapping, and previous landslide studies in Ethiopia and around the present study area has been presented.

2.2 Literature Review

Landslide has been defined as a term which comprises almost all varieties of mass movements on slopes, including rock falls, topples, and debris flows, that involve little or no true sliding (Varnes, 1984). It is also defined by WP-WLI (Working Party for World Landslide Inventories), (1993) as a movement of a mass of rock, earth, or debris down a slope. Slope failures (i.e., landslides) occur when the forces generated by the weight of the soil in a slope exceed the shear resistance (strength) of the soil. The force that is responsible for the occurrence of landslide is gravitational force. Gravity is the force that pulls everything towards the center of the earth. Therefore, materials which are on slope are more susceptibility to force of gravity, which causes landslide, than material which is on relatively flat areas (Nelson, 2010).

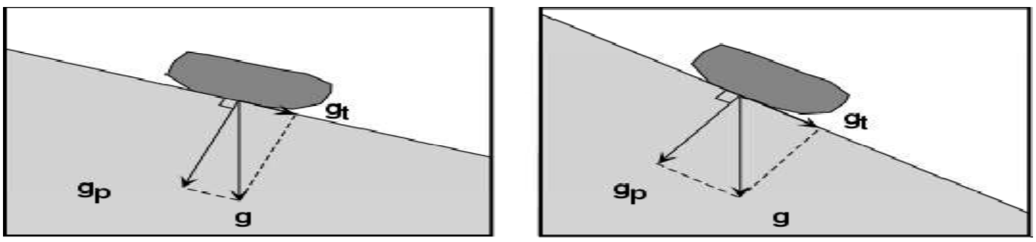

Fig.2. 1 Illustration of tangential components in slope stability analysis *(Nelson, 2010)*

The tangential component of gravity, gt, is called shear stress which favors the movement of materials down the slope and the perpendicular component of gravity, gp, which is resisting movement, is called shear strength which includes frictional resistance and cohesion among the particles that make up the object.

Fs = Shear Strength/Shear Stress …….. eq.2.1

If the safety factor (FS) becomes less than 1.0, slope failure is expected.
Shah and Nagarajan (2004) explained that slope failure is the result of gravitational forces acting on mass which can creep slowly, fall freely and slide along some failure surface or flow as slurry. Besides the gravitational forces, slopes may also fail when seepage forces operating on the regolith are greater than the forces resisting failure (O'Loughline, 2005).

According to Turner (2008), the gravitational forces of the soil, surcharge loads at the surface and seepage forces cause slope to fail. Internal friction in non-cohesive soils and cohesion in cohesive soils are the forces within the soil that resist slope failure. Most soils have both cohesion and friction. Therefore, reducing these forces also will cause land sliding.

2.2.1 Causes of slope Instabilities

There are several factors which makes slope unstable. These factors cause instability either by increasing the shear stress or reducing the shear strength. For the occurrence of landslide there must be a pre existing long term process which prepare the slope to be unstable these are called causal factors (Shuster and Wieczorek, 2002). Varnes (1984) and Anbalagan (1992) named these factors as inherent causative factors. Geology that is lithology and structures, slope morphometry, relative relief, ground water condition, and land use land cover are the major inherent causative factors which are responsible for the causes of landslide (Anbalagan, 1992). Besides, for the landslide to be triggered it needs external stimuli which are called Triggering factors such as; intense rain fall, ground acceleration due to seismic activities and manmade activities.

Shah and Nagarajan, (2004) explained these factors clearly as mentioned in the following paragraph. The chief factors to initiate or trigger mass movements include; (i) heavy and prolonged rain fall, (ii) Cutting and heavy excavation on slopes and (iii) Earthquake tremors.

According to Varnes (1984) some of the causes are inherent in rocks or soils its composition and structures, some constant like inclination of undisturbed slopes, some variables such as; ground water level, some are transient like; seismic vibration, and some are imposed by new events such as; construction activities. Further O' Loughline (2005) also added land use and types of vegetation as causative factors. Generally, the factors which are responsible in causing and triggering slope instability can be grouped as geological factors, geomorphic factor, hydrological factors, land use land cover, manmade activities and seismicity.

Geological factors

Most of the slope failures are shallow which involves only the upper few meters of the surficial deposits. Therefore, particular attention should be given to the geological mapping to the deposits near and at the surface (Varnes, 1984).

Different rock types (or lithology) have varied composition and structure, which contribute to the strength of the material. Therefore, the stronger rocks give more resistance to the driving forces as compared to the weaker rocks, and hence are less prone to landslides and vice versa (Kanungo et al., 2006).

Generally, geological factors which affect the stability of slopes can be related to lithology, mineral composition, geotechnical properties of soils, stratigraphy, and structures of rock mass (Varnes,1984).

Lithology

Lithological condition is the primary causes of slope instability. Most authors who wrote about landslide considered lithology as the first and the fundamental causes of slope instability.

Varnes (1984) explained the contribution of lithology on slope instability as follows;

Lithlogy includes the composition, fabric, texture or other attributes that influence the physical or chemical behavior of rocks and engineering soils.

These attribute are very important in determining the shear strength, permeability, and susceptibility to chemical and physical weathering, and other characteristics of soils and rocks materials, which in turn affects the slope stability.

According to Varnes (1984), material which is susceptible for landslides are those with loose or open structures such as; loess, volcanic ash on steep slopes, and saturated sands of low density, fine grained "sensitive" deposits of clay or rock flour, and cliffs of fractured rock.

The advanced weathering which will lead to degradation of the geotechnical properties of the volcanic tuffs and to the disintegration of the basalts to soils are the main causes of instabilities (Fall et al., 2006).

Most of the landslides in mountainous regions are small shallow failures involving colluviums, soils and weathered rocks (Hearn and Griffiths, 2001), these relatively erodible geological material over steep slopes which results abundant colluvial accumulation often results debris flow (Lin et al., 2002). Dapporto et al., (2005) also added that failure surfaces are generally localized into the colluvial layers. Sensitive or quick clays, which are those that lose much of their strength up on remoulding at constant water content, have been involved in many serious flow-type landslides Varnes (1984). In deeply weathered residual and colluvial soils and alluvial deposits translational and rotation slide usually occur (Kumar, 2009).

Mineral composition

Varnes (1984) explained the impact of mineral composition on slope instability from the point of view of availability of clay minerals in the soil or in the rock. In fine grained sedimentary deposits, the relative abundance of clay minerals, the clay mineralogy, inter-particle bonds, and the presence and chemistry of water are dominant compositional factors influencing slope stability. With increasing water content clay materials lose shear strength.

Geotechnical properties of soils

Besides the mineral composition and texture of soils both physical and chemical characteristics which is the geotechnical properties of soils are the main factors contributing to soil slope failures. According to Kumar (2009), soil composition, depth, shear strength (which depends on density, cohesion, plasticity, dilatancy and the angle of internal friction), porosity, permeability, grading, packing, moisture content and organic matter content are some of the important geotechnical parameters of soils which control slope stability.

Stratigraphy

Stratigraphic condition affects the stability of the slopes in many ways. The presence of a permeable superficial material overlying a more impermeable bed rock unit can result into the formation of high pore water pressure (perched –water table condition) which may trigger shallow instability (Cross, 1998). Therefore, the type of superficial material, taken in conjunction with the type of bedrock unit, is important factors for landslide susceptibility assessment.

The presence of competent and incompetent rock layer in the stratigraphy of the area affect the stability of the slopes by serving the weak layer as a plane of failure.

Structures

Geological structure also control slope stability condition to a great extent. Marden et al., (1992) explained the effects of geological structures on slope stability as; down slope dipping planes separating rocks of different competence or alteration, as well as joints and fractures oriented in the same direction, may impede vertical infiltration and root penetration, as well as acting as potential failure planes. Therefore, the influence of rock structures (bedding planes, folds, joints, and faults) is an important factor in the stability of natural hill slopes.

Kanungo et al., (2006) added that lineaments are the structures which describe the zone / plane of weakness/, fractures and faults along which landslide susceptibility is higher. It has generally been observed that the probability of landslide occurrence increases at sites close to lineaments which not only affect the surface material structures but also make contribution to terrain permeability causing slope instability. The presence of tectonic structures like faults breaks the rock mass reducing the strength (Donati and Turrini, 2001).

According to Kumar (2009) landslides are mainly governed by;

- The line of intersection of discontinuities with the slope;
- The angle of inclination of the discontinuities; and
- The relationship of the discontinuities with the slope aspects.

When the direction of the intersection of the discontinuities surfaces and the slope becomes parallel, the condition is conducive to failure and these increases with its inclination until the angle of inclination of the intersection of the discontinuity surface reaches beyond the angle of slope.

Geomorphic factors

The two geomorphic factors which control slope instability are slope gradient and relative relief. According to Alexander (1999), mass movement will occur where ever a slope is steeped beyond its threshold angle of stability, which is the steepest angle at which it can maintain itself. The hill slope angle supplies the potential energy gradient on which a landslide moves (Cross, 1998). Therefore, at higher angles, the profile of the slope will alter itself to restore stability by undergoing slope failure**.** Relative relief which is the difference in height between the bottom and the top of the slope provides a further measure of gravitational force which exists within the slope (Cross, 1998). Therefore, the more steeper and the higher relative relief of the slope the more liable is to be unstable.

Slope gradient is a significant factor in determining landslide location and hence landslide frequency. Failure in logged terrain occur most frequently on slopes in the 30^o to 40^o slope class, where as landslides in the natural terrain occur mostly on slopes greater than 35^o (Jakob, 2000). Most landslide failures occurred over slopes inclined from 35^o – 50^o but the maximum frequency is observed in the 40^o – 45^o class (Dapporto et al., 2005). Slope angle exerts a significant influence on landslide susceptibility: all things being equal the steeper slopes are more susceptible to failure than flatter slopes (Parise and Jibson, 2000).

Land use land cover

The effects of vegetation on slope stability appear to be complex in that it depends on local conditions of soil depth, slope, and type of vegetation. A vegetation cover in some ways definitely promotes stability and in other ways it may not (Varnes, 1984).

According to Loughlin (2005), land use land cover affects the stability of the slopes as follows;

- Roots contribute to the stabilization of earth flows by creating a reinforced upper soil layer 1-2 m thick that possesses relatively high lateral (tensile) strength as well as enhanced shear strength or increased apparent cohesion.

- The reduction in soil moisture due to evapotranspiation by trees and forests in the upper layer of earth flow material will change cohesion and friction angle of the soils.

- The accumulation of a forest floor consisting of the accumulated litter, humus and tree roots protects the underlying soil from raindrop impact and surface wash.

Kanungo et al., (2006) explained that the incidence of landslide is inversely related to the vegetation density. Hence, barren slopes are more prone to landslide activity as compared to the forest area.

According to Alexander (1999) deforestation or other kind of devegetation can also weaken a slope, as the roots of plants tend to hold soils together, accounting for up to 90 percent of stability on certain slopes.

Hydrological condition

Water is the main triggering factors in destabilizing hill slopes. Identification of water source, water movement, amount of water and pressure are, as important as the identification of the material constituting the slopes. In an area with highly jointed rocks and the presence of thick overburden, the surface and ground water play a crucial role in the evolution of landslides. Geological structures like faults in high slope, because of high permeability, pressure head and seepage velocity bigger than the surrounding area, the impact on slope instability will be higher (Mahajan and Virdi, 2000).

According to Nelson (2010) water has a number of impacts on slope instability among these;

- Water can seep into the soil or rocks filling air spaces. Since water has more weight than air it increase the weight of slope material. This will increase the shear stress there by slope instability.
- Water has the ability to change the angle of repose (the steepest slope angle at which a pile of unconsolidated soil grains remains stable), and is controlled by the frictional contact between the grains.
- Adsorption of water by clay rich soils will lead increase of slope material weight and loss of cohesion which is loss of frictional contact between grains.
- Water can reduce the cohesion between mineral grains by dissolving the cement which is made of calcite, gypsum or halite which is highly soluble in water.
- Liquefaction may result when loose sediments are oversaturated with water and individual grains loose grain to grain contact with one another as water gets between them.

Ground water condition at the surface certainly can be observed, spring located and available precipitation records (Varnes 1984). Therefore, ground water condition of the study area should be observed by the presence of springs, algal growth on shadow areas, gully development, slope toe erosion, stream bank erosion and other water marks on slopes face.

Manmade activities

According to Kumar (2009) conceived, unscientific, mismanaged, unplanned and improperly executed construction activities, both legal and illegal, has give rise to large scale cutting of hill surface for construction of roads, buildings and other infrastructure. Above this ignorance, lacks of awareness, carelessness and due to financial and technical constraints preventive /protective measures are not undertaken to the desired/required extent.

Manmade activities affect the stability of the slopes both by increasing the shear stress and reducing the shear strength. Kumar (2009) explained that man made activities will increase steepness and height of the slope, and mass of slope material due to extra load placed on it, and decrease in shear strength due to loss of vegetation and blasting etc, increased pore water pressure and drainage, increases infiltration etc, and withdrawal of lateral support by road cut.

The removal of lateral support by man's activities are important cause of slope failures in cuts for roads or house sites, excavations, quarries and open pit mines, canals and in the banks of reservoirs during drawdown. Likewise these actions alter stress conditions through the placing of fills, waste-piles, stock piles of ore rock, and structures where no surcharge existed before (Varnes, 1984).

According to Alexander (1999), ploughing or poorly organized drainage on slopes increases infiltration of water which leads to soil saturation and will increase pore water pressure which exerts a positive force that may cause the slope to fail.

Different cropping system, their land preparation and water requirement condition reduces the shear strength of the hill-slope. The retaining water percolate down the rock strata and it assist the weathering. The saturated weathered rocks multiply the load of regolith, which cannot be adjusted by the slope and it starts to fail downwards (Poudel, 1996).

Seismicity

Varnes (1984) explained that in seismically active parts of the world some of the most disastrous of all historic landslides have been triggered by seismic shocks. For landslide hazard zonation it must be intimately linked with seismic zonation through evaluation of the slope material's response to acceleration, amplitude and duration of seismic motion together with estimation of recurrence interval.

2.2.2 Classification of Landslide

Landslide can be classified based on materials involved in slide like; rocks, debris (<80% sand and finer) or earth (>80% sand and finer) and based on the kind of movement involved like falling, toppling, sliding, spreading, flowing or complex. Based on the combination of these two conditions landslide can be classified as per Table 2.1.

Table 2.1 Classification of Landslide *(Varnes, 1978)*

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL		Rock block slide	Debris block slide	Earth block slide
		MANY UNITS	Rock slide	Debris slide	Earth slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow	Earth flow (soil creep)
COMPLEX			Combination of two or more principal types of movement		

The types of landslide which occurred in the present study area can be grouped based on the above classification as Translational, Debris flow for the major type of occurrence, and Rock slide and fall at few places.

Landslide can also be classified based on the velocity of its movement. According to Cruden and Varnes, (1996) those movements which have a velocity > 5m/s are considered as extremely rapid, and those < 16mm/yr are considered as extremely slow. The landslide which occurred in the present study area may be grouped as very rapid and extremely rapid based on the information that was gathered from the local residents.

2.2.3 Types of Landslide

Varnes (1978) identifies types of slope movement as falls, topples, slides (rotational and translational), lateral spreads and flows as elaborated below;

Fall

Fall, the most rapid type of landslide, originates on cliffs or steep slopes and drop vertically or at a sharp angle. Falls can range in size from a small stream of dirt or pebbles to sudden shearing of a massive section of rock face. According to USGS (United States of Geological Survey) (2004) fall are abrupt movement of masses of geological material, such as rocks and boulders that become detached from the steep slopes or cliffs.

Delano and Wilshusen, (2001) added on the susceptibility of rock fall in an area as; rock fall depends mostly on the spacing and orientation of fractures, bedding, and other discontinuities in the rock. Stream banks, highways, and railroad cuts, old mine and quarry areas and other human – made steep slopes are typical settings of rock fall.

Slide

Slide is mass movement of soil or rock that occurs as a coherent unit by slipping along one or more failure surfaces.

According to USGS (2004), the two major types of slides are rotational and translational slides. Rotational slides are in which the surface rupture is curved concavely upward and the slide movement is roughly rotational about the axis that is parallel to the ground surface and transverse across the slide. Translational slide is the landslide mass which moves along a roughly planar surface with little rotation or back ward tilting.

Slump

Slump is a slide having a down ward rotational component along a concave shear surface such that the horizontal movement at the base of the slide zone is greater than that at the top. Slumps, most commonly are caused by (i) increased moisture content, which decrease strength; (ii) removal of support at the toe of a slope (iii) adding material at the top of the slope; (iv) construction of a cut or filled slope that is too steep for materials involved to be stable. Slump failure commonly occurs in thick, uniform soils and weathered rock, but it may occur also in bed rock (Delano and Wilshusen, 2001).

Flow

Flow is a mass movement whose internal structure has become disaggregated, chaotic and turbulent. The rock and /or soil involved in a sediment flow are mixed with water or air which imparts a lubricating effect to the flow. Sediment flows are further categorized as granular flows if they contain less than about 20 percent water and slurry flows if they contain between 20 and 40 percent water.

Both granular flows and slurry flows can entrain debris as they progress down a slope or channel; if sufficient foreign material is accumulated, the flow may be termed as debris flow.

According to USGS (2004) there are five categories of flows that are different from one another these are;

(i) Debris flow: - which is a rapid mass movement which is a combination of loose soils, rocks; organic matter, air and water mobilized as slurry that flows down the slope. Debris flows are commonly mobilized from other types of landslides that occur on steep slopes, are nearly saturated and consist of a large proportion of silt- and sand- sized material.

(ii) Debris Avalanche:-this is a variety of very rapid to extremely rapid debris flow.

(iii) Earth flow: - This kind of flow is elongated and usually occurs in fine – grained materials or clay bearing rocks on moderate slopes and under saturated conditions.

(iv) Mud flows: - It is an earth flow consisting of materials that are wet enough to flow rapidly and that contains at least 50% sand, silt and clay-sized particles.

(v) Creep: - It is the imperceptibly slow, steady, down ward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation but too small to produce shear failure.

Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles, or fences, and small soil ripples or ridges.

USGS (2004) added on the previously described classes of landslide types toppling and lateral spread.

Toppling: Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the action of gravity and forces exerted by adjacent units or by fluids in cracks.

Lateral Spread: Lateral spreads are distinctive because they are usually occurring on very gentle slopes or flat terrain. The dominant mode of movement is lateral extension accompanied by shear or tensile fractures. The failure is caused by liquefaction, the process whereby saturated, loose, cohesion less sediments (usually sands and silts) are transformed from a solid into a liquefied state. Failure is usually triggered by rapid ground motion, such as that experienced during an earthquake, but can also be artificially induced. When coherent material, either bed rock or soil, rests on materials that liquefy the upper units may undergo fracturing and extension and may subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine – grained materials on shallow slopes is usually progressive.

2.2.4 Landslide Hazard Zonation

The occurrences of slope failures generally depend on complex interactions among a large number of partially interrelated factors (Pan et al., 2008). Therefore, analysis of landslide hazard requires an evaluation of the relationship between various terrain conditions and landslide occurrences. For simplicity of observation and analysis of the different causative and triggering factors it is good to zone the study area into different pockets or facets (Anbalagan, 1992; Sharma, 2006).

Zonation has been defind as division of the land surface in to areas and ranking of these areas acccording to degrees of actual or potential hazard from landslides or other mass movements on slopes (Varnes, 1984). It has been defined also by Kanungo et al., (2009), in the same manner except that he added the zones should have near homoginity.

Natural slope failues in the future will almost likely be in geologic, geomorphologic, and hydrologic situations that have led to past and present failures thus we have the possibility to estimate the style, frequency of occurrence, extent, and consequences of failures that may occur in future (Varnes, 1984). Therefore, the aim of landslide hazard zonation is to identify places of landslide occurences over a region on the bases of a set of internal and external factors.

In the present study landslide hazard zonation has been conducted with an assumption that the location, distribution and ground movement of future slope failures will be determined by the distribution and ground condition of the existing or past landslides. This assumption was followed based on the works and findings of (Hearn and Griffiths, 2001).

Landslide hazard zonation mapping techniques

Kanungo et al., (2009) classified different techniques of landslide hazard zonation in to qualitative and quantitative approaches (Fig.2.2).

Kanungo et al, (2009) have explained the different approaches of landslide hazard zonation mapping as described below;

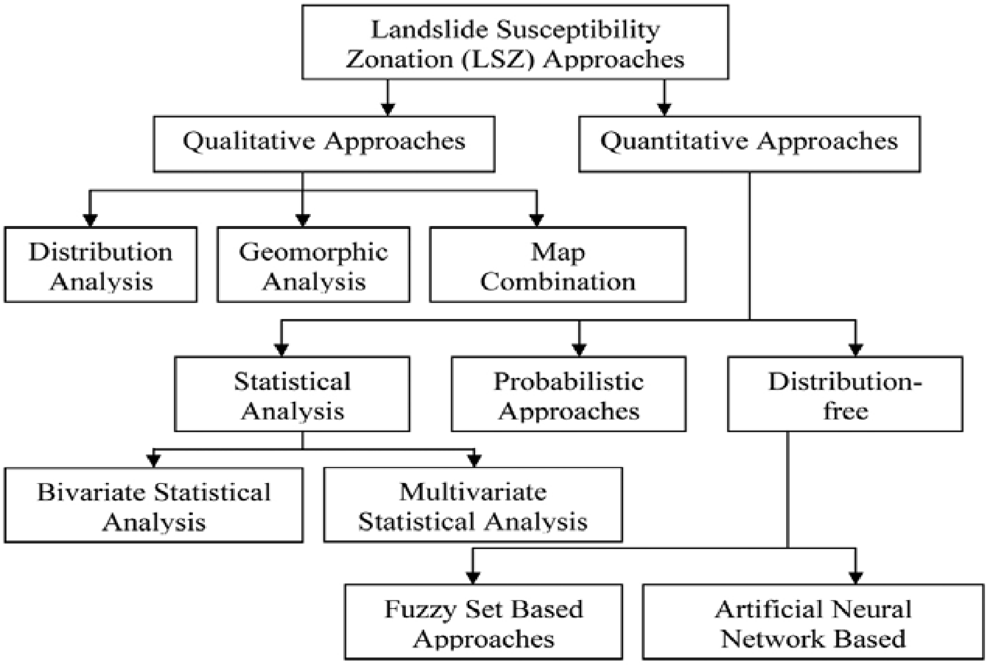

Fig 2.2 Flow chart showing taxonomy of LSZ approaches (*Kanungo et al., 2009***)**

Qualitative approaches

Qualitative approaches of landslide hazard zonation mapping include distribution analysis, geomorphic analysis and map combination approaches. This method has a lot of subjectivity in the preparation of various thematic data layer, which are integrated to the generation of Landslide susceptibility zonation map of the area.

Distribution analysis

It is a straight forward approach which is known as landslide inventory. This map is prepared either by collecting historical information on individual landslide event or using satellite imagery and aerial photograph coupled with field survey by GPS (Safaei et al., 2010). The landslide inventory maps do not provide information on the temporal changes in landslide distribution. The distribution analysis approaches are very time consuming, cumbersome and costly, but maps based on this approach may be useful in providing first hand information on the degree of susceptibility of future landslide activity.

According to Casagli et al., (2004), this map is only partially satisfactory because attributing null hazard levels to areas outside the landslide boundaries, excludes areas in which landslide having not currently been recognized. For this reason, this method is suitable only to areas in which easily recognizable landslides are prevalent.

Geomorphic Analysis

In this approach, the Landslide Susceptibility Zonation is carried out directly in the field by scientist/ geomorphologist based on their experience in the subject, about the area and in other similar situation without describing any rule which have led to this assessment.

Map combination approaches

In this approach for landslide hazard mapping it needs the preparation of thematic data layers pertaining to different causative factors. Commonly these factors include the lithology, lineament, slope, aspect, land use land cover, and drainage etc. The integration of these thematic layers with weights assigned to their relative importance in a GIS environment leads to the generation of a LSZ map. However, in this approach, the weights are assigned on the bases of experience of the experts on the subject and about the study area.

The weight may vary from expert to expert and also from region to region. The subjectivity in assigning weights to each thematic data layer and to its categories is the major limitation of this approach. Also there is a difficulty in extrapolating a model for particular area to other areas. But never the less application of such expert evaluation techniques are more practical, simple in application and provide much more realistic field data well supported by experience of an expert.

These techniques are simple in its application and cost effective over extensive areas with quite satisfactory results (Turrini and Visintainer, 1998).

There are several Expert evaluation techniques available these includes techniques proposed by Anbalagan, 1992; Pachauri and Pant, 1992; Sarkar et al., 1995; Turrini and Visintainer, 1998; Guzzetti et al., 1999; etc.

Quantitative Approaches

In this approach the relative importance of various causative factors can be quantified to produce LSZ map. This approach can reduce the subjectivity in the weight assignment processes. These approaches include statistical analysis, probabilistic approaches and distribution – free approaches.

Statistical Approach

Safaei et al., (2010) explained that terrain units or grid cells are transformed to new values representing the degree of probability, certainty, belief or possibility that the respective terrain units or grid cells may contain or can be expected to be subject to a particular landslide in the future.

The statistical approaches have been adopted for LSZ studies to minimize the subjectivity in weight assignment procedure associated with qualitative approaches. GIS tools are quite useful in this analysis. However, conceptually simple it has some limitation, because of the great complexity in identifying the slope failure process, systematically collecting and representing all predisposing factors related to land sliding, and applying geomorphological predictive modeling of failure over large areas (Guzzetti et al., 1999). In addition, there are several local slope instability indicators (crevices, trenches) that play an important role in the forecasting of a landslide event but are not usually included in statistical analyses.

Statistical approaches can be broadly classified into two types; Bi-variate and Multivariate.

Bi- Variate statistic Approach

In this method each individual thematic data layer is compared to the existing landslide distribution layer. The weight value of each category of causative factors is assigned based on landslide density. This involves the overlay of landslide distribution layer on each of the thematic data layer, and calculation of respective landslide density values.

Multivariate statistical Approach

Multivariate approaches consider relative contribution of each thematic data layer to the total susceptibility within a defined area. These approaches involve analysis of large volume of data and are time consuming. External statistical packages are generally used to support the GIS packages.

Some limitations of this approach are some of the factors may bear weak physical relationship with landslide occurrences, combination of such factors with other factors may generate data which is very difficult to interpret, a mixture of continuous (i.e. slope, aspect, etc) and categorical (i.e. lithology, land use land cover etc) factors leads to incorrect solution, and discriminant and regression analysis require data derived from a normally distributed population that is frequently violated.

Probabilistic Approach

The probabilistic approaches have also been used for LSZ studies to minimize the subjectivity in weight assignment procedure. This approach compares the spatial distribution of landslides in relation to different causative factors within the probabilistic frame work.

Although the probabilistic approach is considered to be a quantitative approach for LSZ mapping, certain subjectivity in the weight assignment procedure for different causative factors exists.

Distribution free approaches

Distribution free approaches are such as fuzzy based and ANN based approaches. The fuzzy set based approaches addresses the determination of ratings of the categories only. In most of the ANN black box approach for LSZ mapping single neural network architecture has been attempted.

2.2.5 Landslide studies in Ethiopia

A team from Addis Ababa University and Italy has studied the landslide occurrences in Ethiopian highlands and Rift margins. The findings of this study revealed that the high relief and the rugged topography induced by a strong Plio-Quaternary uplift, the occurrence of clayey horizons within the sedimentary sequences, the dense network of tectonic fractures and faults, the thick alluvial mantles on volcanic outcrops, and the thick colluvial–alluvial deposits at the foot of steep slopes are the predisposing factors for a large variety of mass movements. Heavy summer rainfall is the main triggering factor for most of the landslides (Bekele Abebe et al., 2009).

Shiferaw Ayele (2009) delineated landslide hazard zones in the Gohatsion - Dejen section by utilizing Remote Sensing and GIS approach. For the study the causative factors considered were; slope, structures, aspect, geology, groundwater condition, drainage, and land-use/ land-cover. The Landslide hazard zone map prepared was validated with the past landslide activities in the study area and it was found that 67% of the past landslide locations lie within the maximum hazard zone delineated by this study.

Engdawork Mulatu et al., (2009) conducted landslide hazard zonation mapping around Gilgel-Gibe II, Southwestern Ethiopia. In their study they have classified the landslide potential areas into high hazard, Moderate Hazard, and low hazard areas.

Henok Weldegiorgis (2008) conducted Landslide Hazard zonation mapping in Blue Nile Gorge. In his study he has used Anbalagan (1992) LHEF method for zonation and classified the study area into high, moderate and low hazard zones. By utilizing Limit equilibrium method he further made quantitative analysis for critical slopes.

Jemal Saed (2005) presented an inventory of landslides mainly along the road alignment between Gohatsion and Dejen towns. This inventory on landslides showed 17 critical slope sections. He further attempted a detailed slope stability evaluation on critical slope sections to suggest suitable remedial measures.

Lulseged Ayalew and Yamagishi (2003) described slope failures in the Abay Gorge from the point of view of landscape evolution. In their study they attempted to relate topographical characteristics with the process of landslide and rock fall. They concluded that slope instability was part of the mega-forces that shaped the entire Abay river basin and that it also contributed to general landscape evolution.

Berhanu Temesgen et.al (2001) has studied the occurrence of landslide in Wondogenet area. In their study they have evaluated the relationship between the landslide occurrences with various controlling parameters using GIS and remote sensing techniques and they have prepared the Hazard and Risk map of Wendogenet area.

Similar landslide studies were carried out by Fikre Girma (2010), Lulseged Ayalew (1999), Kefeyalew Terefe (2001), Gebretsidik Eshete (1982), Almaz et al (1994) etc.

2.3 Previous studies in and around the study area

There is no previous study about landslides in the present study area. However, in the nearby area at the town of Wuchalle a team from Wolo University has carried out assessment for the landslide which was triggered at the same time as that of under the present study. The study concluded about the causes of slope instability in the study area. The dominant factors that might have created suitable conditions for the occurrence of landslide were; Type of lithological unit, presence of structural lineaments (as weak zone), nature of underlying bed rock and overlying deposits, topographic and slope features. Factors that have triggered the sliding phenomena were; water related factors (geo-hydrological conditions, meteorological condition, and activities of river – gully incisions) and human activities that have disturbed natural stability of the area (Assay et al., 2010).

In Dessie town, which is 75km south of the present study area, many research studies have been conducted on landslides.

Tenalem Ayenew and Barbieri (2004) conducted inventory of landslides and susceptibility mapping in the Dessie area. According to them the main influencing factors for the occurrences of landslide in the area are topography, land-use, geology, and geomorphology, geotechnical properties of rocks and soils and hydro-metrological conditions. In their study they have described the most important landslide types as complex earth and debris slides and flows in silty clay soils associated with alluvial and colluvial deposits overlying highly weathered basalts and intact basaltic rocks experienced rock fall and toppling in steep slope areas.

Kefyalew Terefe (2001) conducted research in Dessie town in which he identified 20 different large scale landslide areas including very dangerous rock falls.

Lulseged Ayalew (1999) has carried out research in Dessie area. According to him some of the recent landslides which affected the large towns, densely populated villages and main roads are clearly first time failures and these recent failures are characterized by semicircular slip planes with an average width of about 30m and a length of 50m from the toe to highest peak scarp.

Gebretsadik Eshete (1982) conducted landslide studies in Dessie area. According to him two of the common causes which seem to play a considerable role in causing instabilities in the Dessie area are the water content and weathering. The water content at the time of rain attributed to excess hydrostatic pressure which reduces the shearing resistance. The formation of clay as a result of weathering in joints and faults can reduce the resistance and causes sliding as a consequence.

2.4 Methodology followed during the present study

All different kinds of available techniques for the landslide hazard zonation mapping have its own advantage and disadvantage. The choice of suitable techniques depends on number of factors. Some of these factors are; availability of sufficient data, the scale of the study, complexity in application, etc.

After a thorough literature review LHEF (Landslide hazard evaluation factor) technique proposed by Anbalagan (1992) was found to be a suitable technique for the present research study. The LHEF is an empirical technique which consider the relative influence of inherent causative factors like; geology, slope morphometry, relative relief, land use and land cover and groundwater conditions. However, LHEF technique has certain limitations on adoption of inherent causative and external factors. A modified technique which basically overcomes the limitations of LHEF is being developed by Raghuvanshi (2011) which has been adopted for the present study. A detailed description on modified technique is presented in Chapter 3.

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CHAPTER THREE METHODOLOGY

3.1 Preamble

Landslides are becoming a common and serious problem in mountainous region of Ethiopia. The occurrences of landslides in towns, such as; the present study area, makes life and property highly vulnerable and the damage and risk is becoming more severe. Therefore, it is very important to classify mountainous areas for its degree of landslide hazard, particularly for those areas which are near to the residential or settlement area so that proper measures can be adopted before any devastating event occurs. Identification of such slope instability problems in the initial stage of planning and investigation of engineering structures may lead to evolve possible remedial measures which may either be adopted to improve the slope stability or such problematic slopes may be avoided if identified during the initial planning stage (Anbalagan and Singh, 1996).

There are several methods which may be employed to identify and analyze the slope stability problems in mountainous regions. Each of these methods has its own advantages and disadvantages. Landslide hazard zonation techniques are one of such methods, which help to evolve zonation of relatively larger areas that may delineate the zones of varied potential for instability. According to Anbalagan (1992) landslide hazard zonation provides a great help to planners and field engineers for selecting suitable locations to implement developmental scheme in mountainous terrain as well as for adopting appropriate mitigation measures in unstable hazard prone areas.

The detailed methodology adopted during the present study is described in the following paragraphs;

3.2 Methodology adopted for landslide hazard zonation mapping of the study area

After a thorough literature review LHEF (Landslide hazard evaluation factor) technique proposed by Anbalagan (1992) was found to be a suitable technique for the present research study. The LHEF is an empirical technique which consider the relative influence of inherent causative factors like; geology, slope morphometry, relative relief, land use and land cover and groundwater conditions. The total maximum LHEF rating designated to all causative factors is 10 where; lithology, relationship of structural discontinuities with slope, slope morphometry and landuse/ landcover has maximum rating of 2.0 each. Relative relief and groundwater conditions shares maximum LHEF rating of 1.0 each only. Further, within each causative factor class the maximum LHEF ratings are further subdivided depending on various conditions. The criteria on which these ratings are assigned, mainly depends on the significance and relative contribution of each causative factor on stability condition. The total estimated hazard (TEHD) is determined by summing up all the ratings for each causative factor. Thus, the degree of landslide hazard is defined by TEHD. This implies that larger the TEHD value higher will be the degree of Hazard.

Observational past experience of author gained from the study of causative factors and their contribution for instability with conditions anticipated in the study area forms the basis of LHEF. The LHEF technique is simple in its application and cost effective over extensive areas with quite satisfactory results (Turrini and Visintainer, 1998). Perhaps for this reason only LHEF technique has been utilized successfully over the years by many researchers. But never the less application of LHEF evaluation technique have merit for its more practical approach, simple in its application and it utilizes much more realistic field observed data well supported by experience of an expert.

3.2.1 Shortcomings of LHEF Technique

According to Raghuvanshi (2011), despite its merit of simplicity LHEF has significant shortcomings. Descriptions on these short comings or limitations are given in the following paragraphs.

The LHEF technique is based on inherent causative factors of slope instability such as geology, slope morphometry, relative relief, land use and land cover and groundwater conditions. However, it does not account for external factors which trigger instability in the slope. These external factors are seismicity, rainfall and manmade activities such as; construction activities, mainly roads, and cultivation practices on slopes. Thus, this may be considered as one of the limitation of LHEF technique.

The maximum LHEF rating for groundwater is under assigned as the role of groundwater is significant in triggering the landslide activity. The total LHEF rating assigned for groundwater is 1.0 only whereas for lithology, relationship of structural discontinuities with slope, slope morphometry and land-use and land-cover maximum LHEF rating has been assigned as 2.0 each. Landslide activities are increased during rainy season when the groundwater is recharged considerably. This shows that, the role of groundwater is significant in landslide process, however the LHEF rating value assigned to it is very low.

The LHEF rating assigned for lithology and relationship of structural discontinuities with slope is 2.0 each. The relationship of structural discontinuities with slope has to be given more ratings than the lithology. As in rock slopes instability is significant when kinematic condition, defined by relationship of structural discontinuities with slope, are satisfied whatever lithology constitutes the slope (Hoek and Bray, 1997). Thus, the maximum LHEF rating for relationship of structural discontinuities with slope is under assigned.

In LHEF rating system the orientation of structural discontinuity their interrelationship and relationship of structural discontinuities with slope is only considered. The condition of rock mass with respect to structural discontinuities and characteristics of structural discontinuities has not been considered. These characteristics such as; spacing, continuity, surface characteristics, separation of discontinuity surface and thickness and nature of filling material within the discontinuity surfaces are very important in defining stability condition of the rock mass (Johnson and DeGraff, 1991).

Thus, keeping all these shortcomings of LHEF technique in mind a modified technique is being developed by Raghuvanshi (2011) so that a more realistic stability assessment and zonation can be performed. Further, for the present study this modified technique was adopted to carry out Landslide hazard zonation of the study area.

3.2.2 Modified Technique

For the present study modified technique was followed in which attempt was made to overcome the above mentioned short comings of Anbalagan's (1992) LHEF rating system. In the modified technique intrinsic parameters such as; slope geometry, slope material (lithology or soil type), structural discontinuities, land use and land cover and groundwater were used. In addition to these intrinsic parameters external parameters such as; rainfall, seismicity and manmade activities were also accounted.

Numerical Rating Criteria for Modified Technique

For modified technique numerical ratings were assigned to each of the intrinsic and triggering parameters on the basis of their relative contribution for instability. Each of the parameters was assigned with numerical ratings based on logical judgments acquired from its relative impact on instability. The distribution of maximum ratings assigned to different intrinsic and external triggering factors is based on their relative order of importance in contributing instability (Table 3.1).

For the purpose of landslide hazard mapping (LHZ) the area of slopes has been divided into individual slope facets. Slope Facet is defined as a land unit which is characterized by more or less uniform slope geometry in terms of slope inclination and slope direction. For this purpose topographical maps were utilized to demarcate the slope facets. Facet boundaries were delineated by major or minor hill ridges, primary and secondary streams and other topographical undulations (Anbalagan, 1992).

Table 3.1 Distribution of maximum ratings assigned to different intrinsic and external triggering factors

Slope Stability Susceptibility Evaluation Parameter		Maximum Rating
Intrinsic Parameters		
Slope Geometry	Relative Relief	1.0
	Slope Morphometry	2.0
Slope Material		1.0
Structural Discontinuities		2.5
Landuse and landcover		1.5
Groundwater		2.0
External Triggering Parameters		
Seismicity		2.0
Rainfall		1.5
Manmade Activities		1.5
Total		15

Intrinsic Parameters

As it is already discussed, intrinsic parameters are slope geometry, slope material, Structural discontinuities, land-use / land-cover and groundwater (Anbalagan, 1992). The maximum rating value assigned to each category of these parameters will be discussed as follow.

Slope Geometry

Slope geometry includes relative relief and slope morphometry of the slope. The relative relief is the difference in maximum and minimum elevation within a facet. Relative relief has been categorized into five classes; low (< 50 m), moderate (51-100 m), medium (101-200 m), high (201-300 m) and very high (>301 m). Slope will be more prone for instability if the relative relief is more (Hoek and Bray, 1997), accordingly ratings has been assigned (Table 3.2).

The slope morphometry indicates the steepness of the slope. The slope morphometric classes are adopted same as that of Anbalagan's (1992) LHEF rating scheme, accordingly the classes are; escarpment/cliff (> 45°), steep slope (36°-45°), moderately steep slope (26°-35°), gentle slope (16°-25°) and very gentle slope (< 15°). The ratings for each sub class of Slope morphometry and relative relief are given in Table 3.2.

Slope Material

The criteria for assigning ratings to sub classes of rock type are based on intact rock strength and degree of weathering. The rock classes are adopted from classification of rocks based on uniaxial compressive strength proposed by Hoek (1997). These classes are; Very weak rock (1-5 MPa), Weak rock (5-25 MPa), Medium strong rock (25-50 MPa), Strong rock (50-100 MPa), Very strong rock (100-250 MPa) and Extreamly strong rock (>250 MPa).

The degree of weathering has been considered as; Fresh, Slightly weathered, Moderately weathered, Highly weathered, Extremely weathered and Rock as soil. The description of weathering classes is given in Table 3.2. Thus, depending upon weathering class rock type rating was adjusted. The adjustment factor for each weathering class is also given in Table 3.2.

For soils the rating criteria is based on the genetic class and depth of the soil cover. The residual soils are more consolidated and possess better shearing strength than the alluvial or recent deposited soils (Anbalagan, 1992). Thus, the various soil types considered and their relative ratings are presented in Table 3.2. Depth of soil cover is also considered while assigning ratings to various soil types.

Structural Discontinuities

The structural discontinuities play an important role in defining stability condition of the rock slopes (Hoek and Bray, 1997). The important factors of structural discontinuity planes which influence the stability of the rock mass are; orientation, spacing, continuity, surface characteristics, separation of discontinuity surface and thickness and nature of filling material within the discontinuity surfaces (Johnson and DeGraff, 1991).

Orientation of the discontinuity planes plays an important role in stability condition. For the stability condition of rock mass following points are important;

a) The extent of parallelism between the directions of the discontinuity, or the line of intersection of two discontinuities and the slope.

b) Discontinuity plane or plunge of line of intersection of two wedge forming planes day light the slope at less than the slope angle.

These conditions make the slope kinematically unstable (Hoek and Bray, 1997).

The spacing of discontinuity also affects the stability condition of the rock mass. If the spacing of discontinuities are small, the rock mass will be more prone for instability condition (Johnson and DeGraff, 1991). The continuity of discontinuity planes influence the stability of the rock mass provided the orientation of discontinuity is kinematically critical. If the continuity of the discontinuity planes is more the rock mass will show more unstable condition in comparison to the case when continuity is less and there are intact rock bridges in between. Three factors are involved when the surface characteristics of discontinuities are considered.

a) The waviness or undulation of the surface.
b) The smaller scale roughness of the surface.
c) The physical properties of the infilled material between the two surfaces of discontinuity plane.

These surface characteristics of discontinuities are also important in defining stability condition of rock mass (Johnson and Degraff, 1991). Accordingly while assigning ratings characteristics of structural discontinuities their interrelationship and their extent of parallelism to slope has been considered (Table 3.2).

Landuse and landcover

The stability condition of a hill slope to a large extent is influenced by landuse and landcover. A thick vegetation cover over a slope is an indication of stable condition as the vegetation cover prevents excess seepage of water into the slope (Arora, 1997). Besides, the roots of the plants bind the soil mass thus contributing to increase the shear strength of the soil mass (Turrini and Visintainer, 1998). Surface erosion in the form of gullies is also checked with thick vegetation cover. The type of groundcover affects the stability of a slope: as the areas that are barren are more prone to erosion and weathering (Turrini and Visintainer, 1998). Barren and sparsely vegetated lands are more prone to soil erosion and slope failures (Wang and Niu, 2009). Thus, while assigning rating for landuse and landcover above mentioned points were considered (Table 3.2).

Groundwater

Slope stability studies for hazard mapping over relatively large areas makes it difficult to have direct observations of groundwater behavior within slopes. Moreover, information on water table levels and fluctuations is rarely available. For a quick appraisal, indirect measures can be used to assess the role of groundwater in inducing instability to a slope. These indirect measures are the surface indications of groundwater like; damp, wet, dripping and flowing (Anbalagan, 1992) (Table 3.2).

External Parameters

The most important external parameters which may trigger instability in slopes are rainfall, seismicity and manmade activities.

Rainfall

Slope stability problems aggravate with rainfall intensity. This is evident as the slope failure increases during the rainy season. The rainfall recharges the groundwater and in general saturates the slope. Rainfall is an important slope instability triggering external parameter. In order to incorporate its effect in modified rating scheme mean annual rainfall has been considered as a means to assign ratings.

Further, the rain induced manifestation on slope such as; gully formation, toe erosion, stream bank erosion etc. has also been considered while assigning ratings for rainfall. In order to assess the impact of rainfall on slope instability factors such as; type of slope material, discontinuity orientation with respect to slope, slope morphometry has also been considered.

Seismicity

Seismicity produces ground acceleration which results into landslides or slope failures (Keefer, 2000). Hillslopes that might remain stable under static load of overlying material can fail under dynamic loads due to seismic activity (Hoek and Bray, 1997). Slopes composed of rock mass having considerable structural discontinuities when subjected to ground acceleration results into widening or opening of structural discontinuities. Thus, the shear strength along structural discontinuity reduces and instability of slopes increases. Slopes composed of unconsolidated soft sediments or surfacial deposits having steep slopes, high seasonal groundwater levels, and shallow rooted or sparse vegetation are also prone for failure under seismic loading.

Table 3.2 Slope Stability Susceptibility Evaluation Parameter (SSEP) Rating Scheme

Intrinsic Parameters

1. Slope Geometry

(i) Relative Relief			**(ii) Slope Morphometry**		
Class	**Value Range**	**Ratings**	**Class**	**Value Range**	**Rating**
Very High	>301m	1.0	Escarpment/cliff	$>45^0$	2.0
High	201-300m	0.8	Steep slope	36°-45°	1.7
Medium	101-200m	0.6	Moderately steep slope	26°-35°	1.0
Moderate	51-100m	0.2	Gentle slope	16°-25°	0.6
Low	<50m	0.1	Very gentle slope	< 15°	0.3

Estimation of Slope angle (Anbalagan, 1992)

Number of contour lines over one cm length (1 : 50,000)	**Slope angle**
>25	$>45^o$
19-25	36^o-45^o
13-18	26^o-35^o
8-12	16^o-25^o
< 7	$<15^o$

2. Slope Material

(i) Rock Type

	Class *	**Description***	**Ratings**
Grade I	Very weak rock	**Strength:** 1-5 MPa ; **Field Estimate of Strength:** Crumbles under firm blows with point of a geological hammer, can be peeled by a pocket knife. **Examples:** Highly weathered or altered rock.	1.0
	Weak Rock	**Strength:** 5-25 MPa ; **Field Estimate of Strength:** Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of a geological hammer. **Examples:** Chalk, rocksalt, potash.	0.8
Grade II	Medium strong rock	**Strength:** 25-50 MPa; **Field Estimate of Strength:** Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single blow from a geological hammer **. Examples:** Claystone, coal, concrete, schist, shale, siltstone.	0.5
	Strong Rock	**Strength:** 50-100 MPa ; **Field Estimate of Strength:** Specimen requires more than one blow of geological hammer to fracture. **Examples:** Limestone, marble, phyllite, sandstone, schist, shale.	0.4
Grade III	Very strong rock	**Strength:** 100-250 MPa ; **Field Estimate of Strength:** Specimen requires many blows of a geological hammer to fracture it**. Examples:** Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, limestone, marble, rhyolite, tuff.	0.3
	Extremely strong rock	**Strength:** >250 MPa; **Field Estimate of Strength:** Specimen can only be chipped with a geological hammer **. Examples:** Fresh basalt, chert, diabase, gneiss, granite, quartzite	0.1

Adjustment Factor for Weathering grade for rock mass

Weathering Grade**	**Description****	**Adjustment Factor**
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces	1
Slightly weathered	Discoloration indicates weathering of the rock material and discontinuity surfaces	1.2
Moderately weathered	Less than 35% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework as core stone	1.5
Highly weathered	More than 35% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework as core stone	1.65
Extremely weathered	All the rock material is decomposed and/or disintegrated to a soil. The original mass structure is still largely intact	1.8
Residual soil	All the rock material is converted to soils, the mass structure and material fabrics are destroyed	2.0
Note: The adjustment factor for weathering of rock has to be multiplied to the respective rating of fresh rock type of Grade II and Grade III rocks.		
* Rock mass classification and description adopted from Hoek 1997 ** Weathering class and description adopted from Irfan and Dearman, 1978		

(ii) Soil Type		
Class	**Description**	**Ratings**
Collapsible Soil	Loose mix of granular material comprising mainly sand and silt. Mainly cohessionless material which may undergo suffusion.	1.0
Alluvial Deposits	Well graded material comprising mix of cobble/ pebbles, sand and silt in a matrix of clay.	0.8
Residual Expansive Soils	Mainly comprising clay. Exhibits swelling when saturated and typical shrinkage cracks when dry.	0.6
Poorly Graded Colluvial Material	Poorly graded rounded to sub-rounded rock fragments/ cobble/pebbles mixed in a matrix of fine grained sand or silt.	0.5
Fluvio-glacial Deposits	Well graded angular rock fragments mixed in a matrix of clayey material. Partial interlocking of angular rock fragments.	0.4
Well Graded Colluvial Material	Well graded angular to sub-angular rock fragments mixed in a matrix of clayey material. Partial or well interlocking of angular rock fragments.	0.3
Residual Soils	Well compacted residual deposits of soil mainly comprising silt and clay.	0.2

3. Structural Discontinuities

(i) Parallelism between discontinuities dip direction and Slope

$(\alpha_j - \alpha_s)$ or $(\alpha_i - \alpha_s)$	Rating
0^o	0.5
1^o-5^o	0.4
6^o-10^o	0.3
11^o-15^o	0.25
16^o-20^o	0.2
$>20^o$	0.1

Planer Mode of Failure $(\alpha_j - \alpha_s)$
Wedge Mode of Failure $(\alpha_i - \alpha_s)$
α_j - Discontinuity dip direction
α_i - Direction of line of intersection of two wedge forming discontinuities
α_s - Direction of Slope inclination

(ii) Relationship between dip of discontinuity and inclination of slope

$(\beta_j - \beta_s)$ or $(\beta_i - \beta_s)$	Rating
$< (-10^o)$	0.5
0^o-(-10^o)	0.4
0^o	0.2
10^o-0^o	0.15
$> 10^o$	0.1

Planer Mode of Failure $(\beta_j - \beta_s)$
Wedge Mode of Failure $(\beta_i - \beta_s)$
β_j - Dip of Discontinuity plane
β_i - Plunge of line of intersection of two wedge forming discontinuities
β_s - Direction of Slope inclination

(iii) Dip of discontinuity or plunge of line of Intersection of wedge forming planes

(β_i) or (β_s)	Rating
$> 45^o$	0.5
$45^o – 35^o$	0.4
$34^o – 30^o$	0.25
$29^o – 20^o$	0.15
$< 20^o$	0.1

(iv) Soil cover depth

Depth	Rating
> 20 m	2.5
20 – 15 m	1.8
14 – 10 m	1.4
9 – 5 m	1.0
< 5m	0.5

(v) Structural discontinuities and Rock mass condition ****

Condition	Rating
Disintegrated – poorly interlocked, heavily broken rock mass with a mixture or angular and rounded rock pieces.	0.25
Blocky/ Disturbed – folded and/or faulted with angular blocks formed by many intersecting discontinuity sets.	0.2
Very Blocky – interlocked, partially disturbed rock mass with multifaceted angular blocks formed by four or more discontinuity sets.	0.1
Blocky – very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets.	0.05

(vi) Characteristics of structural discontinuity

Continuity	Rating	Seperation	Rating	Roughness	Rating	Infilling	Rating
< 1m	0.02	None	0.02	Very rough	0.02	None	0.02
1 – 2m	0.04	< 0.1 mm	0.05	Rough	0.03	Hard filling < 5mm	0.04
3 – 9 m	0.07	0.1–0.9 mm	0.07	Slightly rough	0.07	Hard filling > 5mm	0.07
10 – 20 m	0.10	1 – 5 mm	0.12	Smooth	0.10	Soft filling < 5mm	0.12
> 20 m	0.15	> 5mm	0.15	Slickensided	0.15	Soft filling > 5mm	0.15

Weathering	Rating
Unweathered	0.02
Slightly weathered	0.05
Moderately weathered	0.07
Highly weathered	0.10
Decomposed	0.15

**** Hoek, 1997

4. Landuse and Landcover

Class/ Description	Rating
Barren land – No vegetation, land not used for any activity	1.5
Sparsely vegetated – Very thin scattered vegetation in the form of wild grass, bushes, scrub and random small trees.	1.2
Moderately vegetated area - Moderately covered vegetation land in the form of wild grass, bushes, scrub and trees.	0.75
Thickly vegetated forest area – Dense forest area with very thick vegetation cover.	0.4
Cultivated land with populated area	0.4

5. Groundwater

Surface traces of groundwater	Ratings
Flowing – presence of spring on slope face	2.0
Dripping – dripping of water through structural discontinuities.	1.5
Wet – water marks on rock surface, some droplets along structural discontinuities, algal growth in shadow areas.	1.0
Damp – Moist conditions on rock face surface, moss and algal growth in shadow areas.	0.6
Dry – rock face surface is dry, no water traces along structural discontinuity surfaces	0.0

External Parameters

1. Seismicity

1. Seismicity		2. Rainfall		
Ground acceleration*	**Rating**	**(a) Mean annual rainfall (mm)**		
		Class	**Mean annual rainfall (mm)**	**Rating**
1.0 – 0.5g	2.0	Very High	> 1500	0.75
0.5 – 0.1g	1.5	High	1101 - 1500	0.6
0.1 – 0.05g	1.0	Moderate	701 - 1100	0.3
0.05 – 0.01g	0.8	Low	300 - 700	0.2
0.01 – 0.005g	0.4	Very low	< 300	0.1
< 0.005g	0.4			

* For ground acceleration estimation refer Fig. 3.1 and seismic intensity map of the area

(b) Rain induced manifestation on slope

Surface Traces	Rating
Slope Toe erosion – Toe of the slope is eroded by stream flow, Surface material overhangs and prone for failure.	0.25
Stream bank erosion – Stream water has undercut the banks and made the sides of the slope hang.	0.15
Gully erosion over the slope face	0.1
No Rain induced manifestation on slope	0.0

(c) Slope Material

Description	Rating
Soil mass – Rainfall will saturate soil mass and pore water pressures will develop.	0.25
Disintegrated – heavily broken rock mass. Much of the rain water will seep into the rock mass and will recharge groundwater considerably.	0.2
Blocky/ Disturbed – folded and/or faulted with angular blocks formed by many intersecting discontinuity sets.	0.15
Very Blocky – Partially disturbed rock mass having four or more discontinuity sets.	0.1
Blocky – Undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets.	0.05

(d) Discontinuity orientation with respect to slope

Description	Rating
Soil Mass	0.25
More than one discontinuity dipping into the hill or the bedding joint/discontinuity dipping into the hill.	0.25
At least one discontinuity dipping into the hill. Which may or may not be a bedding joint.	0.12
None of the discontinuities dips into the hill.	0

Rainfall adjustment factor for slope morphometry #

Class	Value Range	Adjustment factor
Escarpment/cliff	$>45^0$	0.1
Steep slope	35°-45°	0.25
Moderately steep slope	25°-35°	0.5
Gentle slope	15°-25°	0.75
Very gentle slope	< 15°	1.0

Rainfall adjustment factor for slope morphometry has to be multiplied with Rainfall rating obtained after summing up (a), (b), (c) and (d).

3. Manmade Activities

(a) Developmental Activities		**Adjustment factor for developmental activities ##**	
Description	**Rating**	**Description**	**Adjustment factor**
Steep soil mass cut (slope > 45^o). Slope overhangs.	1.25	Slope toe supported by retaining structure.	0.15
Moderate steep soil mass cut (slope 35^o - 45^o).	1.0	Proper drainage system provided.	0.1
Soil mass cut into gentle slope (slope < 35^o).	0.75	Slope face dressing into terrace design.	0.1
Steep rock mass cut (slope > 45^o). Slope overhangs.	1.0	Excavated material not dumped over the down slope.	0.1
Moderate steep rock mass cut (slope 35^o - 45^o).	0.75	## Adjustment factor for developmental activities has to be subtracted from the rating of development activity.	
Rock mass cut into gentle slope (slope < 35^o).	0.5		
(b) Cultivation Activities		**Adjustment Factor for Irrigation*** **	
Description	**Rating**	**Irrigation practice**	**Rating**
Sparsely cultivated land with small populated area	0.1	Rain fed irrigation	0.75
Moderately cultivated land with medium populated area	0.15	Unplanned irrigation	1
Dense cultivated land with large populated area	0.25	Channelized Planned	0.5
		*** Multiply adjustment factor for irrigation with ratings of cultivated land	

The ground acceleration can be related to the intensity of the seismic activity. Hays (1980) developed a relationship between intensity of earthquake, based on Modified Mercalli intensity scale, and the ground acceleration (Fig. 3.1). This provides indications of g – values; ground motion expressed in terms of gravitational accelerations appropriate to engineering calculations (Johnson and DeGraff, 1991). The intensity of earthquakes can be determined from the seismic maps of the area. Thus, based on the relationship between intensity of earthquake (Modified Mercalli intensity scale) and the ground acceleration ratings are assigned and are presented in Table 3.2.

Manmade Activities

In addition to natural triggering parameters, manmade activities also increase the potential instability of the slopes. Manmade activities in hilly terrains which affect the slope stability conditions are the developmental activities such as; road or building construction and cultivation activities. Thus, all these factors were considered for the modified technique.

General Methodology for Modified technique

As a general methodology for modified technique first of all the area of slopes to be covered has been divided into individual slope facets. Slope facet is characterized by more or less uniform slope inclination and slope direction. For this purpose topographical map at a scale of 1:50,000 were utilized to demarcate the slope facets. Slope facet boundaries were delineated by major or minor hill ridges, primary and secondary streams and other topographical undulations. Later, this slope facet map served as a base map for various intrinsic and external causative factor maps.

Relative relief map was prepared with the help of DEM of the study area. DEM of the study area was clipped to each facet using ERDAS Software. For each individual slope facet maximum and minimum elevations were noted and the difference of the two elevations classified the slope facet into various relative relief classes. Accordingly, the relative relief map was prepared using ARC GIS software and numerical ratings were assigned to each individual slope facet from Table 3.2.

To prepare the slope morphometry map, DEM of the study area was clipped to individual facets using ARC GIS software. Slope sections along general slope direction within the individual slope were clipped and facets have been noted with the help of Global Mapper software. Using ARC GIS software slope morphometry map of the study area was prepared. Depending upon the slope class ratings were assigned to individual facet (Table 3.2).

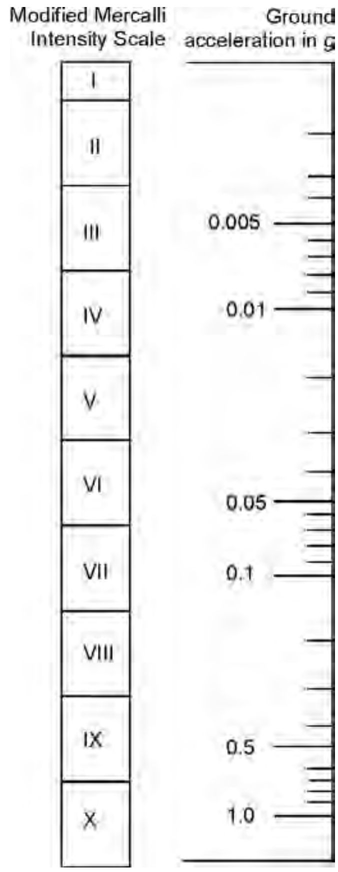

Fig. 3.1 Relationship between intensity of earthquake and ground acceleration (Hays, 1980)

In order to prepare slope material map base maps or a pre field map was prepared using topographic map, where the lithology and soil coverage was transferred over the slope facet map. Later, during the field work the various rock types were classified in terms of intact rock strength and degree of weathering. The soil type was classified based on visual observations and soil depth was assessed from the slope cuts along the road side, stream cuts or any other surface indications. Accordingly, ratings were assigned and slope material map was prepared.

For structural discontinuities data facet wise observations or simple measurements were made during the field work. The various discontinuity sets present within a slope facet were measured for their orientations in terms of dip direction and dip amount. Besides, observations were made for general condition of rock mass and characteristics of discontinuities such as; spacing, continuity, surface characteristics, separation of discontinuity surface and thickness and nature of filling material within the discontinuity surfaces. Later, parallelism between discontinuities and slope face strike was computed.

Besides, relationship between dip of discontinuity and inclination of slope was also determined. Accordingly, ratings were assigned from Table 3.2.

A pre field map was prepared by utilizing the Topographical maps and satellite imagery. Land use land cover map classification was done using ERDAS Software. Later, during the field work verification of various land use and land cover units were done and appropriate ratings were assigned from Table 3.2.

Indirect measures on surface indications of groundwater such as; damp, wet, dripping and flowing were made slope facet wise and recorded during the field investigations. While assigning ratings other surface traces such as algal growth, water marks etc. were also considered (Table 3.2).

Rainfall is an important slope instability triggering parameter. Mean annual rainfall has been considered as a means to assign ratings. The distribution of rainfall over a given area will be more or less uniform therefore the rating will be same for all slope facets. However, the rain induced manifestation on slope such as; gully formation, toe erosion, stream bank erosion etc. has been considered while assigning ratings for rainfall. The impact of rainfall on slope instability factors such as; type of slope material, discontinuity orientation with respect to slope, slope morphometry has also been considered.

The intensity of earthquake can be determined from the seismic maps of the area. Thus, based on the relationship between intensity of earthquake (Modified Mercalli intensity scale) and the ground acceleration ratings were assigned. In most of the cases the seismic intensity over a given area will be same therefore the corresponding ground acceleration will be identical. However, the seismic impact over the slope stability condition will vary facet to facet depending upon the variations in intrinsic causative factors.

The major manmade activities in hilly areas are road or building construction and cultivation practices. Facet wise observations were made for such developmental activities to know in what manner the slopes were cut, how the excavated slope material was disposed off and what type and in what manner slope stabilization and drainage measures were adopted.

Besides, for cultivation type of irrigation being practiced has also been considered. Accordingly ratings were assigned for manmade activities from Table 3.2.

Landslide Hazard Evaluation

In order to evaluate landslide hazard zonation of the area individual facet wise ratings for causative intrinsic parameters and external triggering parameter ratings were summed. The sum total of all ratings for causative intrinsic parameters and external triggering parameter gave Evaluated landslide hazard (ELH). The ELH has been categorized into five classes and is presented in Table 3.3.

$$ELH = Sum\ of\ Ratings\ of\ intrinsic\ parameters\ (\text{relative relief} + \text{slope morphometry} + \text{slope material} + \text{structural discontinuity} + \text{Landuse and landcover} + \text{Groundwater}) + Sum\ of\ Ratings\ of\ External\ parameters\ (\text{Rainfall} + \text{Seismicity} + \text{Manmade activities})$$

Table 3.3 Evaluated landslide hazard Classes

Landslide Hazard Zone		Landslide Hazard Class	Evaluated Landslide hazard
Very high hazard zone	(VHHZ)	V	> 12
High hazard zone	(HHZ)	IV	12 - 8
Moderate hazard zone	(MHZ)	III	7.9 - 5
Low hazard zone	(LHZ)	II	4.9 - 2
Very low hazard zone	(VLHZ)	I	< 2

Thus, based on the ELH values for each individual facet, Landslide hazard zones were delineated and finally the Landslide hazard zonation map was prepared. Later, this map was validated with the actual landslide inventory data.

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CHAPTER FOUR GEOLOGICAL SETTING AND HYDROLOGY

4.1 Preamble

Geology and hydrology plays a pivotal role in controlling the occurrences of landslide in an area. Therefore, in this chapter the geology and hydrology of the study area have been presented.

4.2 Geological and tectonics setting

The general geological setting of Ethiopia is explained by Kazmin (1975). According to him the basement rock upon which all the younger formations were deposited contains the oldest rocks, with ages of 600 million years, and is exposed in areas where the younger rocks have been eroded. Uplift occurred at the end of the Precambrian times, which was followed by a long period of erosion. Then subsidence began in the Mesozoic, with age some 225 million years ago. Extensive fracturing and volcanism occurred in the early Cenozoic which covered the western half of Ethiopia and the Afar depression. The origin of these volcanic directly related to rifting in this area that started during the tertiary period and continuous to the present (Faure, 2001).

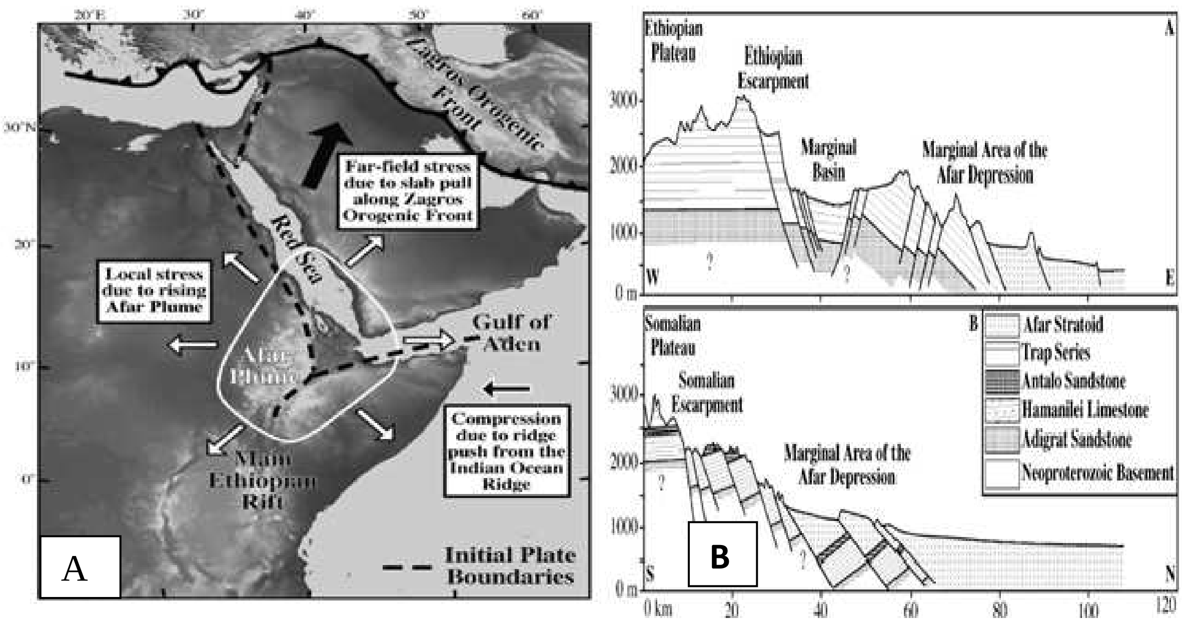
From its physiographic and geological point of view, Ethiopia can be grouped in to the Rift, North Western & South Eastern plateau.

The geological setting of the western Ethiopian escarpment, where the present study area is found, can be associated with the evolution of Ethiopian rift system. In the Ethiopian rift, the heat released by the Afar plumes has increased the temperature of the overlying lithosphere and caused significant regional uplift which resulted in rifting of the continental crust and thinning of the lithospheric mantle. This rifting subsequently widens forming, the head of the afar plume underling the triple junction diameter of 2000km (Faure, 2001). These resulted the pulling away of the Somalian plate from the Nubian plate which makes much of Africa. These plates are also moving away from the Arabian plate which makes a triple rift junction at the Afar depression.

The tensional movement from the afar plumes, (Fig. 4.1) which resulted to the fissure volcanism; create a local stress in the surrounding area. The effect of extensive tectonics in the present study area can be depicted by the occurrence of block faulting, formation of marginal grabens and tilting of blocks (Fig.4.1), drainage pattern of the streams, the presence of dikes, faults, and the general geomorphology of the area. Besides, the active seismicity of the area is a result of the extensive tectonics observed in the margin.

The Ethiopian continental flood basalt (CFB) province (~30 Ma, >3 × 10^5 km^3) was formed as a result of the impringement of the Afar plume beneath the Ethiopian lithosphere (Dereje Ayalew et al, 2001). This bulk of eruption in mid tertiary from fissure builds up a typically 500-1500m thick and locally attaining 3000m , covering an area of presently 600,000 Km^2 and not less than 750,000km^2 before erosion forming the volcanic plateau (Mohr,1983). According to Hofmann et al., (1997), this big volume of traps volcanism, have been inferred to mark the appearance of the Ethiopian-Afar plume head at the earth’s surface and it is erupted approximately 30Myr ago, over a period of 1Myr or less.

According to Alebachew Beyene and Abduselam (2005) the Ethiopian Escarpment which separates the Afar depression from the Ethiopian plateau characterized by N-S trending marginal basins and hilly terrain of faulted blocks which forms the western margin of the Afar depression. These marginal basins developed at the foot of the Ethiopian escarpment with an average width of 5km and 30km long. The N-S trending marginal basins of the Dessie map sheet include Haro, Mersa, Mehal Amba, Hayk, Hardibo, and parts of the Borkena with hilly terrain of the rift ward tilted faulted blocks, and these basins have an average width 3-5 km and length 5-10 km long (GSE, Geological Survey of Ethiopian, 2011).



(Source: Alebachew Beyene and Abduselam , 2005)

Fig 4.1 A, The afar plume, B, Faulted blocks of Margional area

4.3 General Geology

The basement Precambrian metamorphic rocks, Paleozoic – Mesozoic sediments associated with transgression regression of the sea and Cenozoic volcanic rock which is directly overlying the Precambrian metamorphic and Mesozoic sedimentary rocks, are the main rock units found in Ethiopia. Among these rock units the geology of the study area and its surrounding can be grouped in to the Cenozoic volcanic rocks.

According to Peccerillo et al, (1997), The Ethiopian volcanic can be related to two main magmatic stages. The first is the Oligocene – Pliocene large fissure eruptions of basalts which build up thick flood lava sequence (known as Ashange and Aiba basaltic formations) associated with late ignimbrite sheet (Alaji Rhyolitic formations). This magmatic stages was closed by the formation of huge basaltic shield volcanoes (Tarmaber formation). However in the recent studies about the continental flood basalts of north-western part of Ethiopia, the whole formations were considered as a single unit which was flooded in less than 1 my around 30my ago (Hofman et al, 1997; Pik et al, 1998).

The second stage of volcanic activity is related to Pliocene to Recent in age and is more closely related to the formation of rift valley and Afar. In this group the volcanic rocks are associated with basaltic cinder cone and lava flows that are aligned along extension faults parallel to the rift and intermediate rocks are very scarce.

Recent classification for continental flood basalt of North western part of Ethiopia was followed as Lower formation, upper formation and the shield volcano. Both the lower and upper formation of the continental flood basalt was emplaced 30 my ago with short period less than 1my (Hofmann et al, 1997).

Lower formation

The lower formation of flood basalt is the ashange basalt. Mohr and Zenitttin (1988) explained the different characteristics of continental flood basalts in the following paragraphs:-

Ashangie formation has been defined according to three characteristics: - it has experienced a marked dip into the flow sequence of up to 40^{o}, flow thickness average only about 5m, and individual flows are rarely traceable for more than a few kilometers along strike, the flow is locally cataclysed and faulted.

The Ashangie basalt is the most dominantly observed volcanic rock near to the present study area. It is exposed along Dessie – Mekelle route, north central plateaus and in most part of the Afar rift marginal grabens. The Ashangie basalts are characterized by strong weathering, different directional tilting, columnar jointing, intense fracturing and crushing. In many of its exposure it is dominated by inclined columnar jointed aphanatic basalts. The unit also contains intercalated layers of agglomerate and volcano - clastic sediments and vesicular basalt (GSE, 2011).

Upper formation

Upper formation includes Aiba basalt and Alaje rhyolite. According to Mohr and Zenitttin (1988) Aiba formation is typically composed of entirely of massive flood basaltic flows, with or without intervening agglomerate beds. The flow are between 15 to 50m thick (in extreme cases pounding to 100m) and are generally composed of dense, dark, fine grained olivine basalt, commonly columnar. The flows extends sub horizontally for at least tens and possibly a hundred or more kilometers.

Plate 4.1 Morphology of the Ashange & Aiba Basalt (*Source: GSE, 2011 & Tesfaye Kidane, 2010, respectively from left to right***)**

The other group of upper formation is Alaje rhyolite. Aiba basalts are overlain conformably by silicic (trachite /rhyolite) Ignimbrite. The Ignimbrite succession maintains a similar thickness over kilometers or where preserved, even tens of kilometers lateral extent. Individual flows are up to tens of meters thick.

Shield volcano

According to Keffer et al. (2004) the lava flows of shield volcanoes are thinner and less continuous than the underlying flood basalts.

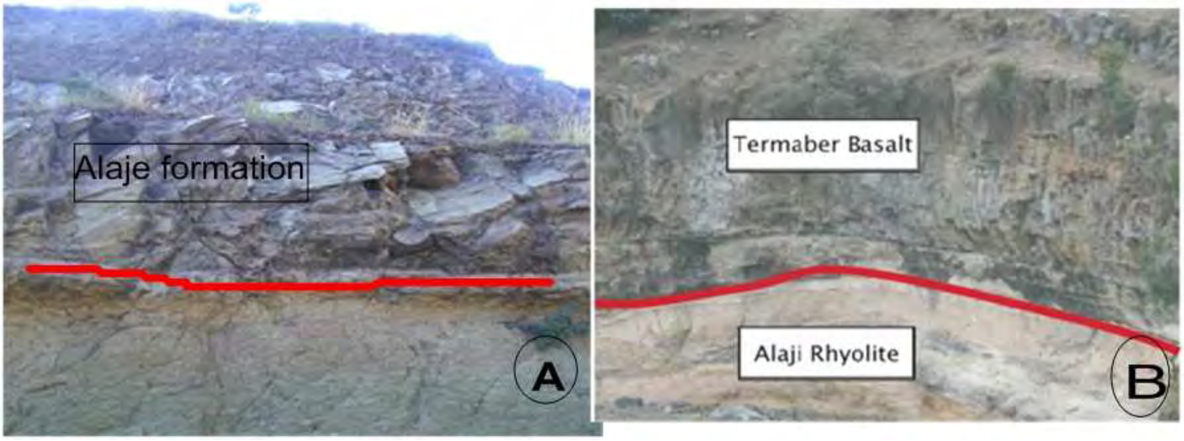


Plate 4.2 (A) Alaje formation (Wuchalle) (B) Contact between the Alaji rhyolite and Termaber Basalt (Source: Tesfaye Kidane, 2010).

It is more porphiritic containing abundant and often large phenocrists of plagioclase and olivine. Like the flood volcanic, the shield volcanoes are bimodal and contain sequences of alternating basalts, rhyolitic, and trachytic lava flows, tuffs and ignimbrites, particularly near their summits.

4.4 Stratigraphy

According to Mohr and Zennetine (1988), the period of most voluminous volcanism in Ethiopia was late Oligocene – early Miocene (32-21My), with flood emission of transitional basalt lava, and this volcanic pile can exceed 2000 meter neglecting the shield. In most of the studies of the old classification of Ethiopian continental flood basalt, Ashange formation is the pre-oligocene cycle, which is situated at the base of all the other flood basalts. Aiba basalts and the conformably overlain alaje formation, is groups as Oligocene cycle. Finally, the flood basalts are overlain by the shield Tarmaber formation with ages Oligocene – Miocene cycle.

However, this classification system is not currently followed by the recent studies of the continental flood basalts of Ethiopian. Pik et al., (1988) explained that in their field observation combined with petrological characteristics of the lavas, they conclude that the old stratigraphic classification is not valid for the whole of north western plateau and there is also a continuous lava sequence from the base to the top of the plateau.

Stratigrahic investigation of the study area has been conducted by EIGS (1998), for the purpose of oil and gas exploration. Data has been taken in stream gorges which is called

Bosena stream, Girem Stream, Leglencha stram ,and Genfo chefe which is situated near the study area. In their report they concluded that, there is an intercalation of shall, oil shall, silt and mud stone with the massive, basalts. The sediments which are more of argillaceous compositions are sandwiched with the volcanic rocks and concealed by the volcanic rock and are very small in thickness (EIGS, 1998).

According to EIGS (1998) the maximum thickness of oil shall observed in the area is 15 meter, and each of the sediment units is not more than 20 meters except that in Bosena section the measured thickness of clay stone reaches 30 – 35 meters. However, the basal flows separating the sediments have got the different thickness which varies from five to ten of meters.

4.5 Local Geology

The geological map of the Mersa study area adapted from the Regional geological map of Mersa area which is done by EIGS (1998) at a scale of 1:50,000 and the geological map of Wurgessa study area has been adapted from geological map of Wuchalle – Woldiya area which is done by Tesfaye Kidane (2010) at a scale of 1: 50,000. The geology of Mersa and Wurgessa study area is mainly composed of basic volcanic rocks and associated sediments.

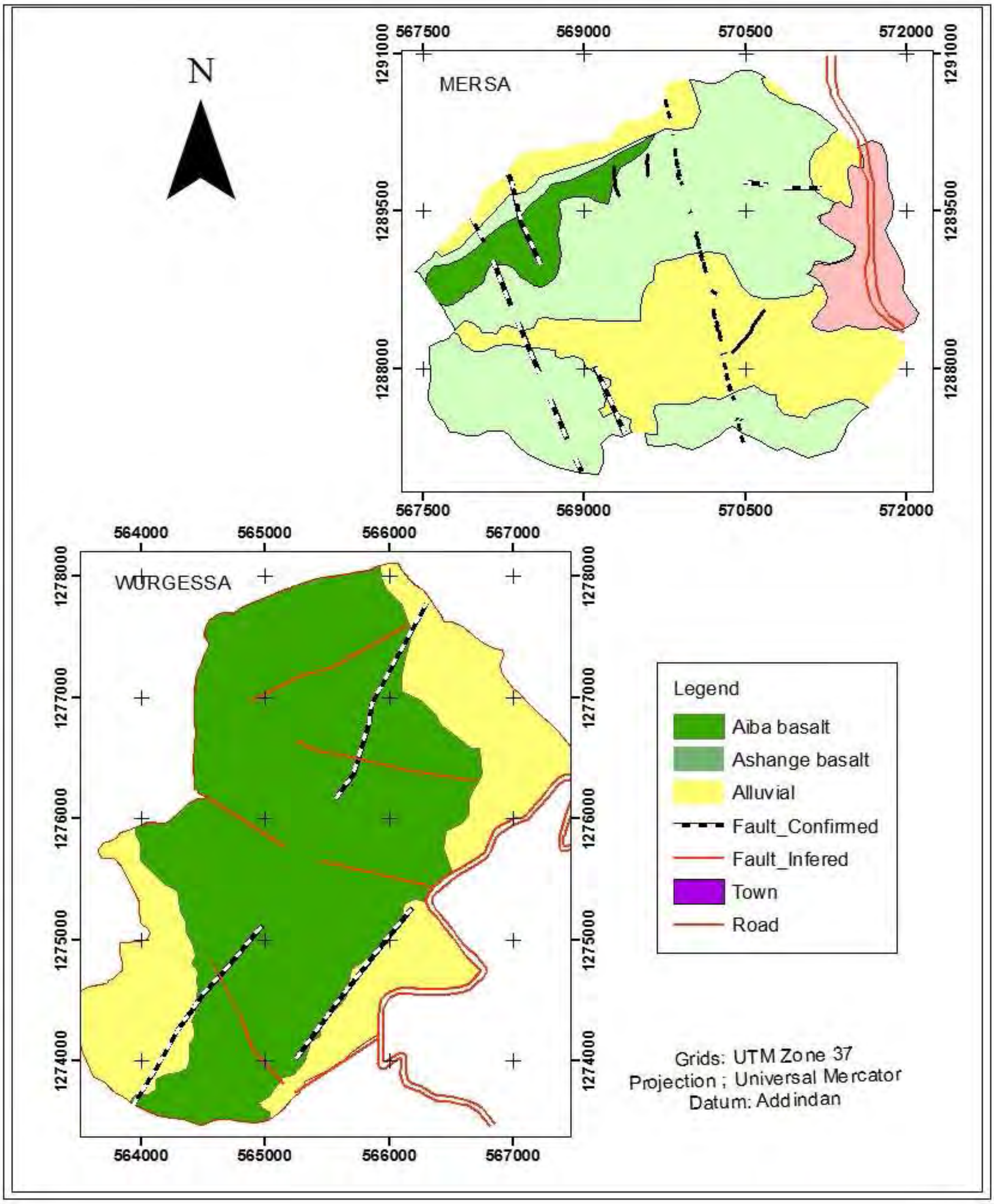
For classification of the local geology of the study area Morphology, texture, structure, degree of alteration has been utilized.

Litho logical formations which are found in the study area are Ashange, Aiba basalts and. quaternary sediments. The basalts include porphiritic, Aphanetic, scoracious basalt. Lithological description of the local geology of the study area has been presented in the following paragraphs.

Ashange basalt

The ashange basalts are observed in the study area at lower elevation of the North – western and south – western and central parts of Mersa area. Morphologically it is subdued. Due to its weak strength, it can’t form a steep cliff.

These rock units of the area show Porphiritic texture. Basalt of this unit is the main outcrop of the study area in Mersa. Microscopic examination shows that Pyroxene and olivine grains are seen as phenocrysts over plagioclase, pyroxene and iron oxide dominated ground mass (EIGS 1988).



(*Source: Wurgessa area adapted from Tesfaye Kidne, 2010 & Mersa area adapted from EIGS, 1998*)

Fig 4.2 Geological map of the study area

According to EIGS, (1998), thin section examination of this basalt revealed that 35% olivine, 18% plagioclase, 12% opaque minerals and 3% glass mineral assemblage. Several flows have formed the study area among which pyroxene and olivine basaltic flows are assumed to be the main one.

This rock unit in the study area highly weathered, altered and at places intruded by aphanetic basaltic dikes (Plate 4.4). Spheroidal weathering has affected the rock mass of this unit (Plate 5.1.a). Being highly altered, this rock unit is friable by hand and with a single blow of geological hammer it crumbled into soils.

According to (Tesfaye Kidane,2010) at a place called Molale with GPS co ordinates N10º08'21.1", E039º54'39.1", Ashange formation is characterized by the vein material that fill the fractures and pore spaces. This material is altered as well as an HCL acid test indicated the materials filling is calcite and overlying this unit relatively fresher basalt observed. In the study area at place called Seblo ridge with GPS co ordinates E0569465 & N1289899 the same rock units which is highly altered and filled by secondary filling material have been observed.

In Mersa area the scoracious basalt which is highly weathered and altered rocks are observed.

Aiba basalt

Aiba basalt is the most dominantly observed rock units in the study area. This rock unit is found in the higher elevation above the ashange formation. According to EIGS (1998), Lava flows, dikes and sills are mode of occurrences of this unit. Collumnar jointed Aiba basalts are exposed at Golo River and in the south-western part of wurgessa study area. It is also observed in the high elevated hills of seblo ridge of Mersa area and dike intrusions in many parts of the study area (Plate 4.4).

This rock unit form steep cliff than the Ashange basalts. Mostly it shows aphanetic texture. Basalts of this unit in the study area show wide opening joints of different set. Aiba basalt shows less alteration and relatively resistant to weathering.

Quaternery Sediment

Alluvial and colluvial, unconsolidated sediments are deposited in the low-lying areas of the study area. Very thick alluvial deposits are found in Mersa study area in both sides of Birbissa River. However in the sloppy part of the mountain in both of the study area residual soils and colluvial material with thickness less than 5m are deposited.

Geological Structure

Since the study area is located in great proximity to the Afar depression which is the most active zone, the area is highly affected by tectonics. This tectonics event has given rise to the development of different geological structures in the study area. Some of the structures which are found in the study area are faults, Dikes, fractures, bedding plane and, joints.

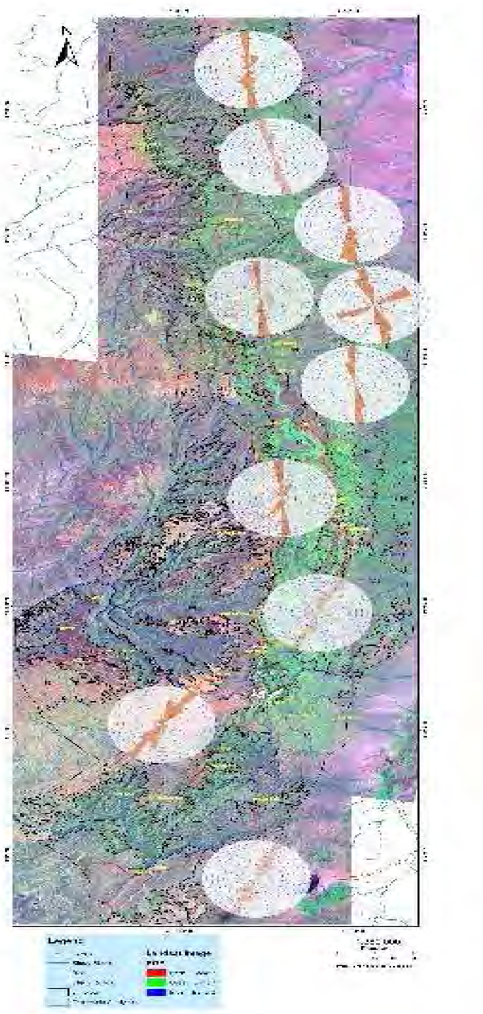


Fig 4.3 Along strike variation of the trend of the Rift as we go from Shenkora – Arerti area to the Woldiya –Robit regions. (*Source : Tesfaye Kidane, 2010)*

The general structural trend of the major faults as we go from central Ethiopia towards the Northern Ethiopia, it changes from dominantly from Northeast-south west to NNW-SSE and later into N-S direction (Tesfaye Kidane, 2010).

In Woldiya and Dessie area (fig 6.6) the NNW-SSE fault populations are the dominant trends however, some minor NE-SE trends are also observed to exist in the alignment of regional dykes observed in the region (Tesfaye Kidane, 2010).

Therefore, the main structural orientation of the study area, which is between Dessie and Woldiya very near to Sirinka, considered as, NNW-SSE.

Faults and Fractures

Faults are geological structures where weakness and disintegration of rocks prevailed. In the study area faults and fractures affect the rock mass to a great extent. Most of the drainage pattern of the area controlled by faults and fractures prevailed in the area. The streams in the study area are aligned in straight line deviate from the general stream direction sharply. Some of the major faults are parallel to the major escarpment however some faults are having a strike direction of west to east and north east to south west.

Plate 4.3 Faults and fracture in Mersa &disintegrated beds at the left bank of Golo stream Wurgessa respectively (2011).

Dikes

Basaltic dikes with strike orientation of NW-SE exposed near seblo ridge (Fig 4.4) and at the crossing of Birbissa stream of Mersa area and near to Gatira Giorgis of Wurgessa area. These dikes are aphanetic basalt with width 1 to 2 meter. These are weak zones which favors passage of basaltic lavas through easily.

Joints

Joints are geological structures which are formed as a result of expansion due to cooling, or relief of pressure as overlying rocks are removed by erosion. Some of the joints and fractures and bedding planes are parallel to the slope that they may serve as a plane of sliding surface. Characteristics of discontinuities like joint orientation, opening, continuity, nature of filling material and degree of weathering affect slope instability and these have been considered as a parameter for landslide hazard zonation mapping of the study area. The Characteristics of structural discontinuities for different facets of the study area facet wise has been given rating as per the standard table of chapter three table 3.2. The water flow through these structural discontinuities may be the main causes of slope instability in the study area.

4.6 Hydrology

Hydrology plays a major role in controlling the occurrence of landslide in the study area. Heavy summer rainfall is the main triggering factor for most of landslides (Bekelle Abebe et al., 2009; Tenalem Ayenew and Barbieri, 2004). Numbers of researches have been conducted near to the study area for the purpose of Kobo Girana and Raya valley irrigation development projects. However, no boreholes data and other relevant detailed studies to know the ground water potential of the aquifer within the study area have been recorded. Therefore, in this chapter surface and ground water hydrology condition of the study area based on field observation and literature review has been discussed.

Plate 4.4 Dikes near Seblo ridge in Mersa area.

Plate 4.5 Faults in Wurgessa study area.

4.6.1 Surface water Hydrology

Regionally the study area is characterized by high potential of surface and ground water. It is the upper part of the Awash basin catchment. The potential of surface and ground water in the area can be described by the abundance of Lakes and perennial streams in the area. Haik, Ardibo, and Golbo are some of the lakes which are found near the study area in the marginal grabens. Rivers namely; Mille, Golo, and Derek wenz of Mehal Amba, Eba, Mersa, Sirinka and Gelana are the main perennial rivers which are found near to the study area.

There are three big perennial streams flowing in Mersa within the study area. Two of these streams are Adem Wuha and Irgibo which bound the study area in the northern and southern parts, respectively. The other stream namely Birssissa flows dividing the study area in to two parts.

In Wurgessa area there are also three big streams. Two streams namely; Tiso and Wula Wuha are bounding the study area in the southern and northern parts, respectively. The Golo stream flows through the middle portion of the study area (Fig. 4.7).

All these streams are flowing from west to east towards the Girana basin and finally join the Gelana River which later forms the Mille River together with other streams.

In the south – western part of Wurgessa study area there is a pond (lake) at the foot of the escarpment (Plate 4.6.B). This pond has a perimeter of 440 meter, and it has area coverage of 14,820 km^2, which is equivalent to a foot ball field. Depth estimation of the lake using conventional method was not possible. Due to its topography and geological setting of the area it seems that there is a relationship between this lake and the perennial streams down, however it needs some additional investigation.

Plate 4.6 Ground water & Surface water potential Indication of the study area.

4.6.2 Groundwater hydrology

There is no bore hole and spring discharge data, which will be very helpful to know the aquifer characteristic of the study area. According to Tenalem Ayenew (2008), on their Hydrological investigation of Northern Ethiopian report, where hydro geological data are not available field observations such as distribution and magnitude of discharge of springs, degree of fracturing of rocks, grain size rounding and sorting type and degree of cementation, weathering condition are taken into consideration for the classification of aquifer potential of an area qualitatively. Therefore ground water potential of the area will be discussed qualitatively from field observation and previous works.

Regionally the area is characterized by very high potential of ground water. Boreholes drilled in Girana basin indicated high amount of discharge and it is planned ground water irrigation development in the area. Sediments in the intermountain areas such as kobo, Raya valley, and Borkena around kombolcha have high productivity, Tenalem Ayenew (2008).

Local ground water potential of the study area can be described by the presence of springs and hand dug wells in the study area.

Rock types which are found in the study area are Ashange formation and Aiba basalt. These rocks of the area most dominantly have texture of porphiritic basalt, scoracious basalt which is highly weathered and disintegrated showing spheroidal weathering, aphanetic basalt which is columnar jointed.

Most of the rock mass intruded with dikes and highly affected by the faults. These resulted for the formation of secondary porosity which will be used for the permeability of rain water into the aquifer.

Most of the rock type in the study area and nearby is volcanic (Ashange formation & Aiba basalt) which most dominantly have primary and secondary porosity.

According to Tenalem Ayenew (2008), Flood basalts which are commonly injected with dikes and sills have from moderate to high productivity, and Aiba basalts which is highly fractured and weathered have moderate productivity.

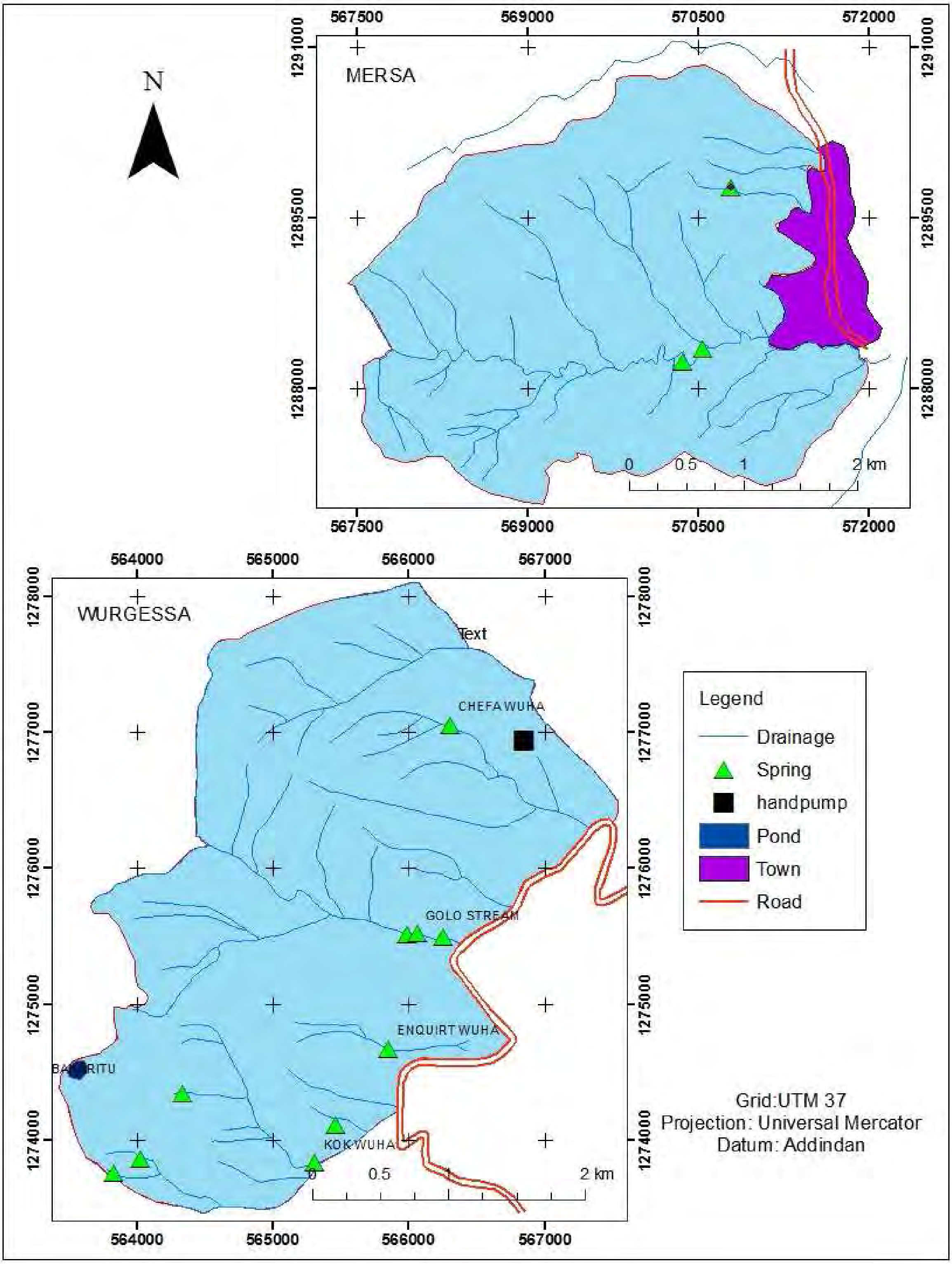


Fig 4.7 Illustration of surface and ground water potential of the study area

Hand Dug well

The hand dug well near Gatira Giyorgis in Wurgessa show high discharge at the time of field work. From interview of locals the static water level was 2 meter, and it has good potential of ground water. This indicates that the area has good potential of ground water at shallow depth.

Springs

The springs in Mersa area have little discharge and distribution. However, in Wurgessa area they have high discharge and much distribution (Plate 4.6 A and D, Fig 4.4).

The wurgessa town water supply is from the spring near Gatira Giworgis. In this area the spring called Chefa Wuha (Plate 4.6 A) has estimated discharge of 0.5 l/s at the time of spring development; however discharge measurement at this time is very difficult due to the flow of water in many directions. The spring which is called Kok Wuha, (Plate 4.6. D) and Enquirt Wuha, in Wurgessa area have estimated discharge of more than 0.5 and 0.6 l/s at the dry season respectively. These springs have very high discharge (like River) at the time of rainy season. In August 2010 kok Wuha spring has caused a translation sliding, (chapter 5, Plate 5.5) and Enquirt Wuha has caused very huge amount of debris flow (chapter 5, Plate 5.6).

The geological setting of the western Ethiopian escarpment, where the present study area belongs can be characterized by active tectonics. Rocks are highly weathered and disintegrated by different sets of discontinuities. The general discontinuity orientation of the study area is NNW-SSE however locally NNE-SSW and E-W trending fractures, bedding planes and joints are also observed.

The groundwater potential of the study area is very high. Hence, during rainy period springs flows out in significant amount, carrying huge amount of debris.

Significance of geology and hydrology condition of the study area in causing slope instability together with other causative and triggering factors and their contribution for slope instability will be discuss in the following chapter.

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CHAPTER FIVE CAUSES, MODE OF FAILURE & EFFECTS OF THE LANDSLIDES

5.1. Preamble

Identifying the causes of slope instability and factors which have initiated the Landslides in the present study area is very important in order to plan and design proper remedial measures. It is also necessary to investigate the extent of damage caused due to the landslides which have occurred in 2010 in the study area; thereby following which policy makers may take appropriate decisions. In this chapter factors which have caused instability of the slopes, triggering factors which have finally initiated the landslides, the degree of damage due to these landslides and the anticipated future conditions is presented.

5.2. Causes of Landslides

There are different factors which have possibly affected the stability of the slopes in the study area. These factors have induced instability by reducing the shear strength and/or increasing the shear stress within the affected slopes. These factors could be either intrinsic or triggering factors.

5.2.1. Intrinsic factors

Intrinsic factors are causative factors which may be responsible in reducing the strength of the slope material and makes it susceptible for landslide activity. Intrinsic factors are the long term factors associated with the slope material. The major intrinsic factors causing instability of slopes in the study area are geologic factors, groundwater condition, slope geometry and Land-use/Land-cover (Anbalagan, 1992, Varnes, 1984) which are described in detail in the following paragraphs.

5.2.1.1. Geologic factors

Geologic factors such as type of lithology and its susceptibility to weathering, structural discontinuity and tectonic setting of the area are the prime geological factors that might have contributed for landslides in the study area.

Type of rock and its susceptibility to weathering

Types of lithology are the main predisposing factors which have contributed for the occurrence of landslides in the study area.

The main lithological units in the study area are weathered and disintegrated scoracious and porphritic basalts, some columnar jointed aphanetic basalts, colluvial and alluvial soil materials, sediments between different flood basalts and residual soils overlying bedrock.

The occurrences and degree of weathering in an area depends on many factors. Climate, type of rocks, rock mineral composition, texture and topography are some of the factors that influence the occurrences of weathering in an area.

The continuous rain fall of summer with cold weather condition and the dry, sunny weather of winter are the main climatic factors that might have resulted into weathering of rocks in the present study area. Therefore the previously mentioned rock types with their texture are highly susceptible to weathering.

According to (Tesfaye Kidane, 2010) petrographic examination of the Ashange formation near Robit area, which is close to the study area, shows holocrystalline rock, fine grained and strongly porphiritic (~ 25%), phenocryst include olivine (~ 10%), plagioclase (~85) ,opaque oxide (5% aline) and rock name is porphiritic plagioclase – olivine basalt.

As it can be seen from the Bowen’s reaction serious those minerals which crystallize first at a higher temperature like olivine and plagioclase will have high susceptibility to weathering than those minerals which crystallize last like quartz (Goldich, 1938).

Therefore, weathering has played a major role in weakening the strength of the slope materials in the study area. The weathering process produced residual soils of thickness less than 5m in the study area (Plate. 5.1b). These superficial shallow materials overlying relatively impermeable rocks of weathered basalts underneath are highly susceptible to landslides.

The most commonly observed type of weathering in the study area is spheroidal weathering (Plate 5.1a). This type of weathering has affected the rock mass by removing the outer part of the rock like onion cover thereby causing disintegration of the rock mass.

The significant impacts of weathering on the rock units of the study area has been checked and verified by observation during the field investigation of the study area.

Thus, the poor strength of the rock exposed in the area suggests potential for instability of the slopes formed by these rocks. As it is quite evident that rocks which posses poor strength are more prone for instability. However, there must be other factors which also contribute to the instability of the slope.

Plate 5.1 (a) Spheroidal weathering in Mersa (b) Residual soils in Wurgessa

The other significant effect of weathering on slope material in the study area is in the formation of residual soils and colluvial materials.

Significance of soils for Instability

From the residual soils a total of four disturbed samples were collected for the laboratory analysis. The index test was conducted on all four samples in Central Laboratory of Construction Design Share Co. For the soil samples sieve analysis was conducted for gradational test. These samples were collected to represent the general soil types in the area. The location and depth of the samples taken is described in Table 5.1. The laboratory results are presented in Annexure N.

Table 5.1 Location, depth and quantity of soils samples, taken for laboratory test

Sample No	Soil Type	Colour	UTM		Depth
			Northing	Easting	
S1	Sandy-silt	Dark gray	1274559	563509	30cm
S2	Sandy-silt	Dark gray	1275201	0566072	30cm
S3	Sandy-silt	Dark gray	1289206	0571370	30cm
S4	Sandy-silt	Dark gray	1289186	0571331	70cm

The gradation test was performed on all four samples and the particle size distribution thus obtained is presented in Fig. 5.1 and Table 5.2.

For the colluvial material of the study area only visual observations were made in the field and no further laboratory tests were performed. For the purpose of classifying of residual soils of the study area USCS (Unified soil classification system) was followed.

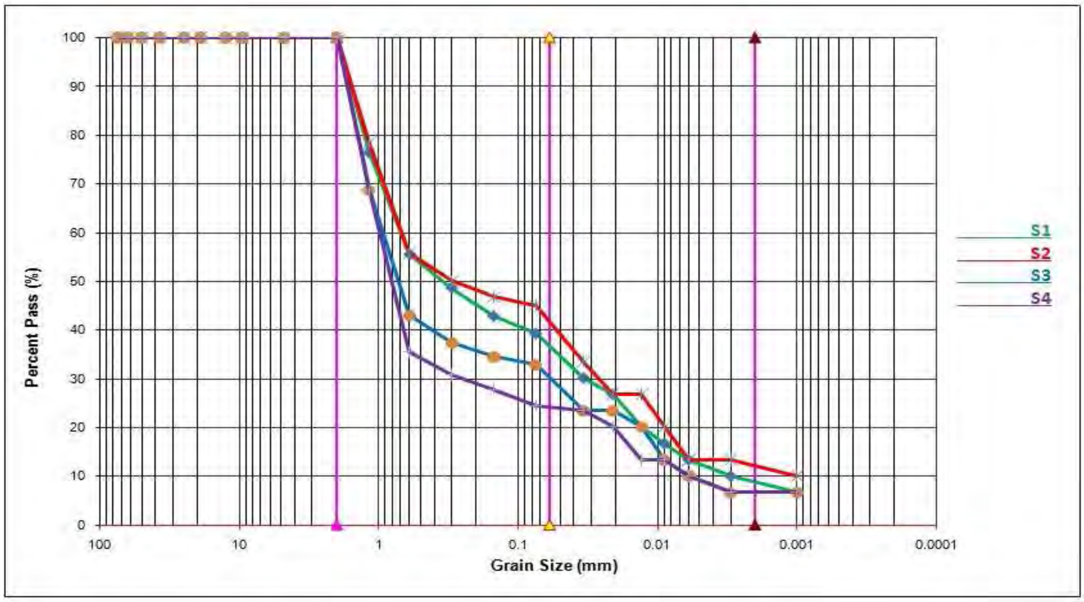


Fig 5.1 Gradation curve of the samples of the study area

Table 5.2 Gradation of the soil samples collected from the study area

Sieve size (mm)	Percent pass (%)			
	Soil Sample (S1)	Soil Sample (S2)	Soil Sample (S3)	Soil Sample (S4)
75	100.00	100.00	100.00	100.00
63	100.00	100.00	100.00	100.00
50	100.00	100.00	100.00	100.00
37.5	100.00	100.00	100.00	100.00
25	100.00	100.00	100.00	100.00
19	100.00	100.00	100.00	100.00
12.5	100.00	100.00	100.00	100.00
9.5	100.00	100.00	100.00	100.00
4.75	100.00	100.00	100.00	100.00
2	100.00	100.00	100.00	100.00
1.18	76.40	78.34	68.78	68.66
0.6	55.54	55.90	43.04	35.52
0.3	48.66	50.12	37.34	30.86
0.15	42.88	46.84	34.52	27.86
0.075	39.26	45.12	32.88	24.56
0.034	30.16	33.51	23.46	23.46
0.021	26.81	26.81	23.46	20.11
0.013	20.11	26.81	20.11	13.41
0.009	16.76	20.11	13.41	13.41
0.006	13.41	13.41	10.05	10.05
0.003	10.05	13.41	6.70	6.70
0.001	6.70	10.05	6.70	6.70

For all four samples, the percent pass for 0.075 mm (No 200, US Standard sieves), was less than 50% (Table 5.2). Therefore, it is classified as coarse grained soils in the USCS classification systems. Since more than half of the coarse fractions (100%), of the samples are smaller than No 4 sieve size (4.75mm) therefore it is classified as sand (Table 5.2).
To determine whether in sand fraction there is an appreciable amount of fines or little or no fines, further, coefficient of uniformity $C_u=D_{60}/D_{10}$ and coefficient of curvature $Cc=D^2_{30}/D_{10}D_{60}$ has been determined for each of the soil samples (Table 5.3).

Table 5.3 Uniformity coefficient and coefficient of curvature of the soil samples analysed

Sample No.	D_{60}	D_{30}	D_{10}	C_u	C_c
S1	0.725	0.034	0.003	241	0.53
S2	0.7	0.029	0.0013	538	0.924
S3	0.98	0.06	0.0068	144	0.54
S4	1	0.028	0.0068	147	0.11

The larger the numeric value 'C_u' the more is the range of the particles. For all the four samples the Cu values are high therefore the range of particle size is more. Also, for a well graded soil, the value of the coefficient of curvature must lie in between 1 and 3 (Arora, 1997). However, the values of Cc for all four soil samples fall less than one thus the soil is not well graded. Thus, for all four samples, Cu and Cc are not meeting gradation requirements for both well graded and poorly graded sand with little or no fines in it.

Further Atterberg limits were also analyzed for the soil samples and the results are presented in Table 5.4.

Table 5.4 Soil samples Labratory test results

No	Location	Moisture Content (%)	Natural Unit weigh (Kg/M^3)	Atterberg limit		
				LL (%)	PL (%)	PI (%)
1	Ninber	11.19	1650	39.65	31.52	8.13
2	Wurgessa	7.38	1592	40.19	30.45	9.74
3	Mersa	7.20	1630	36.45	29.60	6.85
4	Mersa	7.70	1508	35.46	29.52	5.94

From the Atterberg limit analysis (Fig. 5.2) liquid limit vs. plasticity index has been plotted and all four samples fall below A line. Therefore, it is classified as silty sand, sand-silt mixture or (SM). These kinds of soils have high water permeability capacity. Therefore, the water which percolates through the weathered profile, when it reaches to the low permeable media, the seepage forces develops and ultimately leads to potential instability of the slope.

The plasticity index of the soils of Wurgessa area (S-No 2) is 9.74 and Mersa (S-No 3 and 4) are 6.85 and 5.94, respectively (Table 5.4). Therefore, according to the plasticity index classification system (Atkins, 2003) (Table 5.5), the soils of Wurgessa area are grouped as Moderate plastic and the soils of Mersa area as slightly plastic soils.

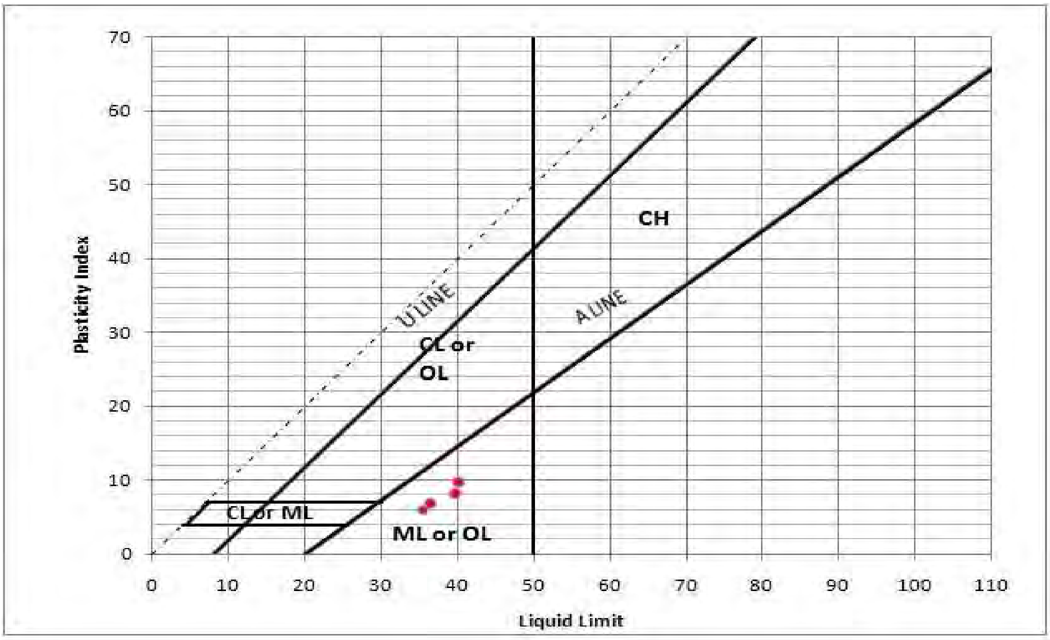


Fig 5.2 Plasticity chart of the samples analysed.

Therefore, it can be concluded from the above analysis that the residual soils of the area have some clay content. However, it is in small amount thus soils in general posses low cohesion, same has been deduced from the laboratory results also. From field observation at the time of the landslide in Mersa area, and from the interview of the community, the sticky clayey nature of the soil has been observed while it is moist. Moreover, the good permeability nature of the sand size soil particles, allow infiltration of water which will saturate the slope material and thus, thereby induce slope instability.

Significance of colluvial and Alluvial material for Instability

Colluvial is material that moves downslope primarily under the influence of gravity. These materials consist of rock fragments and soil which is accumulated on the slopes. The colluvial and alluvial deposits of the study area were characterized by visual observations only. Laboratory test has not been conducted due to difficulty in sampling owing to its complex composition with respect to particle size. The colluvial soils in the study area (Plate 5.2, A & C) are loose, unconsolidated, composed of highly fragmented rocks. The soil matrix which is found in association with disintegrated rock mass of the study area is coble, gravel, sand, and silt size. It is characterized by low clay content which has no sticky nature.

Table 5.5 Soil classification according to plasticity Index *(Source: Atkins, 2003)*

Plasticity Index (PI)	Terms	Dry strength	Field test
0 - 3	Non plastic	Very low	Falls apart easily
4 - 6	Slightly plastic	Low	Easily crushed by fingers
7 - 15	Moderately plastic	Low to Medium	Slight pressure required to crush
16 - 35	Plastic	Medium to high	Difficult to crush
Over 35	Highly plastic	High	Impossible to crush with fingers

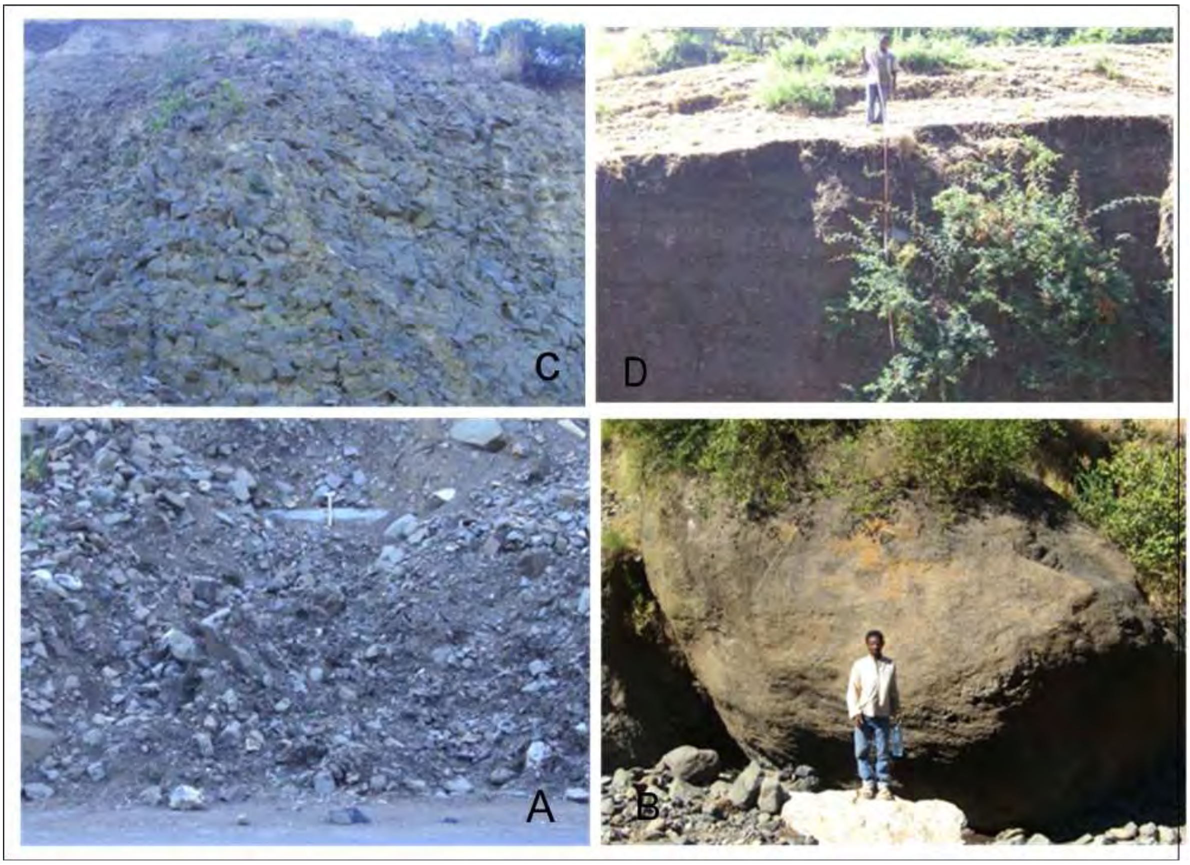


Plate 5.2 (A) Colluvial material slide with rock fragments of sharp edge. (B) Boulder slide at the foot of the slope (C) Loose rock fragments (D) Alluvial deposits (Wurgessa)

Mostly the colluvial material in the present study area is composed of soil and rock fragments which range in size from less than 1cm upto as big as ~ 6m (Plate 5.2 B). Some of these rock fragments are rounded however at some slope sections angular, sharp edge rock fragments have also been observed (Plate 5.2 A). Colluvial material composed of rounded to sub rounded rock fragments with matrix of low clay content has more susceptibility to slope instability than material with angular to sub angular rock fragments composed of clay soil matrix. Therefore, the colluvial material of the study area is relatively more prone to failure in those areas where rounded to sub rounded rock fragments within the colluvial mass are present.

Alluvial deposit is loose unconsolidated material which is composed of varying sizes. Unlike the colluvial material of the study area, this deposit is mainly found in the flat lying and in very gentle sloppy areas**.**

The slope instability in association with alluvial deposit of the study area concentrated where there are streams. In the study area stream toe and bank erosion was observed (Plate 5.2 D and Plate 5.10) where streams has steeply cut the slope and made it susceptible to failure.

Generally, the colluvial and alluvial materials in the study area is characterized by loose poorly sorted permeable material overlying relatively impermeable layer of basalt. Therefore, the water which infiltrate through these materials will induce slope instability by saturating the material and reducing the shear strength of the material. Hence, these materials are highly susceptible to slope instability.

Colluvial has been considered as the main problematic slope material in inducing slope instability in Abay Gourge in between Gohatsion and Dejen as reported by Samuel Molla, 2011; Shiferaw Ayele, 2009; Henok Weldegiorgis, 2008 etc.

Stratigraphy

Geologically the study area is characterized by different flood basalts of one unit overlying the other. These basalts have different degree of alteration, texture, morphology which results into varied strength characteristic.

Besides sediments like paleo soils (Plate 5.3) are observed in between different basaltic formations. According to (EIGS, 1998) sedimentation in the study area is mainly argillaceous in composition which includes oil shale, clay stone; siltstone sandwiched within the volcanic rocks and is discontinuous.

These intercalations of weak and strong rocks (competent basalt and incompetent sediments layers) may contribute to slope instability particularly in situations when other causative factors also provide favorable condition for such instabilities. Under such circumstances the incompetent layers may serve as plane or zone of failure along which mass movement can take place.

Palate 5.3 Paleosoils between different flood basalt

Tectonic Setting

The tectonic condition of the study area can be explained in relation with the Afar plume and Main Ethiopian Rift system. The study area is part of the western escarpment of the main Ethiopian Rift Valley.

Since it is found at the immediate vicinity of the Afar plume and the Main Ethiopian Rift which is part of East African Rift System, the area is highly affected by tectonics. The tectonic effect of the study area can be clearly observed from the geomorphologic setting, structural discontinuities (faults), drainage pattern and the presence of basaltic dikes cutting the lithology in the study area.

The tectonically affected sites of the area are weak zones along which many springs are developed and streams are aligned in straight lines. From the landslide inventory made in the present study area most of the landslides are concentrated along these zones (Plate 5.4).

The past tectonic effect which has contributed for the current geomorphology of the area including the marginal graben, steep escarpments, tilted blocks and the active tectonics have directly or indirectly contributed for slope instability in the study area.

Structural Discontinuities

Structural discontinuities of the study area have played a major role in causing instability of slopes in many ways. These structural discontinuities exist in different sets crossing each other and have disintegrated and loosen the rock mass. The general discontinuities orientation in the area is NNW-SSE (Tesfaye Kidane, 2010). However, locally there are E-W trending discontinuities in most of the study area.

Plate 5.4 Landslide occurrences along Golo stream Wurgessa (2010).

Faults, bedding planes and joints of varying size ranging from a fraction of a meter to more than a kilometer have affected the lithology of the area. There exists parallelism between orientation of these discontinuities and slope inclination at some slope sections of the study areas.

The bedding planes dip into the slope in Mersa town near the catastrophic landslide observed as well as left bank of Golo River and in parts of the slopes in Wurgessa study area (Chapter 6; Fig. 6.1). Water was observed flowing through the discontinuities which may reduce the cohesion and slope instability may occur along the plane where the bedding planes are dipping down the slope. Seepage of water through the columnar jointed basalts may also develop pore water pressure which causes slope instability by reducing the cohesion and friction angle of the rock mass. This situation has contributed for the failure of slopes in the present study area.

As it can be seen (Plate 5.5) that the different sets of discontinuities disintegrated the basalts and make it loose and susceptible for falling at many locations. In this slope section it has been observed that small rain during the month of November 2010 has triggered the rock falls.

From the observations made during the field study it has been deduced that the structural discontinuities in the study area has affected the stability of the slopes by allowing infiltration of water, which might have reduced the strength of the rock, besides facilitating the rock blocks to disintegrated and fall easily.

Plate 5.5 Rock mass comprising of Basalt in Mersa town affected by structural discontinuities

5.2.1.2. Groundwater condition

Most of the springs and rivers are flowing from west which is the mountainous area to east into the graben. The general groundwater flow direction in the valley is from west to east except that there are localized flow components observed in the vicinity of elevated hills, boundaries of each sub basin and along the river banks (MOWR-KGVPIP & MCE, Ministry of Water Resource- Kobo Girana Vally Pressurized Irrigation Project & Metaferiya Consulting Engineers, 2009).

Groundwater has caused great impact on the stability of the slopes in the present study area. The groundwater condition of the area has been studied by observing the presence of springs, water marks on slope face, and algal growth within structural discontinuities. In the study areas springs are available; however in Wurgessa area it is abundant and has high discharge than the springs in Mersa area (Chapter 4, Fig. 4.4). Most of the springs in the areas are located at the toe of the slopes.

The springs which are flowing from the upper part of the slopes have chances to saturate the slope material than the springs which are situated at the toe of the slope. This has been prevailed in Wurgessa around Seblo ridge. The landslides in association with these springs are very destructive.

According to Kumar, (2009) flowing groundwater exerts pressures on soil particles thus impairing the slope stability. Abrupt changes in the water level cause the pore water pressure on slopes to increase, Mechanical strength of soil to decrease by washing out soluble cementing substances and this, in turn, may lead to slope instability. These effects of slope instability have been prevailed by the occurrence of large amount of landslides in association with springs and shallow ground water in the study area.

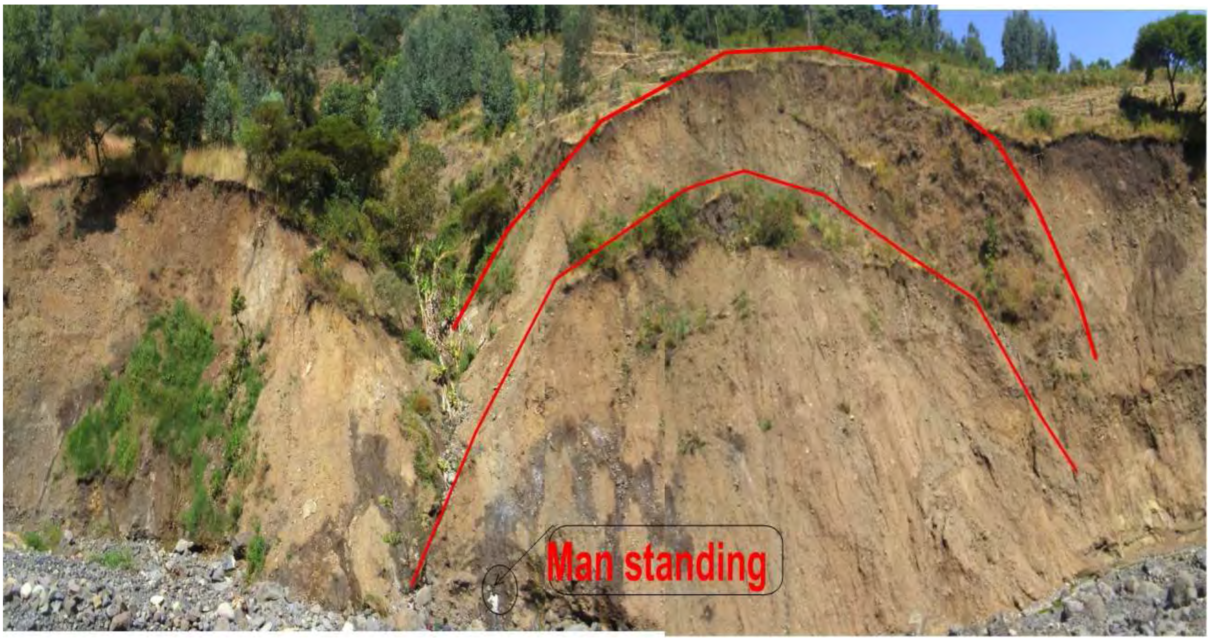


Plate 5.6 Landslide in association with Kok Wuha spring upper catchment of Tiso River (2010)

Translational Landslide occurred in the upper catchment of Tiso River at spring of Kok wuha (Plate 5.6). During field investigation for the present study, in the month of November (dry season), Enqirt-Wuha spring had an estimated discharge of more than 0.6 l/s. However in August, 2010 during the prolonged rainy season of summer, the spring was flowing like streams with high discharge and has caused several translational landslides and debris flows. Due to this event the main road was blocked by huge debris flow material which slide down from the neighboring slope (Plate 5.7).

Thus from the above discussion it may be concluded that the groundwater has played a major role in triggering the landslides in the study area.

5.2.1.3. Slope Geometry

Slope geometry includes relative relief and slope morphometry. Elevation difference for the study area in Mersa is 330 meters and that of Wurgessa is 1038 meter. Most of the slopes that have failed have gradients greater than 35^0 which can be classified as very steep and have high relative relief. Steepness of slopes in relation with the strength of slope forming material is very important. However, steepest slopes may not always be those more likely to fail (Varnes, 1984) as there are other causative factors also which jointly contributes for instability of slopes.

Plate 5.7 Debris flow due to Enqirt Wuha spring in August, 2010 (HWCO, 2010)

In the present study area there are some slopes which are as steep as 80^0 but still has no signs of slope instability (Plate 5.8).

Most of the slope sections of the study area (Chapter 6, Fig 6.4 & 6.5) are characterized by steep slopes and high relative relief. However, some of the slope sections (Plate 5.9) in the study area are severely affected by the landslide not because they are steep instead the instability was induced due to weak slope material. In general, high relative relief and steep slope morphometry in the study area has facilitated increase in natural gravitational pull for poorly graded colluvial material and highly weathered, fractured and weak rock formations resting over/ or forming such slopes. In addition to this highly disintegrated rock mass and poorly graded colluvial material also facilitates more infiltration of water during prolonged rainy season which ultimately might have contributed for instability of slopes in the present study area.

Plate 5.8 steep slopes with competent rock mass. **Plate 5.9 steep slopes with incompetent rock mass.**

5.2.1.4 Land use /Land cover

Deforestation or changing the Land use land cover of the area is another important factor in causing slope instability of the study area. Due to the absence of land use land cover map of the study area of past years, it was difficult to compare the land use land cover to the present condition. However, it is tried to compare the Land-use/ Land-cover map of the study area which is done by classifying the 2005 Land sat image with the Land-use / Land-cover map done by classifying the 1986 Land sat image (fig 5.3). This Land-use/Land-cover map shows that in Mersa area the thickly vegetated forest which was 27% of the study area in 1986, changed to 0.3% of the study area in 2005. While in Wurgessa area the thickly vegetated forest which was 22.4% of the study area in 1986, changed to 8% of the study area in 2005. Based on the information gathered from the local residents also it is concluded that there is a considerable increase in deforestation in the study area in association with the increase in settlement expansion nearby areas.

Vegetation cover plays an important role in stabilization of the slopes by modifying the soil moisture distribution, reduction in pore water pressure and mechanically increasing shear strength through plant root system. During field investigation, it was observed that most of the vegetations in the study area are scattered bushes, wild grasses, which are characterized by shallow roots. Trees with deep roots are rare in the study area.

The local residents confirmed that the present land cover of the area is a result of extensive deforestation, same was also observed during the field investigation for the present research study. Further, proper land use is not practiced in the area, sloppy areas and stream banks are used for agricultural purpose with unplanned irrigation practices. This has led to infiltration of significant amount of water into the slope which has caused considerable erosion at places, thereby inducing slope instability. Therefore, deforestation and unplanned irrigation practice in the study area might have contributed to some extent for slope instability in the area.

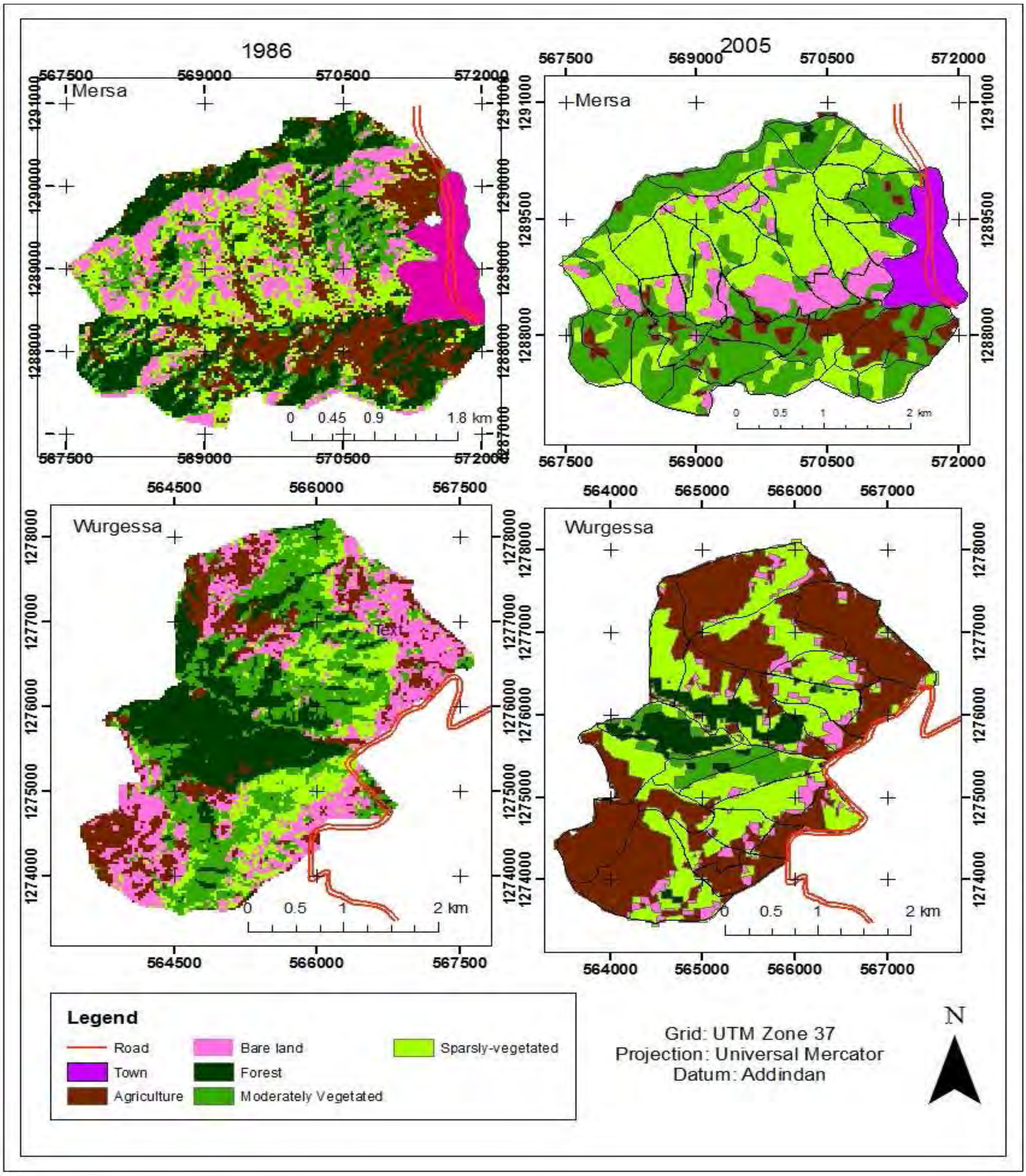


Fig 5.3 Land-use/ Land-cover map of the study area in 1986 (Left) and in 2005 (Right)

5.2.2 Triggering factors

Triggering factors are factors which initiates the failure mechanism in slopes. These triggering factors may be natural or manmade. Among the natural triggering factors rainfall and seismicity are the major ones whereas manmade activities mainly accounts for construction activities and cultivation practices.

5.2.2.1 Rainfall

Rainfall is the main triggering factor which has initiated the landslides in the present study area. The amount of rainfall recorded in Mersa area was 871.5 mm, which is from the month of July (2010) to the end of August (2010**)** for total of 50 days. In proportion it is about 90% of the mean annual precipitation. The total rainfall recorded in Wurgessa area was 1038.7mm, which is from the month of July (2010) to the end of August (2010) for total 50 days. In proportion it is about 87% of mean annual precipitation.

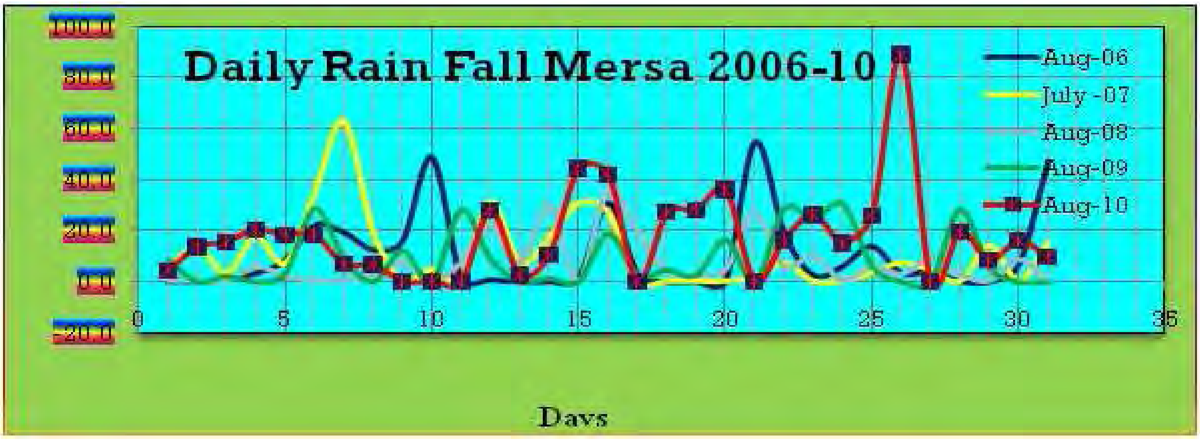


Fig 5.4 Daily rainfall for highest month from 2006 –2010 for Mersa town

A perusal of Annexure F clearly indicates that from May 15, 2010 upto July 10, 2010, it was totally a dry period. Later from July 10, 2010 up to August 30, 2010 a total rain fall of 1038.7mm and 871.5mm was recorded in Wurgessa and Mersa area, respectively.

Further, sufficient precipitation data was not available for the present study area. The monthly rainfall data for July and August, 2010 was compared with rainfall data from Sirinka Metrological station which is located near to the study area. Rain fall data of Sirinka metrological station (1966 – 2005) (Annexure G) confirms that the maximum monthly rainfall was recorded in the month of August, 1969 which was 421 mm.

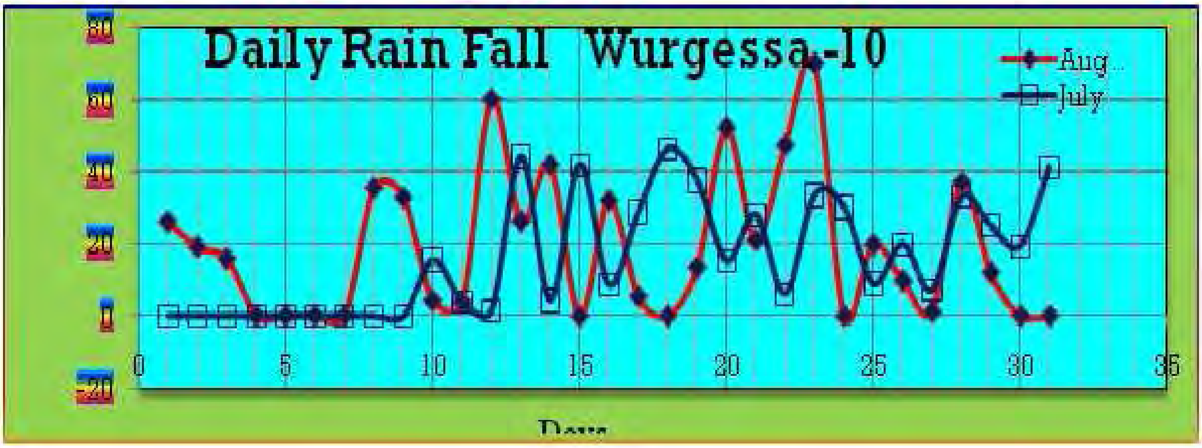


Fig 5.5 Daily rainfall for the month of July and August 2010 of Wurgessa

As it is previously discussed, the rainfall amount recorded in the month of August, 2010 was 587.2 mm and 546.9mm for Wurgessa and Mersa area, respectively. From this, it can be concluded that the monthly rainfall of August, 2010, was the maximum recorded precipitation for the last 44 years. This clearly shows that, the high amount of rainfall which has fallen was the major triggering factor for slope failures/ instability in the study area.

It was attempted to correlate the maximum daily rainfall amount of the study area (Fig 5.4 and Fig.5.5) with the date of landslide occurrences. The maximum rainfall amount recorded was 89mm in August 26, 2010 in Mersa area and 70mm in August 23, 2010 in Wurgessa area. From the interview of the local residents and HWEP & LAO (2010) report, the landslide occurrences was on August, 22, 2010 in Mersa area, however in Wurgessa area Debris flow continued up to the end of August, 26, 2010. Therefore, from this it can be concluded that it was not a single day rainfall, rather the prolonged rainfall which has triggered the landslides in the study area.

5.2.2.2 Stream Toe and Bank Erosion

The majority of the study area is characterized by highly elevated steep slopes, rugged morphology with highly undulating surfaces, forming ridges and valleys. Thick residual soils are concentrated in the valley portion of the slopes. Alluvial and colluvial material which are more of unconsolidated nature can easily be affected by stream toe and stream bank erosion. Slope toe erosion and stream bank erosion of the study area can be seen in Plate 5.9 and Plate 5.10, respectively. Gully erosion, steam bank erosion and stream toe erosion over the slopes, erode and cut the slope material and overhangs it, thereby the slope material may readily fail resulting into landslides. Therefore, the slope material of the study area is highly susceptible to landslide with respect to stream bank and stream toe erosion.

Plate 5.10 Slope toe erosion (Wurgessa)

Plate 5.11 stream bank erosion (Wurgessa)

5.2.2.3 Man made activities

Man made activities which may probably trigger the landslides in the study area are; construction of drainage ditches and trenches for water impoundment, steep slope cut for road and house construction, quarrying and excavation for the purpose of road construction, and vibration due to dynamites and cultivation with traditional irrigation practices.

More than 50% of the present mountainous parts of the study area are covered with drainage ditches (Plate 5.12) which has average dimension of 0.5 – 1 m depth, 1 to 3 meter length and 1 m width. These ditches were constructed intentionally by spending many resources in collaboration with government, nongovernmental organizations and the community for the purpose of flood control and soil harvesting.

Plate 5.12 Drainage Ditches in the upper slope of the Main Landslide

Fig 5.13 Hand dug well for crop storage (Abandoned)

The upper part of the landslide in Mersa which has killed 14 people was an abandoned village. People in the area have been using hand dug wells with maximum depth of 2.5 meter and diameter of 1 to 2 meter which were used for crop storage (Plate 5.13). The rock mass condition of these slopes is highly disintegrated, highly affected by different sets of discontinuities (Plate 5.5). Therefore, these ditches and dug wells for crop storage might have resulted into water pounding. The accumulated water continuously may infiltrate through discontinuities. The seeping water will decrease the cohesion between discontinuities and will cause slope failure.

The other man made activity which was observed in the study area was steep slope cuts for the purpose of road and house construction. In Mersa town people have over steepened the slopes and constructed houses (Plate 5.14). Excavation and quarrying has affected the slopes at the left bank of Golo stream. This site has been main site for ERA quarry for many years. In this area, part of the mountain has changed into flat land due to the excavation (Plate 5.15). As the local residents confirmed, a lot of dynamite has been used for the purpose of quarrying. This vibration caused frequent vibrations which might have also contributed to instability of slopes to certain degree.

The cultivation practice in most parts of the study area is traditional. People in the area cultivate vegetables like; onions, and cereals like; Tef and maize. For this purpose they use unplanned irrigation by diverting water from the main stream. This will allow significant amount of water infiltration into the slopes which will result into slope instability in the area.

Plate 5.14 Slope cut for house construction in Mersa

Plate 5.15 Quarry Site of ERA. (Wurgessa)

5.3 Failure mechanisms and types of the Landslides

The failure mechanisms of landslides are controlled by a number of factors. The types of slope material dominantly observed on the slopes, slope geometry and the causative and triggering factors dominantly involved in causing slope instability will determine the types of landslide's failure mechanisms. The occurrences of slide- Debris flows have a close relationship with bedrock geology, slope gradient, vegetation cover, and micro land forms (Fuchu, D. et al, 1999). The types of failure mechanisms also determine the extent of damage which will result from these landslides. The dominant failure mechanisms of the landslides in the study area are: - Sliding and flowing. However at few places and in very proximity of the study area, at a place called Nini-Ber, falling is also observed.

At the very steeper portion of the slopes near the summit of mountain, the residual soil experienced of shallow landslides which are called soil slips. The majority of the landslides of the study area are characterized by this type of failure. The slide materials continue flowing down the slopes carrying soils, sands, boulder, and vegetation roots. It finally joined the existing channels and flows into the road (plate 5.7).

Sliding failure mechanisms, which are observed in the study area show translational and rotational movement.

The types of Landslides triggered in the study area are, Shallow soil slips, Translational slide, Rotational slide, Debris flow and Rock and/or Soil falls. The description of the types of landslides most dominantly observed in the study area will be discussed as follows;

Shallow Soil Slips Soil slips of the study area dominantly observed in the steeper portion of the slopes. It is very shallow which vary in depth from very few centimeters up to less than a meter.	

Translational Soil slide Some of the landslides which occurred in the residual soils and colluvial materials overlying relatively less weathered volcanic rocks characterized by this kind of Landslides. Sometimes like in the figure when the impact of stream toe erosion and spring water become excessive part of slope material slide leaving scarp on the original material. Slides of this type show recognizable surface from which the slide begins and have translational movement.	 
Rotational Soil Slide This type of slide occurred in the upper portion of the slope. In this kind of slide the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface.	
Debris flow Debris flows which is composed of soils, sands, gravels, and boulders with plant roots and vegetations observed in the study area. At places this debris flows (fig 5.7) highly fluidized due to the high water content, with fine grained soils. This kind of debris flows moves with high speed causing many damages.	
Rock falls / Soil falls Rock falls/ Soil falls is not dominant types of landslide in the study area. However this type of slide observed at very steeply cut natural and artificial slopes of the study area, at a place called Nini-Ber near the study area	

5.4 Effects of the Landslide

The landslides of August 2010 have caused; many casualties, damaged properties and houses, roads and bridges disturbance, farm land degradation and psychological disaster on the local residents. Acccording to HWEP&LAO (Habru Wereda Environmental Protection & Land Administration Office) and HWDP&PA (Habru Wereda Disaster Prevention & Preparedness Agency) (2010) report (Annex Q&R) , the landslide triggered by the rainfall of 16/12/2002 (E.C) night in Mersa and Wurgessa area has caused 14 people to die in Mersa town. Near to the study area at Limo 4 and in Berebiyu 5, totally 23 people died on the same day. Furthermore, twenty four people have been affected by the incident. Out of these, eleven people have got serious injuries. The type of landslide which caused casualties was shallow landslides and debris flow. As reported, due to its muddy and sticky nature it has prohibited people from escaping the hazard.

A total of 657 households and 2,444 families in Wurgessa and 45 households and 160 families in Mersa have been affected by flooding and landslides (HWEP & LAO, 2010). The damage resulted from the landslides of the study area can be seen in (Fig 5.16). It has affected all social and economic sectors of the society. It has caused loss of life (Fg 5.16g), damaged houses (Fig 16, b, c, h), properties has been buried (Fig. 16, a), Irrigation canals has been affected (Fig. 16, d), road has been damaged (Fig. 16, i, k) and also retaining walls has been affected (Fig. 16, e and f).

According to HWEP & LAO (2010) report in Habru Wereda two modern and one, traditional irrigation canal was completely damaged by the landslides. Furthermore, 14 irrigation canals have been affected partially (Plate 5.16d).

5.5 Anticipated Future condition

From field investigation of the present study area tension cracks with dimension from few centimeters to as width of 0.25 meter and a displacement of 3 meter were observed (Plate 5.17). Most of these cracks are concentrated on the right and left side of the main Landslides. At some places eucalyptus trees are tilted. Most of the area has been degraded and the previous land cover conditions have been changed considerably.

These cracks are safe passages for water infiltration and internal erosion will cause removal of soil grains which may leads to slope failures. Further, gully erosions may also remove soil

(a) Woman searching her properties which is buried by the landslide (Mersa).

(b) Part of the houses completely damaged by the landslide (Mersa).

(c) Partially affected houses by the first coming rock fall before the main slide began. (Mersa).

(d) Irrigation canal affected by the landslide (Mersa).

(e) Retaining wall affected by the landslide at the main bridge of Golo River (Wurgessa).

(f) Retaining wall affected by the landslide (Wurgessa).

(g) Local residents are searching for bodies buried in Mersa.

(h) Partially buried house by Debris flow in Wurgessa.

(i) Water pipeline has been damaged.

(j) People stranded until the debris removed from the road

(k) The road affected by debris flow

(L) people stranded until the road will be cleaned

Plate 5.16 Some of the Damages due to the 2010 Landslide (Mersa and Wurgessa)

from the slope face which may later initiate debris flow. In Mersa town near the catastrophic landslide small rainfall has triggered some rock falls in the month of November (2010).
In the future heavy or even moderate rainfall may trigger extensive landslide in the area. These cracks are mostly concentrated in Wurgessa between Tiso and Golo rivers and in Mersa around the main landslides.

Plate 5.17 Displacement of cracked land (A) and tension crack (B) due to the 2010 Landslide Wurgessa

The occurrences of Landslides cannot be attributed to a single factor only. For a given slope to fail, a number of causative and triggering factors are responsible. The causative factors are those which have weaken the slopes for long period of time and make it susceptible to landslide. All the causative factors like relative relief, slope morphometry, slope material, land use land cover, structural discontinuities and groundwater condition have believed to cause slope instabilities in the study area. The triggering factors are those which have finally initiated the landslide. The triggering factors which are responsible in initiating the landslides are rainfall, seismicity and manmade activities. By analyzing the long term rain fall data, it is clearly observed that rainfall was the main triggering agent for the immediate initiation of the landslides of the study area. The damage resulted due to these landslides was very severe. Many casualties, properties loss, infrastructures and economic loss have been recorded. Besides, these landslides left marks in the area, tension cracks, crackled lands, and tilted trees have been observed. Further, with all these instability manifestations it has been anticipated that the area has potential for future landslide activities, particularly when the slopes will be subjected to anticipated adverse conditions.

CHAPTER SIX LANDSLIDE HAZARD ZONATION

6.1 Preamble

Landslide has caused much casualties and significant economic loss within and near to the study area. Identifying those areas which have high susceptibility to failure and reducing the risks of the landslides were the major objectives of the present research study. Thus, Landslide hazard zonation mapping was carried out to identify and zone those areas which have possibly high potential for future landslide hazard.

Hazard has been defined as the potential to cause damage or the probability of occurrence of a potentially damaging phenomenon within the specified period of time and in a given area. The natural slope failures in the future will most likely be in geologic, geomorphic, and hydrologic situations that have led to past and present failures. Thus, there is a possibility to estimate the style, frequency of occurrence, extent, and consequence of failure that may occur in future. This can be done by classifying the area into zones of hazard with varied degree of landslide susceptibility. Thus, zonation can be defined as the division of land surface into areas and ranking of these areas according to degrees of actual or potential hazard from landslides or other mass movements on slopes (Varnes, 1984).

The landslide hazard zonation mapping has great help for town planner to adjust the existing town master plan or to consider the degree of hazard in future town planning. It also helps the road construction authorities for maintenance and to take remedial measures for high and very high hazard slopes if they fall near to the roads. Local residents and concerned government bodies will be highly benefited from this hazard map to take some action with respect to landslide risk (Anbalagan, 1992).

There are different techniques which are used for landslide hazard zonation mapping, already described in detail in chapter two. For the present study modified technique, being developed by Raghuvanshi (2011), was adopted in which attempt were made to overcome the short comings of Anbalagan's (1992) LHEF rating system (Raghuvanshi, 2011). In the modified technique intrinsic parameters such as; slope geometry, slope material (lithology or soil type), structural discontinuities, land use and land cover and groundwater were considered. In addition to these intrinsic parameters external parameters such as; rainfall, seismicity and manmade activities were also accounted.

6.2 Landslide Hazard Zonation

As a general methodology for the modified technique first of all the area of slopes to be covered has to be divided into individual slope facets. Slope facet is characterized by more or less uniform slope inclination and slope direction (Anbalagan, 1992).

For this purpose topographical map on scale of 1:50,000 were utilized to demarcate the facets. Facet boundaries were delineated by major or minor hill ridges, primary and secondary streams and other topographical undulations. Field observation and interpretation of the slope map of the present study area were used for modification and verification of facet map (Fig.6.1).

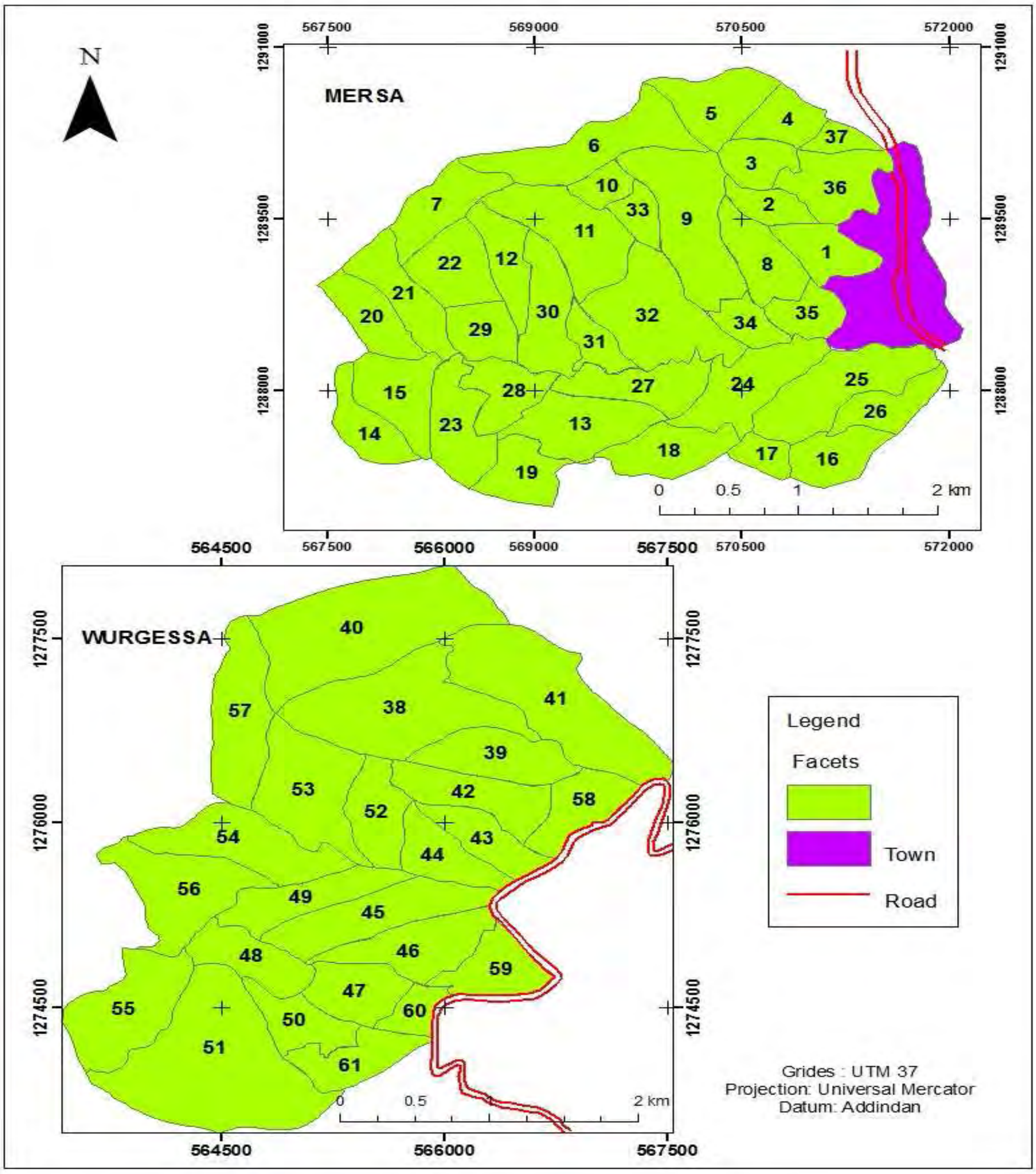


Fig 6.1 Facet map of the study area

Therefore, the facets of the study area are believed to have more or less similar characters of slope, showing consistent slope direction and inclination (Fig 6.2). The facet map forms the basis for the preparation of thematic maps in general and LHZ mapping in particular.

Totally 61 slope facets were delineated in the present study area, out of these 37 fall within Mersa and 24 facets fall within Wurgessa area (Fig. 6.1).

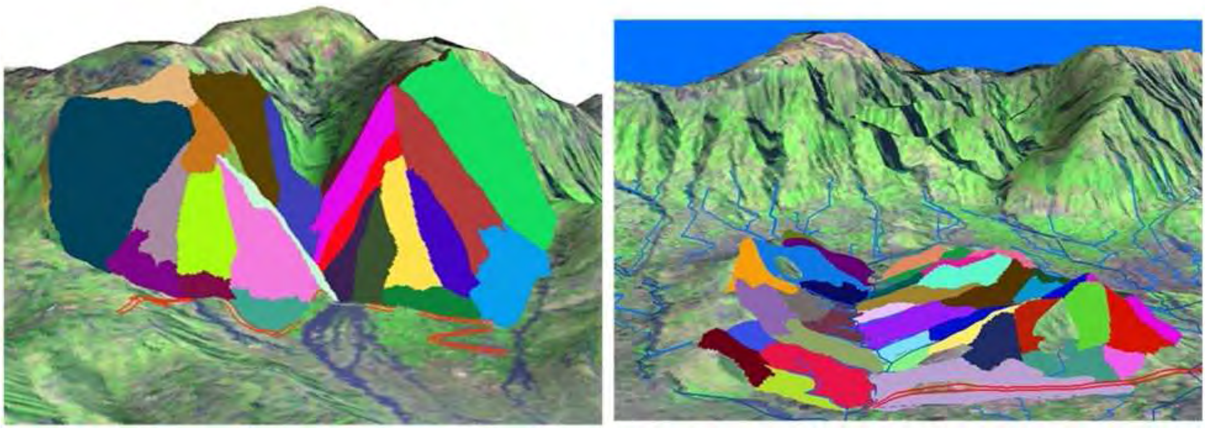


Fig 6.2 3D-view of the facets in the present study area Wurgessa (Left) and Mersa (Right)
Note. Color represents only the different facets.

The modified technique involves all intrinsic and triggering parameters responsible for slope instability. The slope stability is mainly governed by intrinsic parameters such as; slope geometry, slope material (lithology or soil type), structural discontinuities, land use and land cover and groundwater (Wang and Niu, 2009). Besides, external parameters, both natural and manmade parameters, which are responsible for triggering instability of slopes, are also considered. The natural parameters which, triggers the instability in slopes are mainly seismicity (Keefer, 2000; Parise and Jibson, 2000; Bommer and Rodrı´guez, 2002) and rainfall (Collison et al., 2000; Dai and Lee, 2001; Dahal et al., 2006). However, there are other natural factors which may trigger slope instability such as; snow/ avalanche, wind, permafrost conditions, shoreline processes and volcanic activities which are not included for landslide hazard purpose for the present study. Manmade activities mainly include construction activities and cultivation practices on slopes (Wang and Niu, 2009).

For modified empirical technique numerical ratings are assigned to each of the intrinsic and triggering parameters on the basis of their contribution towards instability of slope. The parameters responsible for instability of slopes has been assigned with numerical ratings which is based on logical judgments acquired from experience of studies of intrinsic and external triggering factors and their relative impact on instability of slopes. The distribution of maximum ratings assigned to different intrinsic and external triggering factors is based on their relative order of importance in contributing instability to the slope. The standard ratings for various intrinsic and triggering parameters has already been discussed and presented in Chapter three, Table 3.2. The general methodology followed for the modified technique is presented in Fig. 6.3.

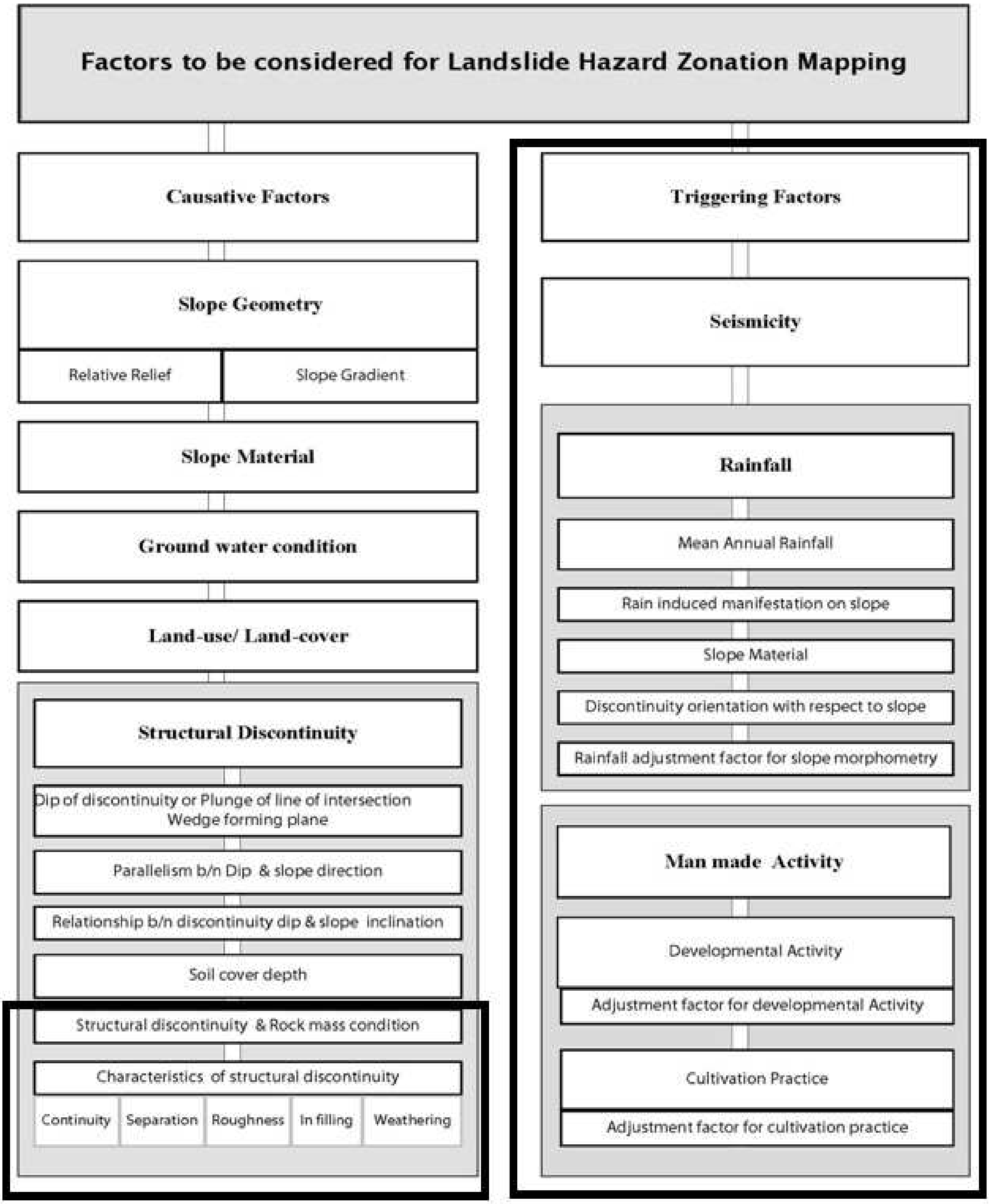


Fig 6.3 General methodology followed for Landslide Hazard zonation

6.2.1 Intrinsic Parameters

Intrinsic parameters are the causative parameters which define the favorable or unfavorable stability conditions within the slope. These intrinsic parameters are slope geometry, slope material, structural discontinuities, land use and land cover and groundwater (Anbalagan, 1992; Wang and Niu, 2009; Lulseged Ayalew, 2004). Depending upon the given conditions for each of these intrinsic parameters they may have an influence over the stability condition of the slope.

Slope Geometry

Slope geometry includes relative relief and slope morphometry of the slope. The difference in maximum and minimum elevation within a facet defines the relative relief. Slope morphometry defines the inclination of the slope (Anbalagan, 1992).

Relative Relief

Relative relief is one of the important causative factors which may cause slope instability. It affects the instability condition by increasing the gravitational energy which pulls the slope material down the slope. The relative relief map represents the local relief of maximum height between the ridge top and the valley floor within an individual facet (Anbalagan, 1992).

Relative relief map of the study area has been prepared from digital elevation model of the area by clipping facets using ArcGIS Software. The difference between highest and lowest elevation for each of the facet has been calculated. Later, ArcGIS Software was also utilized to prepare the relative relief thematic map (Fig.6.4).

In Wurgessa, 95% of the study area falls into very high and 5% of it is under high relative relief category. In Mersa 31 % of the study area fall into high, 46% Medium and 23% moderate relative relief (Fig. 6.4). Thus, it indicates that the majority of the study area is highly susceptible to landslide with respect to relative relief. Facet wise ratings assigned to respective classes are presented in Annexure A.

Slope Morphometry

Slope morphometry defines the inclination of the slope. More steeper the slope is, more it will be prone for instability. Slope morphometry map of the study area has been prepared by clipping the digital elevation model of the study area by individual facets using ArcGIS Software. The average slope angle within each slope facet was determined by using Global Mapper software 11. Later, slope morphometry map of the study area has been prepared by using ArcGIS software.

A perusal of Fig. 6.5 indicates that in Wurgessa area 24% of the slopes fall under the category of moderately steep (25°-35°) and 26% slopes are steep (35°-45°). The remaining slopes fall under Gentle (15°-25°), Very gentle (<15^{o}) and Escarpment (>45^{o}) which accounts for 14 %, 22 % and 14%, respectively.

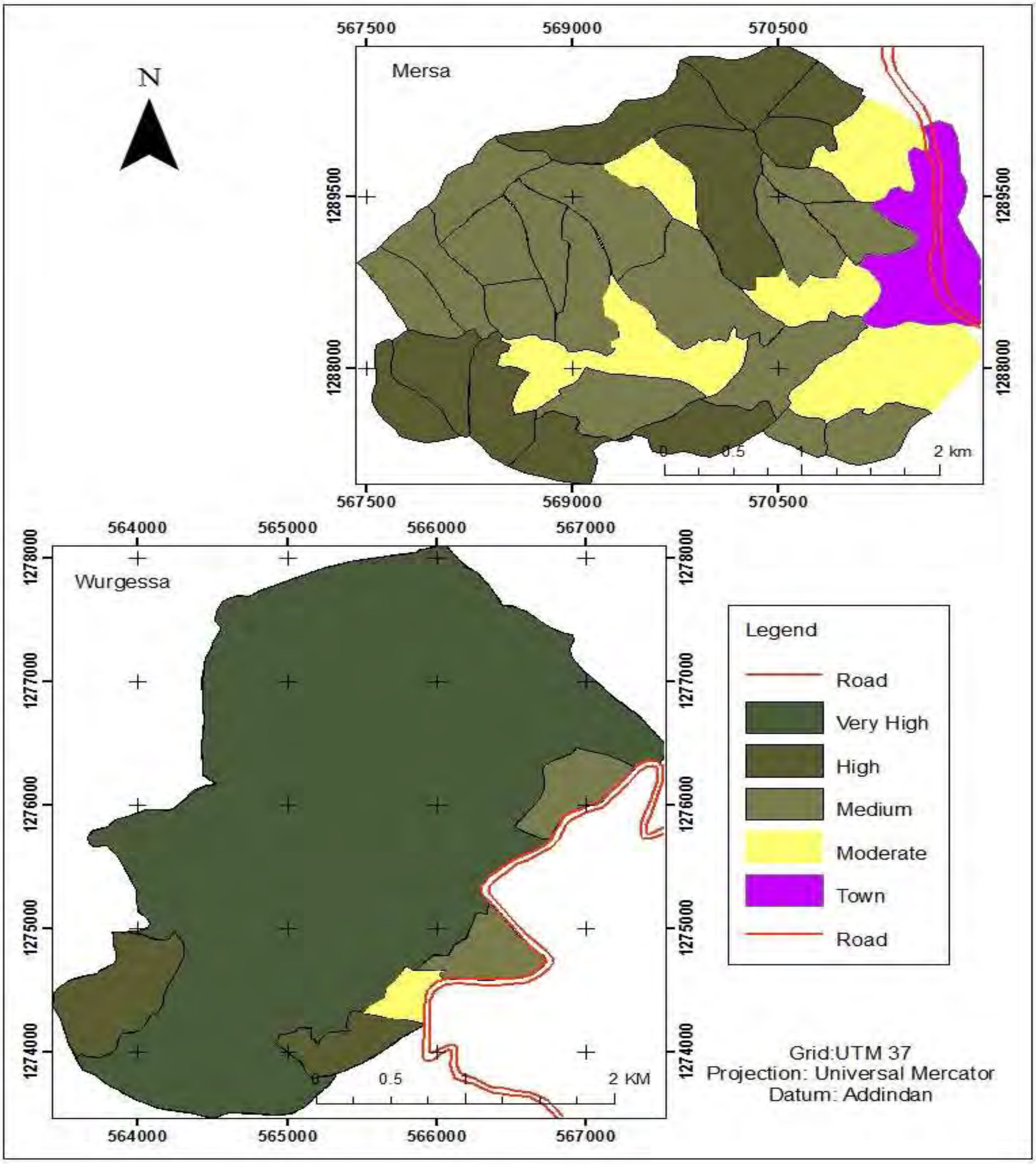


Fig 6.4 Relative relief map of the study area

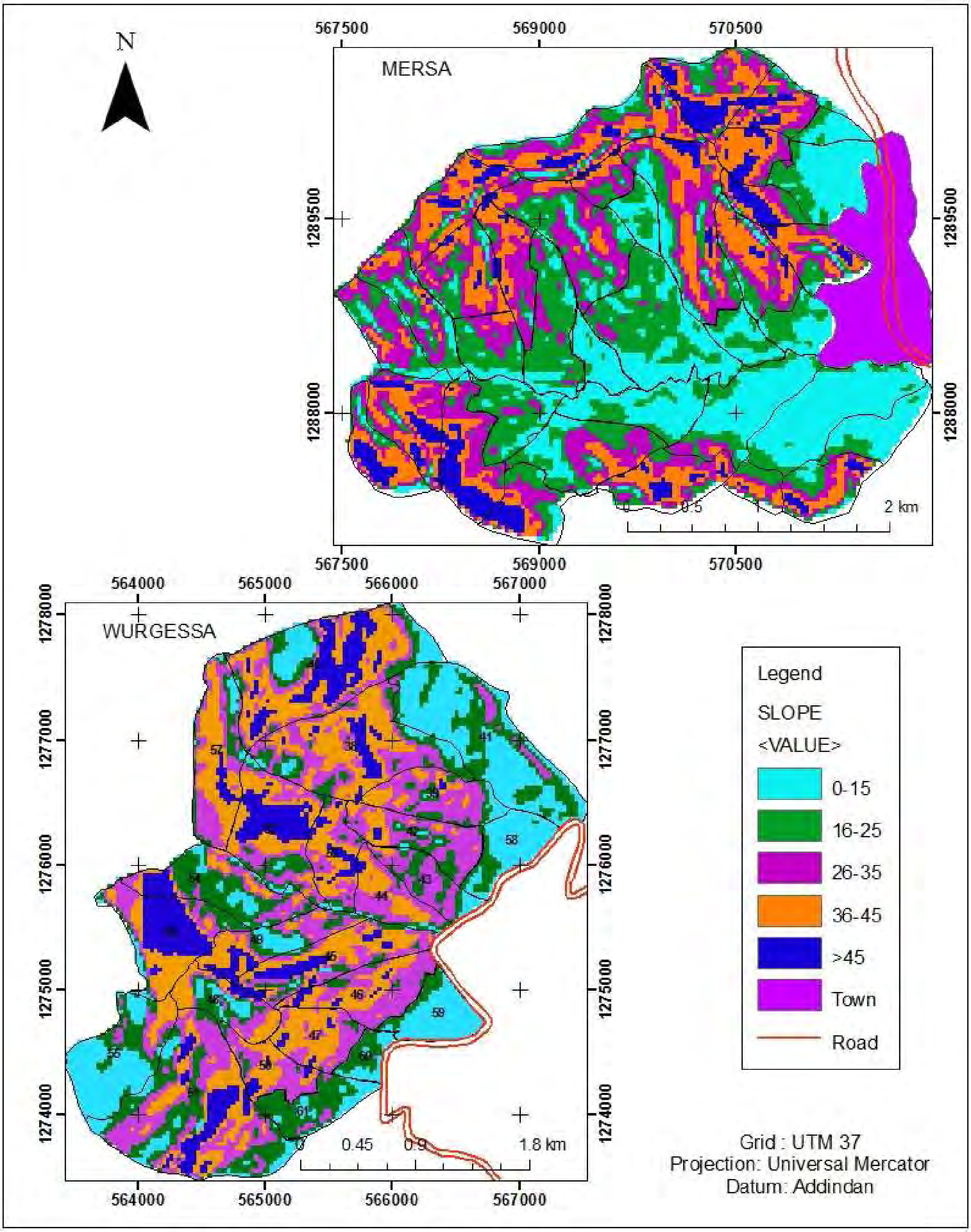


Fig 6.5 Slope Morphometry of the study area

Similarly, in Mersa area 17 % of the slopes fall under the category of moderately steep (25°-35°) and 17 % slopes are steep (35°-45°). The remaining slopes fall under Gentle (15°-25°), Very gentle (<15°) and Escarpment (>45°) which accounts for 27%, 31% and 8%, respectively. The standard ratings were assigned from Table 3.2 and facet wise ratings for slope morphometry are presented in Annexure A.

In general, most of the high steep slopes are found in the rugged topography where big rivers cut the slopes and the gentle slopes are found in the areas where agricultural activities are being practiced.

Slope Material (Lithology)

Slopes may be composed of rock mass or soils or both. The criteria for assigning ratings to sub classes of rock type are based on intact rock strength and degree of weathering. The errodability of rocks is highly influenced by the strength of the rock. Rocks which possess high strength are relatively more resistant to erosion. The rock sub classes are adopted from classification of rocks based on field estimates of strength by observation which is proposed by (Hoek, 1997).

Degree of weathering may affect the relative strength of the rocks therefore it has to be considered while assigning ratings to the rock type. The degree of weathering has been considered as; fresh, slightly weathered, moderately weathered, highly weathered, extremely weathered and rock as soil (Irfan and Dearman, 1978).

For the case when slopes are covered by soils the rating criteria is based on the genetic class and depth of the soil cover. The residual soils are more consolidated and possess better shearing strength than the alluvial or recent deposited soils (Anbalagan, 1992). Depth of soil cover is also considered while assigning ratings to various soil types.

Slope material map of the study area has been prepared from field observation using 1:50,000 scale topographic map as base map (Fig.6.6). Due to the nature of the geological setting of the area, slope material of the study area is characterized by highly weathered and disintegrated rock mass. The most dominant lithological units of the study area are porphiritic basalt, highly disintegrated aphanetic basalt and scoracious basalt. These rock types are highly susceptible to chemical and physical weathering. Spheroidal weathering was dominantly observed in the study area. Dikes, faults and fractures are the dominant geological structures which has affected the slope material. Slope materials which is found within the study area are alluvial deposits, Residual expansive soils, poorly graded and well graded colluvial materials. Recent materials such as slide debris are loose and have low shearing resistance (Anbalagan, 1992).

A perusal of Fig. 6.6 indicates that very weak rocks, poorly graded and well graded materials are exposed in the study area. In Mersa area these very week rocks covers 65% of the total area whereas in Wurgessa it covers 34 % of the study area. Rest of the study area is occupied by the soils only. In Wurgessa area 12% is covered by alluvial deposits whereas 45 % and 9% is covered by poorly graded colluvial material and well graded colluvial material, respectively. Similarly, in Mersa area 35 % is covered by alluvial deposits.

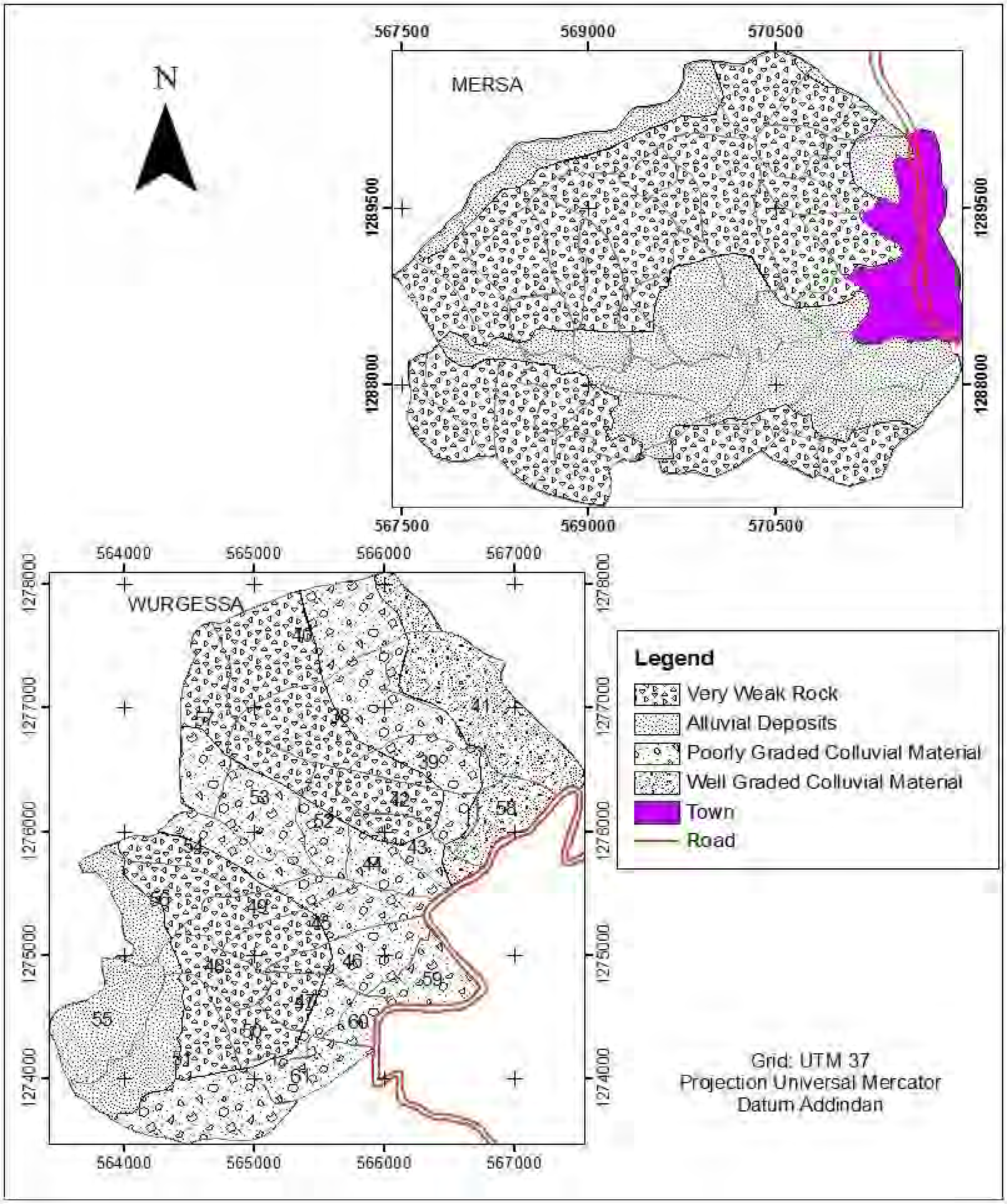
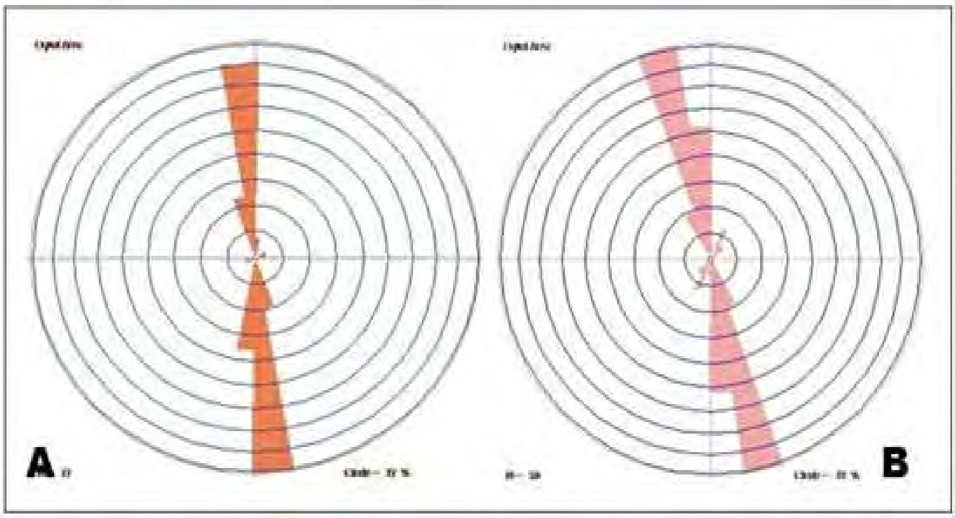


Fig 6.6 Slope material map of the study area

Structural discontinuities

Data pertaining to structural discontinuities orientation has been observed facet wise from the exposed rock mass and its relation to slope inclinations was determined. The rock mass condition with respect to structural discontinuities was also observed. Besides, data on characteristics of structural discontinuities with respect to spacing, continuity, and surface characteristics, separation of discontinuity surface and thickness and nature of filling material within the discontinuity surfaces has also been collected. Accordingly ratings were assigned for structural discontinuities based on standard Table 3.2. Thus, facet wise ratings assigned for structural discontinuities characteristics and its relation to slope orientation is presented in Annexure B and the total value assigned for structural discontinuities in Annex A.



A. Rose diagram of 77 major faults in the Dessie area
B. Rose diagram of 58 fault measurements from the Sirinka – Woldiya area

Fig 6.7 General trends of structural discontinuities (*Source: Tesfaye Kidane, 2010*)

According to (Tesfaye Kidane, 2010), the general trends of structural discontinuities in Dessie and Sirinka- Woldiya area shows NNW-SSE direction with few but regionally big faults trending in the E-W direction. Since the study area lies just near to Sirinka, the general trends of discontinuities in the area are NNW-SSE. NNE-SSW and E-W trending faults and fractures observed in the study area.

From field observation, the majority of the structural discontinuities show dip angle of 35^0-45^0. For those slope sections which show more parallelism between the slope inclination and discontinuity dip direction like (Plate 6.1) of the slopes in the study area and structural discontinuity with high dip angle, more rating values has been assigned.

Plate 6.1 Joints dipping parallel to the slopes (A) Mersa & (B) Wurgessa

Land use Land cover

Vegetation covers play an important role in stabilizing slopes. Vegetation covers stabilize the slope in different ways. It intercepts the rainfall which reduces the force of impact on soils. Dewatering through plant roots reduce water saturation from slope material which trigger landslide, and plant root reinforcement will stabilize the slope by reducing erosion and interlocking the soil layers (Loughlin, 2005).

Land use land cover map of the study area has been prepared by using Land sat Image of 2005. Classification of the land use land cover map has been done using ERDAS IMAGINE Software by a method of supervised classification system. The classification was done into five classes; forest or thickly vegetated, moderately vegetated, sparsely vegetated, barren lands, and agricultural land (Fig. 6.8).

Barren and sparsely vegetated areas show faster erosion and greater instability as compared to reserve or protected forests which are thickly vegetated and generally less prone to mass movement processes (Anbalagan, 1992).

A perusal of Fig. 6.8 shows that in Wurgessa area agricultural land covers 48%, Forests 8%, Barelands and moderately vegetated areas covers 5% each and sparsely vegetated area covers 34%. Whereas, in Mersa area sparsely vegetated land covers 43%, moderately vegetated 38%, bare land 10%, agricaltural lands 9% and forests covers merely 0.3%.

The total percentage of area occupied by bare lands and sparsely vegetated lands is nearly 50%. This shows the high susceptibility of the area for landslide with respect to land-use/ Land-cover of the area.

Facet wise percentage area coverage of land use land cover is presented in Annexure H and the ratings assigned are presented in Annexure A.

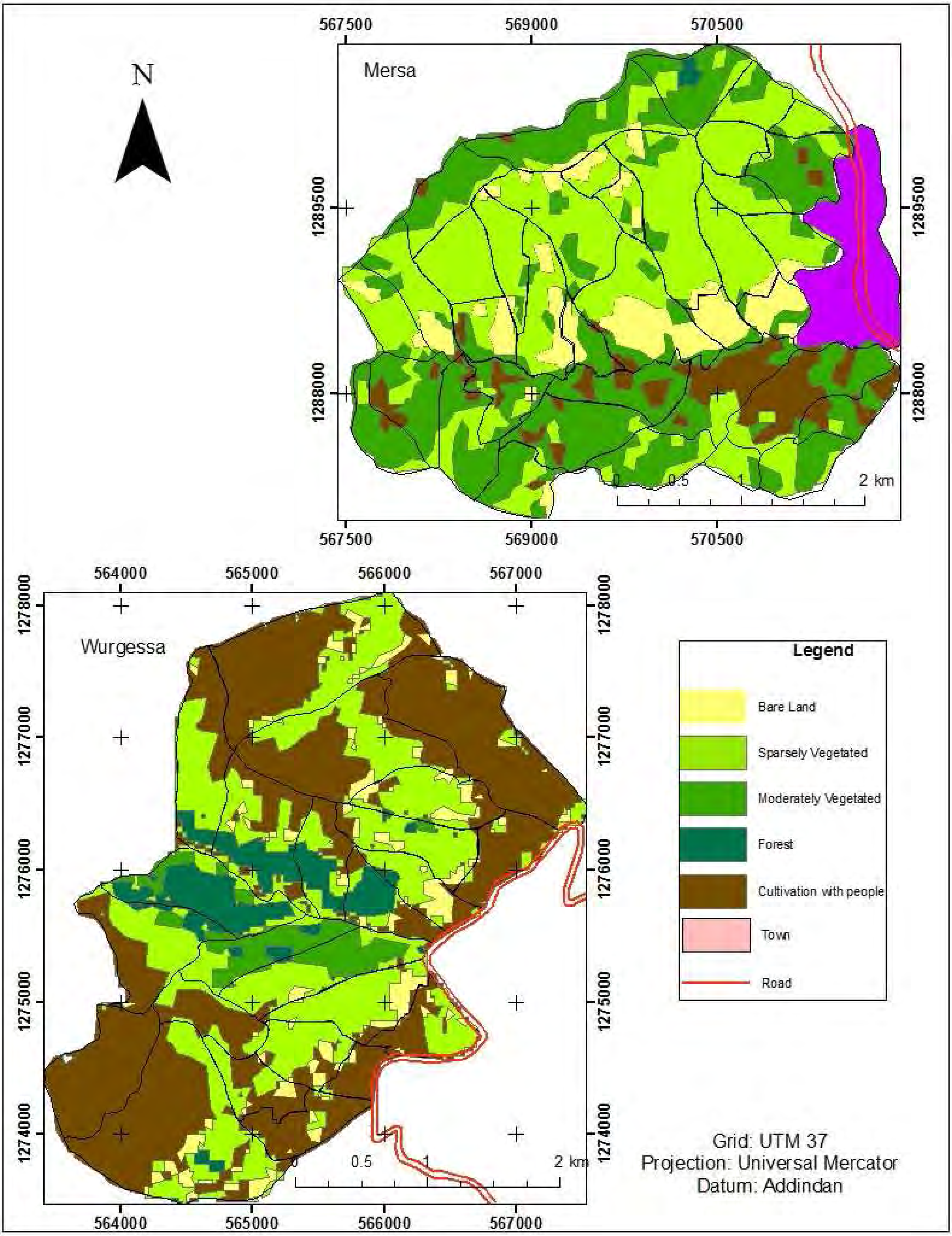


Fig 6.8 Land-use /Land-cover map of the study area

Groundwater

The nature of surface indications of the behavior of ground water such as damp, wet, dripping and flowing will provide valuable information on the stability of hill slopes and these are helpful for rating purpose (Anbalagan, 1992).

Ground water condition map of the study area has been prepared using topographic map as base map and data on ground water indications like presence of spring on slope face, surface marks of the presence of ground water flow, algal growth in shadow areas and dripping of water through discontinuities have been observed. The observations made on surface water traces were taken using GPS and later were transferred to the map using ArcGIS software.

Most of the observations have been taken in the dry season however some observations have been done at the time of landslide during August 2010. Observation taken after the rainy period, provide probably the worst ground water conditions possible (Anbalagan, 1992). Therefore, those areas which are considered as flowing, dripping and wet in the study area (Fig 6.9), are very susceptible for landslide occurrences with respect to ground water condition.

In Mersa study area southern part of Birbisa stream, which covers about 18% of the total area, was considered to posses flowing condition. In this area irrigation is being practiced throughout the year. Besides, perennial stream passes through this area and springs were also observed close to this area. Further, about 43% of the area was classified as damp and 15 % of the area as dry.

In Wurgessa area 80% of the study area was classified as flowing due to the dominant availability of springs with high discharge of water on slope face. About 5% area was classified as dripping, and 15 % of area as wet.

Further, 38% of Mersa and 10% of Wurgessa area is covered with drainage ditches. These drainage ditches (Plate 5.12) were dug by the local community in collaboration with governmental and non-governmental organizations for flood protection and soil harvesting. These drainage ditches are used as temporary storage of water for continuous supply through structural discontinuities. Therefore, the contribution of these drainage ditches has been considered as one of the important factor in causing instability through ground water recharging.

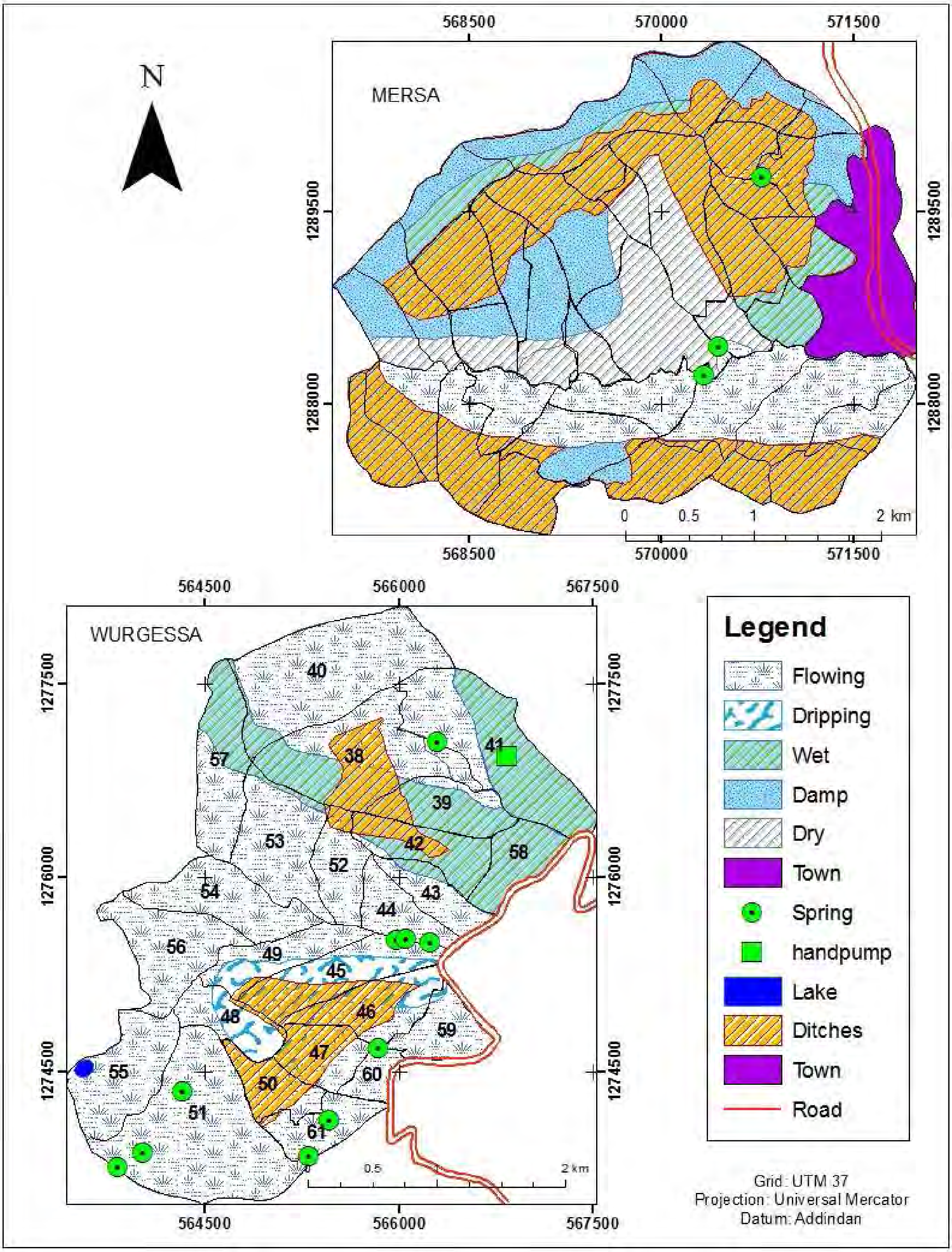


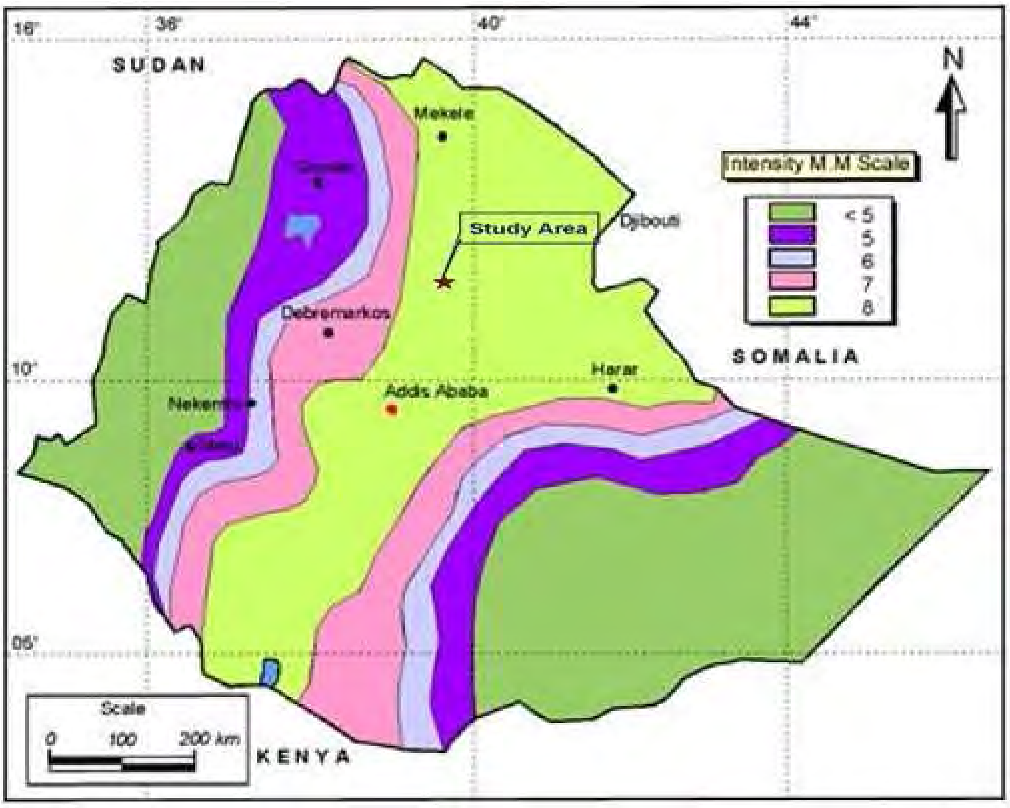
Fig 6.9 Ground water condition of the study area

6.2.2 External parameters

Seismicity

Seismicity plays an impotent role in triggering landslides. From historical records; seismic triggered landslides are common events in the western Afar margins (Gouine, 1979) of which the present study area forms a part. Hence, for Landslide hazard zonation mapping seismicity of the study area has been considered.

In order to consider the seismicity in the study area seismic map of Ethiopia was considered (Laike Mariam Asfaw, 1986). According to this map (Fig. 6.10) the present study area falls in Seismic zone which has an intensity of 8, this zone has a ground acceleration of 0.1- 0.5g. Thus, the rating for ground acceleration of 0.1-0.5g, as per the standard Table 3.2 is 1.5. Accordingly, similar rating has been applied to all 61 slope facets of the study area (Annexure A).



(Source: Laike Mariam Asfaw, 1986)

Fig 6.10 Seismic risk map of Ethiopia 100 year return period, 0.99 probabilities

Rain fall

Slope stability problems aggravate with rainfall intensity (Lulseged Ayalew, 2004; Collison et al., 2000; Dai and Lee, 2001; Dahal et al., 2006). This is evident as the slope failure increases during the rainy season. The rainfall recharges the groundwater and in general saturates the slope. In rock slopes the groundwater within the discontinuities develops water pressure which results into decrease of shear strength along the discontinuity planes (Hoek and Bray, 1997). Also, groundwater lubricates the discontinuity surfaces thus facilitating the process of rock sliding. In soil slopes after saturation from rain water the weight of soil mass increases and thus it adds to the instability of the soil mass. Besides, groundwater helps in pore water pressure development within the soil mass which again aggravate instability (Arora, 1997). Rainfall is an important slope instability triggering external parameter. In order to incorporate its effect in modified rating scheme mean annual rainfall has been considered as a means to assign ratings (Oberoi, 2004). Further, the rain induced manifestation on slope such as; gully formation, toe erosion, stream bank erosion etc. has also been considered while assigning ratings for rainfall. In order to assess the impact of rainfall on slope instability factors such as; type of slope material, discontinuity orientation with respect to slope, slope morphometry has been considered.

Mean annual rain fall

Five categories of mean annual rainfall have been considered for rating purpose in modified technique. These categories are Very high (>1500mm), High (1101-1500mm), Moderate (701-1100mm), Low (300-700mm), very low (<300mm). Maximum ratings given to each of these categories is presented in Table 3.2 (Raghuvanshi, 2011).

Mean annual rain fall of Wurgessa area is 1188 mm which falls in High category and the Mersa area has 962 mm which falls in moderate category of mean annual rainfall. Accordingly the ratings from standard Table 3.2 has been assigned (Annex N).

Rain fall Induced manifestation on slope

Rain fall causes slope instability with its long term impact on slopes. It causes slope toe and stream bank to be eroded and gully erosion to be formed over slope face. In the study area most of the facets have been affected by these rain induced processes. Parameters such as slope toe erosion, stream bank erosion, and gully erosion over slope face have been considered for each facet to assess the possible rainfall impact over the slope face. The maximum rating value given to each of these categories is presented in Table 3.2. Rainfall induced manifestation map of the study area has been prepared using field observation by utilizing topographic map, GPS field data collection and Arc GIS software (Fig.6.11).

The central part of Mersa study area which is on the right and left side of Birbisa stream has been affected by stream bank erosion and slope toe erosion. However, these areas are relatively gentle therefore; possible contribution for instability will be limited.

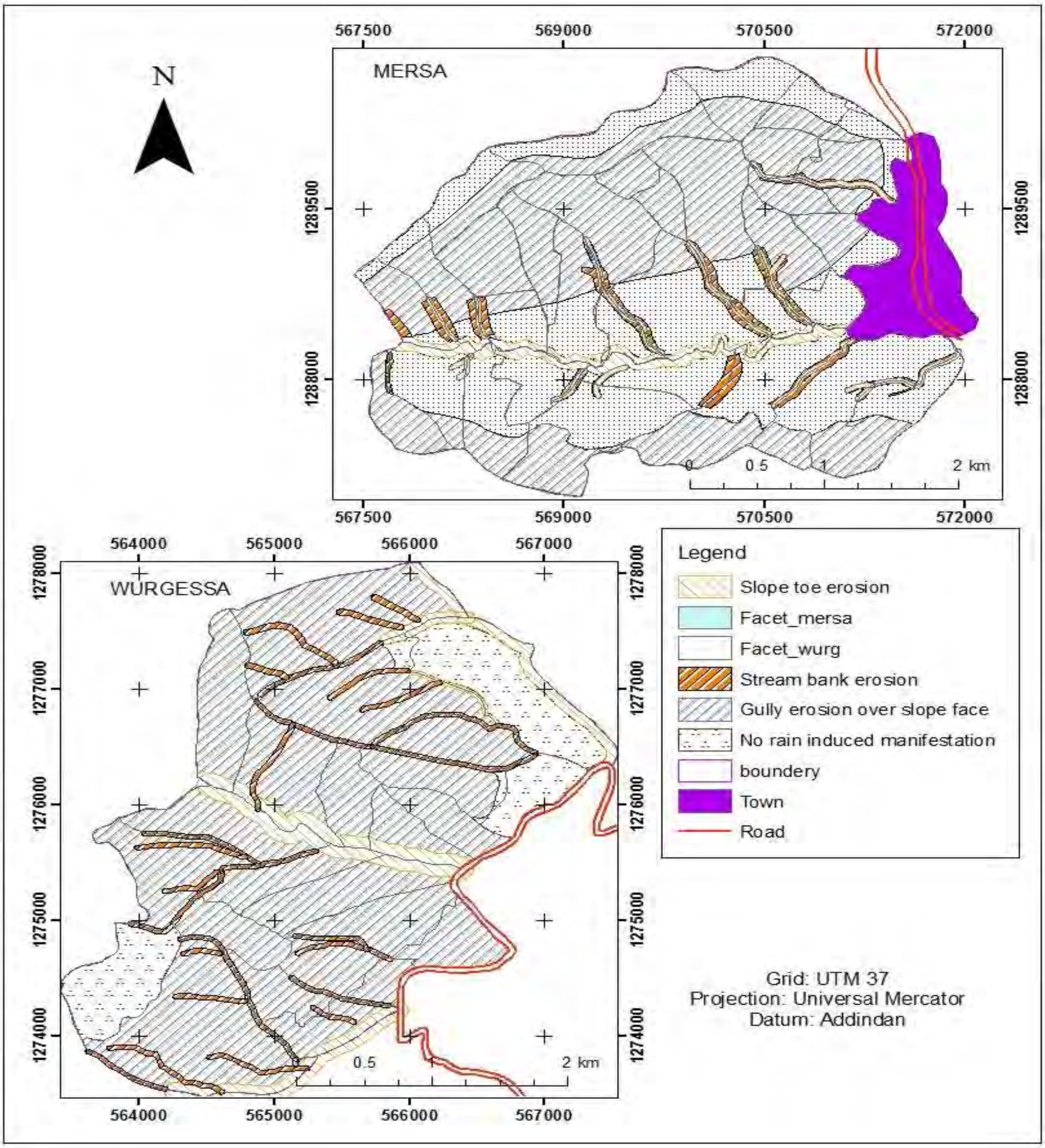


Fig 6.11 Rain induced manifestation over slope face.

In Wurgessa study area almost the entire slope facets have been affected by the rain induced processes (Fig. 6.11).

Due to its steepness and high relative relief (Fig 6.2, Fig. 6.4 and Fig. 6.5), the slopes in Wurgessa study area generally overhang and are relatively prone for slope instability. Therefore, slope toe erosion and stream bank erosion of most of the slope facets in Wurgessa area may result into high susceptibility for landslide. The rating value assigned for this parameters of individual facets presented in Annex N.

Slope Material

Based on the hydrologic response of slope material; the study area is classified into soil mass, disintegrated, and blocky /disturbed (Fig.6.12).

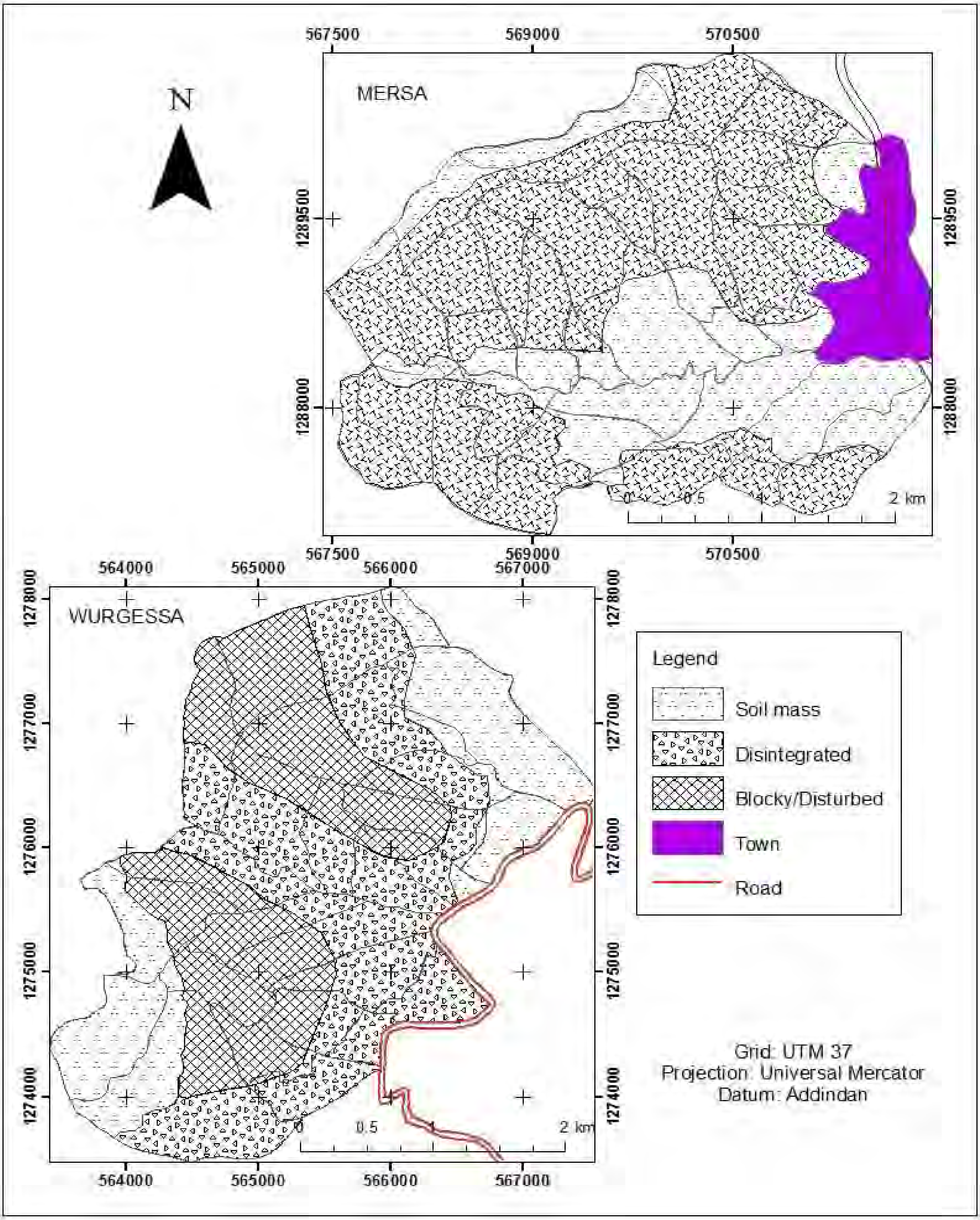


Fig 6.12 Slope material as rainfall parameter

A perusal of Fig.6.12 shows that in Mersa area 64% of the slope material is disintegrated rock mass whereas about 36% of the area is soil mass. In Wugesssa area 43% of the slope material is disintegrated rock mass, 31% is soil mass, and 26% is blocky /disturbed rock mass.

In general in the study area, rocks are highly weathered, disintegrated, closely fractured and faulted. As a result much of the rain water may infiltrate into the slope mass and may induce significant instability to the slope mass.

Discontinuity orientation with respect to slope

Based on the intense tectonic effect and high weathering grade the rock mass in Wurgessa area in general, can be characterized as 45 % disintegrated and 34 % as blocky/ disintegrated rock mass. Besides, 21% of the area is covered by soil mass. Similarly, in Mersa area, 65% area is covered by disintegrated rock mass and 35% by soil mass. Thus, Based on the standard table 3.2 ratings assigned to individual facets in Annex N.

Rain fall adjustment factor for slope morphometry

It is assumed that more steeper is the slope less infiltration of water will take place due to rainfall. It implies that, gentler the slope will be more infiltration of rainfall water will be resulted. Thus, rainfall adjustment factor for slope morphometry has been multiplied with Rainfall rating obtained after summing up ratings for Mean annual rainfall, Rain induced manifestation on slope, Slope Material and Discontinuity orientation with respect to slope (Table 3.2). The total rain fall values given to individual facets are presented in Annexure A.

Man Made Activities

Man made activities generally play an important role in triggering landslides. This is a known fact that most of the landslides are associated with steep cut slopes made for various purposes such as; road construction, building construction, quarry developments and agricultural activities. The main manmade activities which prevailed in the present study area are mainly construction activities and cultivation practices.

Manmade activity map of the study area has been prepared for which field observations were made by utilizing GPS location points over 1:50,000 topographical maps. The main manmade activities which have been observed in the study area are developmental activity such as; road and building construction, quarrying activities and formation of drainage ditches for water harvesting and flood control. Besides, cultivation is also practiced in the study area.

The developmental activities has resulted into steep slope cuttings which has made many slopes to overhang and thus, more prone for landslide activities. The cultivation practices over the slopes have also an impact on slope instability. Unplanned irrigation practices over the slopes makes slope mass recharge and which may result into reduction of shear strength of the soil mass, besides pore water pressures may also develop within the soil mass. Thus, ultimately leading the soil mass to fail provided other causative factors also favor the sliding.

The manmade activities being practiced in the study area is shown through (Fig. 6.13). A perusal of this map shows that in Mersa area 19% of the area is covered by dense cultivation, 18 % by sparse cultivation, 39% by ditches and 0.8% by steep rock mass cut for construction activities. Similarly, in Wurgessa area 13% of the area is covered by dense cultivation, 23% by moderate cultivation 12% by sparse cultivation, 12% by ditches, 0.9% by steep rock mass cut for construction activities, 2% by dumped excavated material and quarry. Thus, accordingly ratings were assigned to each of the slope facets from the standard Table 3.2. While assigning ratings for developmental activities adjustment factors such as; slope toe support by retaining structures, provision of proper drainage system, slope face dressing in to terrace design and dumping of the excavated material down the slope were also considered (Fig. 6.13; Annexure A).

6.3 Landslide hazard Evaluation of the study area

On the bases of the total value of slope stability susceptibility evaluation parameters which include both the causative and triggering factors, Landslide hazard was classified into five categories. These are; Very high hazard zone, (VHHZ, >12), High hazard zone, (HHZ, 8 - 12), Moderate hazard, (MHZ, 7.9 – 5), Low hazard zone (LHZ, 4.9 – 2), and Very low hazard (VLHZ, <2).

Landslide hazard zonation map of the study area has been prepared from the distribution of the total value of the slope stability susceptibility evaluation parameters facet wise. For these facet wise ratings, all intrinsic and trigging parameters were summed up and accordingly various landslide hazard zones in the study area were delineated (Annexure A). Accordingly, the study area has been classified into three major classes; Very High hazard zone, High hazard zone and moderately hazard zone (Fig. 6.15; Table 6.1). A perusal of Fig. 6.15 clearly shows that very low hazard and low hazard zones are not present in the study area.

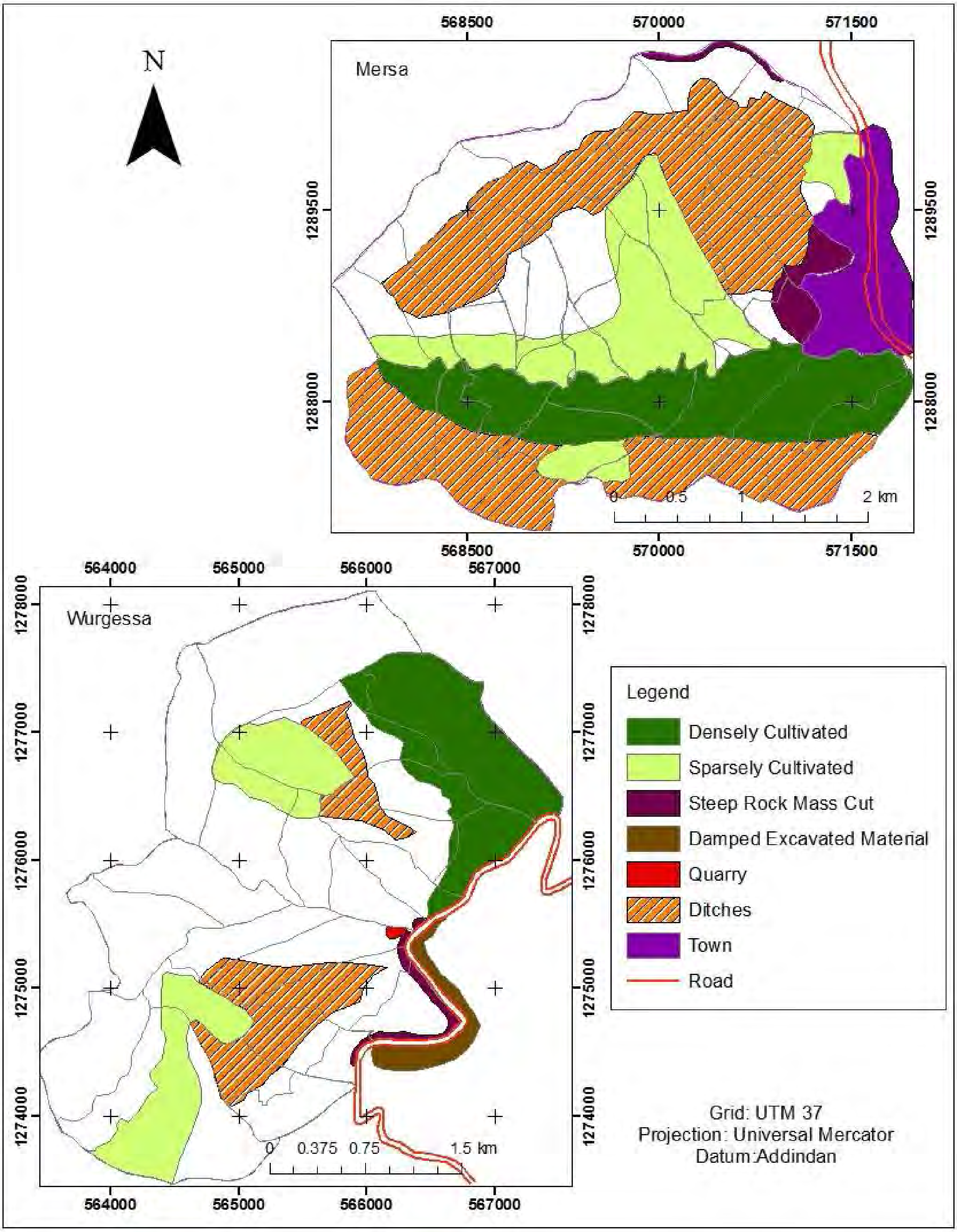


Fig 6.13 Manmade activities of the study area

Very high hazard zone

Out of the total evaluated facets four facets fall in very high hazard zone. Among these, three facets fall in Wurgessa and one in Mersa area. In Mersa area only 2% (with area coverage of 253,319 m^2) of the total area is covered by very high hazard zone whereas, in Wurgessa area it covers 10% (with total coverage area of 1,116,322 m^2) of the total area. In Mersa area very high and high hazard zone is located close to the Mersa town and left bank of Birbisa stream whereas, in Wurgessa it is located in the central portion, just adjacent to Dessie - Woldiya main asphalt road.

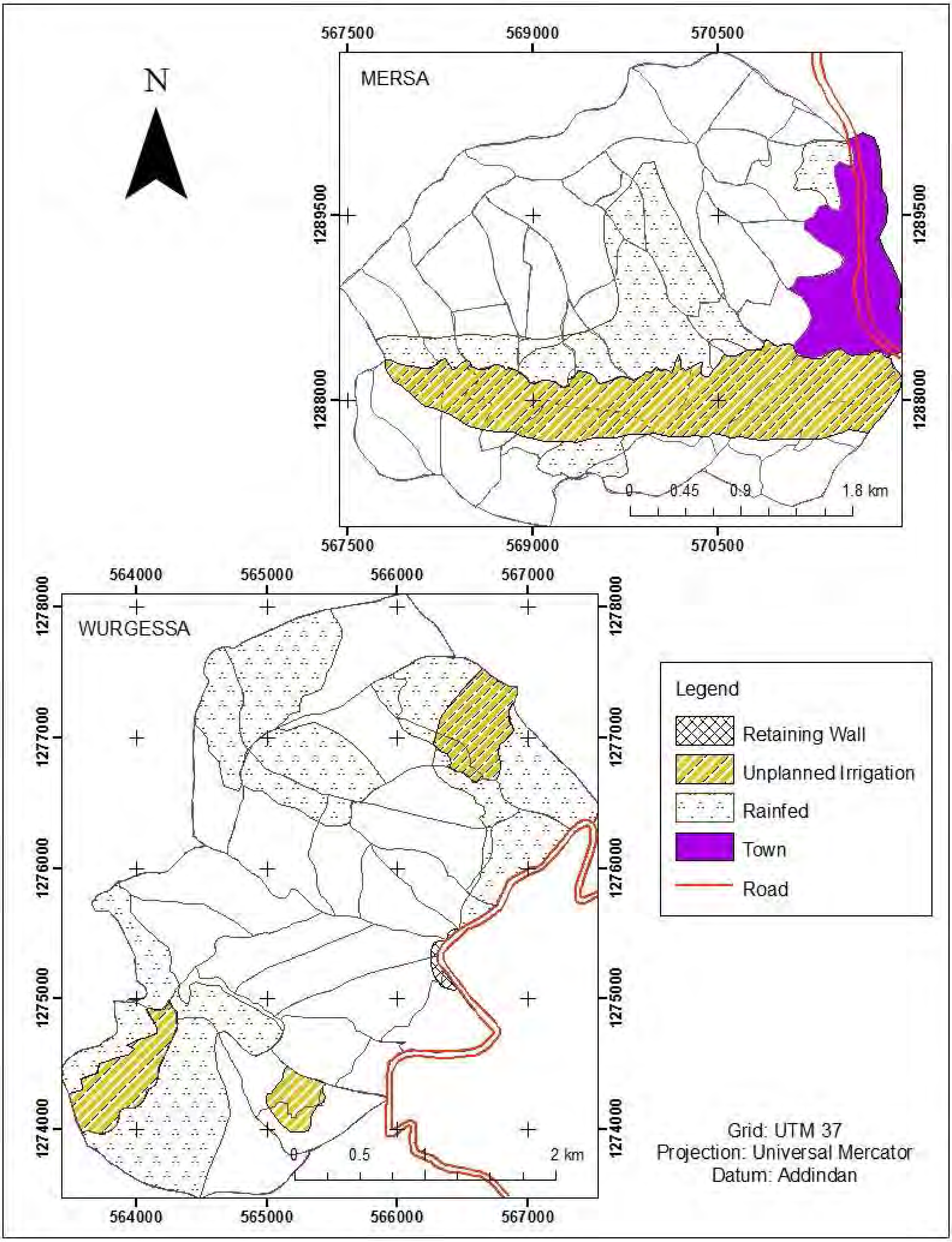


Fig 6.14 Adjustment factors for manmade activities

Table 6.1 LHZ of the study area

Zone	TEHZ	Description of zones	Area (Sq. Km.)	Percentage
V	>12	Very high hazard (VHZ) zone	5.57	6%
IV	8 - 12	High hazard (HHZ) zone	15.40	69%
III	7.9 - 5	Moderate Hazard (MHZ) zone	1.37	25%

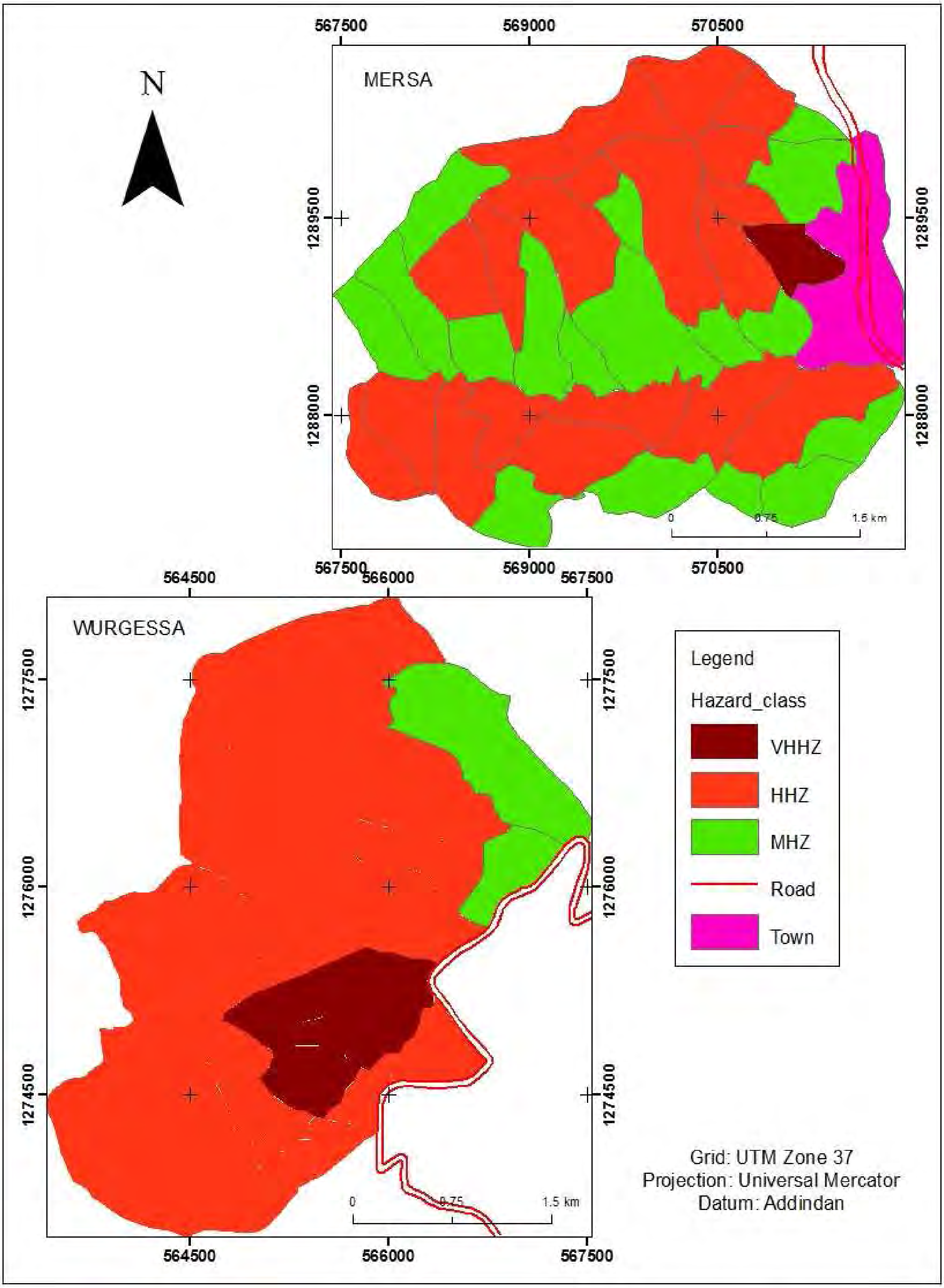


Fig 6.15 Landslide hazard zonation map of the study area

High hazard zone

Majority of the study area falls into high hazard zone. In Mersa area 51% (with total coverage area of 6,847,750 m^2) of the total area, is covered by high hazard zone whereas, in Wurgessa area it covers 81% (with total coverage area of 8,821,012.6 m^2) of the total area. The high hazard zones in the study area generally are characterized by steep slopes and significant groundwater surface traces.

Moderate hazard zone

In Mersa area 39% (with total coverage area of 4,557,916 m^2) of the total area is covered by moderate hazard zone whereas, in Wurgessa area it covers 11% (with total coverage area of 1,162,277m^2) of the total area. The moderate hazard zones in the study area are generally characterized by relatively gentler slopes with dry to low groundwater surface traces.

Facets indicating very high and high hazard slopes have been further studied to investigate the relative influence of intrinsic and external triggering parameters on Evaluated landslide hazard (ELH) within various facets (Table 6.2 and Fig. 6.15). This was performed by taking the percentage values of the ratings for each individual parameter with respect to the ELH. In terms of order of importance structural discontinuities have greatest influence followed by groundwater, slope morphometry, land-use/land-cover, slope material, Relative relief, seismicity, rainfall and manmade activities.

6.4 Validation of Landslide Hazard Zonation

Landslide inventory of the study area has been done at the time of land sliding in the month of August, 2010 and at the time of field investigation for the present research work in the months of October 11 to November, 5 2010.

Field observation and GPS data collection were made for the preparation of Landslide inventory map of the study area. As it can be seen from the inventory map of the study area (Fig 6.16), most of the landslides are concentrated in Wurgessa area however there are some landslide occurrences in Mersa area also. This is due to the abundance of causative and triggering factors in Wurgessa than in the Mersa area.

In the study area a total of 68 landslide activity locations have been recorded during the inventory map preparation. A description of these landslide activities is given in Table 6.3.

Table 6.2 Relative influences of intrinsic and external triggering parameters on evaluated landslide hazard (ELH) within facets falling under Very High and High Hazard Zone in the study area

Facet No	Percent value of ratings with respect to ELH								
	Intrinsic Parameters						External Triggering Parameters		
	Relative Relief	Slope Morphometry	Slope Material	Structural Discontinuities	Landuse and landcover	Groundwater	Seismicity	Rainfall	Manmade Activities
1	4.96	16.52	8.26	20.32	9.95	16.52	12.39	0.74	10.33
2	6.21	20.73	10.36	19.06	11.60	15.55	15.55	0.93	0.00
3	7.97	16.93	9.96	20.31	11.98	14.94	14.94	2.24	0.75
4	8.83	18.77	10.71	20.53	12.00	10.24	1656	2.35	0.00
5	8.38	17.80	10.20	18.43	8.44	8.35	15.70	2.24	10.47
6	9.6	12.01	10.64	21.74	10.41	12.29	18.01	5.28	0.00
8	5.27	17.57	8.79	21.62	10.81	13.18	13.18	0.79	8.79
9	8.60	18.27	10.38	20.10	14.90	8.38	16.12	2.44	0.8
10	2.27	11.37	11.37	21.26	14.80	17.05	17.05	4.83	0
11	7.23	12.06	12.06	22.55	14.45	7.23	18.09	5.43	0.90
12	7.08	11.79	11.79	21.46	13.94	11.23	17.69	5.01	0.00
13	7.28	12.13	11.18	16.98	9.12	16.47	18.19	5.63	15.16
14	9.25	19.65	11.56	18.60	9.45	11.56	17.34	2.6	0.00
15	8.64	18.37	10.52	17.39	8.98	14.48	16.20	2.72	2.70
21	7.16	11.93	11.38	23.50	13.81	7.40	17.89	6.03	0.89
22	6.71	19.01	10.87	22.03	13.42	8.81	16.77	2.38	0.00
23	8.35	17.75	10.44	19.74	8.93	13.89	15.67	2.60	2.61
24	6.70	3.35	8.32	20.10	9.18	21.44	16.75	11.37	2.79
25	2.4	3.60	9.80	20.61	9.70	20.53	18.01	11.36	3.00
27	2.34	3.51	9.37	21.08	7.47	23.42	17.57	12.30	2.93
28	2.28	6.84	10.70	20.53	9.55	21.44	17.11	8.69	2.85
38	9.29	18.57	7.85	23.08	6.83	18.57	13.93	1.19	0.70
39	9.65	9.65	4.57	23.87	10.42	19.30	14.48	6.24	1.81
40	9.45	18.91	6.88	23.21	6.75	18.34	14.18	1.21	1.06
42	10.52	10.52	8.51	21.89	11.94	12.68	15.79	6.16	1.97
43	10.55	10.55	6.80	19.62	11.22	19.41	15.82	6.02	0
44	9.45	16.06	5.15	18.09	5.69	18.89	14.17	3.06	9.45
45	8.26	16.51	6.40	20.39	10.23	16.51	12.39	1.05	8.26
46	8.31	14.12	5.81	20.52	10.26	16.61	12.46	2.67	9.24
47	8.33	14.16	6.79	20.57	9.26	16.66	12.49	2.46	9.26
48	10.25	6.15	9.46	25.32	6.89	17.23	15.38	8.54	0.77
49	9.91	9.91	8.37	24.28	8.09	18.23	14.86	6.35	0
50	9.25	15.72	9.25	21.74	7.55	18.50	13.87	2.73	1.39
51	9.91	19.81	7.05	19.32	7.18	19.81	14.86	1.30	0.74
52	10.17	20.34	6.97	18.32	7.25	19.63	15.26	1.30	0.76
53	10.15	20.31	6.7	18.32	7.63	19.60	15.23	1.30	0.76
54	10.07	10.07	7.50	24.66	5.96	20.13	15.10	6.51	0
55	8.74	3.28	10.93	19.67	4.37	21.86	16.39	13.11	1.64
56	9.51	19.02	5.80	22.82	7.35	19.02	14.26	1.14	1.07
57	10.20	17.34	8.06	20.05	8.65	16.01	15.30	3.24	1.15
59	5.79	2.89	4.82	23.54	7.96	19.30	14.47	11.58	9.65
60	2.28	6.84	5.70	27.80	5.55	22.79	17.09	10.68	1.28
61	9.04	6.78	5.65	20.34	5.99	22.60	16.95	11.37	1.27

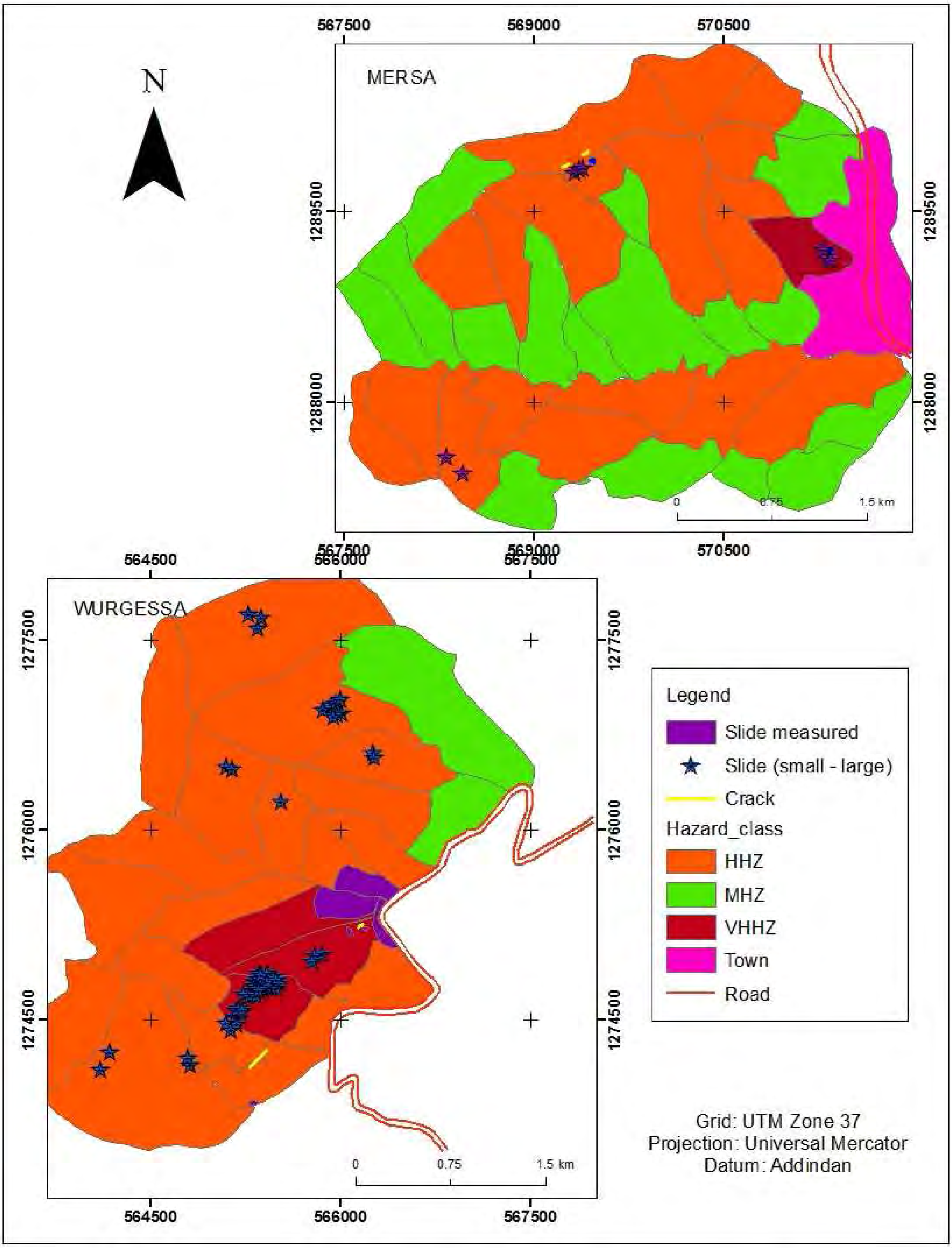


Fig 6.16 Landslide Inventories of the study area

These landslide activities were mainly concentrated along the road section. A perusal of Fig 6.16 clearly shows that most of these landslide activities fall within very high hazard zone and high hazard zone as delineated during the present study. Out of these 68 landslide activities 40 (59%) are falling within Very High Hazard zone and 28 (41 %) of it falls within

Table 6.3 Inventory data of the landslide activities triggered in August 2010 in the study area

No	Location (*Projection: UTM – Zone 37N; Datum: Addindan*)		Description	Landslide Hazard Zone as per SSEP Rating Scheme	Location
	Northing	Easting			
1	1289213	571344	This is the catastrophic landslide which killed 17 people in Mersa. It has 130 meter length and 60 meter width. Mainly composed of sand-silty residual soils. Occurred in August 2010.	Very High Hazard Zone (VHHZ)	Mersa
2	1289099	571457	Mainly comprises of silty sand residual soils which found near the catastrophic landslide of Mersa. Have a dimension 3meter by 1meter.	Very High Hazard Zone (VHHZ)	Mersa
3	1289899	569465	This landslide has dimension of 30 meter by 7o meter, compositionally more of fine sediments of residual soils.	High Hazard Zone (HHZ)	Mersa
4	1289866	569249	In this slope sections there are three activities of landslide each not more than 10 meter apart. Slope material failed is residual soils from steep slopes.	High Hazard Zone (HHZ)M	Mersa
5	1287454	568431	Slopes comprising of residual soils, two landslide activities occurred in this area.	High Hazard Zone (HHZ).	Mersa
6	1275424	566283	A 400 meter by 300 meter size soils slips observed at the Left bank of Golo stream. Comprising of poorly graded colluvial material. Extensive quarrying takes place at this area. Debris flow comprising of a lot of debris material observed.	Very High Hazard Zone (VHHZ)	Wurgessa
7	1275143	566099	This landslide has dimension of 30 meter by 80 meter. The materials involved in this failure are residual soils. Debris flow is observed.	Very High hazard (VHHZ)	Wurgessa
8	1275247	566156	40 meter by 25 meter slide comprising of colluvial material, dominantly soils.	Very high hazard (VHHZ)	Wurgessa
10	1275441	566321	Soil slips observed at the right bank of Golo stream. It covers an area of more than 450 meter by 200 meter dimension. The slope material which has experienced of failure is poorly graded colluvial.	High hazard (HHZ)	Wurgessa
11	1275007	565779	The slope section comprises of colluvial material with dominant sand silt residual soils. Three landslides concentrated which is difficult to measure the extents. Debris flow observed in the area. .	Very high hazard (VHHZ)	Wurgessa
12	1274797	565405	At this slope section more than 25 soils slip activities observed. dimension ranges from 3 meter by 1 meter up 50 meter by 20 meters. Mostly the slip material is residual soils and colluvials. Debris flow is observed as long as which comes to the main road affect the traffic..	Very high hazard (VHHZ)	Wurgessa
13	1274470	565139	At this slope section more than 8 soil slips with dimension vary from 1 X3 meter to 20 X 60 meters comprising of residual soils observed.	Very high hazard (VHHZ)	Wurgessa
14	1274191	564794	Two soil slips comprising of residual soils observed.	High hazard (HHZ)	Wurgessa
15	1273847	565309	A translational slide as big as 70 meter X 50 meter observed in this section. Kok wuha spring is the main causes of slope instability in this section.	High hazard (HHZ)	Wurgessa
16	1276607	566252	In this section poorsely graded colluvial material dominantly angular to sub angular of big size experienced of sliding.	High hazard (HHZ)	Wurgessa
17	1276975	565963	In this section poorsely graded colluvial material dominantly angular to sub angular of big size experienced falling.	High hazard (HHZ)	Wurgessa
18	1277648	565353	High steep cliff, soil slip covering wide area not accessible for measuring.	High hazard (HHZ)	Wurgessa
19	1276513	565081	Right bank of Golo stream. Big soil slip difficult to measure.	High hazard (HHZ)	Wurgessa
20	1274175	564105	In this section the landslide is more destructive. Comprising of colluvial material.	High hazard (HHZ)	Wurgessa

high hazard zone. Thus, the Landslide hazard zonation (LHZ) map prepared by utilizing modified rating scheme during the present study validate with the landslide activities triggered in 2010 in the area.

(a) Landslide which has fallen in steep slope cut (Wurgessa)

(b) Soil slip in the steeper part of the slope.

© Rotational Landslide in the high elevation areas. At 2643m above sea level.

(d) The catastrophic landslide which has killed 14 people (Mersa)

(e) Landslide which has affected retaining wall near Golo stream bridge (Wurgesa).

(f) Retaining wall affected by colluvial slide (Wurgessa near Golo stream).

Plate 6.2 Inventories of landslide which is triggered in August, 2010

6.5 Overall Landslide Hazard of the area

As a part of present methodology, in the study area sixty one slope facets were delineated from topographical map at a scale of 1:50,000. Within each slope facet intrinsic and external parameters were evaluated and assigned with the maximum ratings as per the conditions prevailed within the facet. For this thematic maps for intrinsic and external parameters were prepared. Finally, the total value of estimated hazard for individual facet was calculated, by summing up the respective ratings for all causative and triggering factors. Thus, based on the total estimated hazard value facets which have scored the value greater than 12 were considered as very high, those which scored value between 8 to12 as high and those which have scored values between 5 to 8 as moderately hazard zone. Finally, in the present study area 6% of slopes fall into very high hazard, 69% fall into high and remaining 25% slopes fall into moderate hazard zone. Further, the landslide hazard zonation prepared during the present study validates with the past landslide data as all past landslide events fall into very high and high hazard zones, as delineated during the present study.

CHAPTER SEVEN REMEDIAL AND PREVENTIVE MEASURES

7 .1 Preamble

The landslides triggered in the study area have caused significant causalities and economic loss. Besides, most of the landslides occurred along road sides. The road geology disaster will not only create the enormous direct economic loss, but also the indirect economic loss which is difficult to estimate and the bad social impact because of the disaster interrupting traffic (Li et al., 2009). Therefore, besides preparing the landslide hazard zonation map of the study area, finding appropriate remedial and preventive measures for critical slopes will be very helpful to alleviate or reduce the economic and social problems in the area, particularly during rainy season.

From the present study, it was found that combination of different factors were responsible for inducing slope instability in the study area. Therefore, combination of different mitigation measures should be applied to avoid /reduce the instability condition induced in the study area. The remedial measures to be taken should also be cost effective and feasible.

In order to have a standard format of landslide remediation, the IUGS WG/L commission on landslide remediation (Popescue, 2001) has prepared a check list of landslide remedial measures (Annexure P) which is grouped into four, namely; modification of slope geometry, drainage, retaining structures, and internal slope reinforcement (Popescu and Sasahara., 2009).

Besides, an appropriate remedial measure depends on a) Engineering feasibility, b) economic feasibility, c) Legal/regulatory conformity, d) Social acceptability, and e) environmental acceptability.

However, slope stability analysis, based on which selection and application of specific remedial measures to be decided, is not carried out for the present study. Various general suitable preventive and remedial measures, which may stabilize the critical slope, are discuss in the following paragraphs.

Some of these remedial measures are: - proper managements of drainages, afforestation and reforestation, supporting critical slopes, constructing catch walls, avoiding artificial vibration like dynamite, managing steeply cut slopes, creating awareness on the impact of manmade activities on slope instability, and relocation.

7.2 Proper management of drainage

It has been observed that the landslides of the study area were triggered when the soil moisture and ground water level increased following the heavy rainfall of summer (87% & 90% of mean annual precipitation, Wurgessa and Mersa, respectively). Therefore, avoiding/reducing any water which infiltrate into the slopes and draining out from the slope without hindrance, will reduce the pore pressure developed within the slope material. Therefore, the shear strength of the slope material may not be excessively affected which will causes slope instability. Hence; proper management of the drainages in the study area will be key solution to reduce the instability of the slopes.

Some of the general remedial measures to properly manage the drainage system of the slopes are construction of trench drain, interceptor drain and construction of collection chamber and diverting the water to the existing drainage systems.

The abandoned crop storage holes dug in the upper slope section of Mersa area and the tension crack developed during 2010 landslide may provide safe passage to water into the slopes which will facilitate the slope failure through internal erosion. Therefore, these cracks and openings should be filled with impermeable material. The drainage ditches which were constructed in most parts of the slopes in the present study area may allow continuous infiltration of water through discontinuities. This may intern causes slope instability. Hence, these drainage ditches should be redesigned in such a way that it may not allow infiltration of water. Therefore, it should be impermeable, wide, strong, interconnected and the water should be collected in collection chamber without affecting the surrounding slopes. The collected water may be directed back to the existing drainage systems.

The remedial measures which are described earlier should also be applied to different springs like Kok Wuha spring which has initiated significant Debris flow in Wurgessa area.

7.3 Afforestation and Reforestation

Most parts of the study area (39% for Wurgessa and 53% Mersa) are characterized by sparsely vegetated and bare lands. This has resulted from deforestation of the area in association with the increasing rate of population. The local residents confirmed that the current vegetation cover has resulted due to extensive deforestation in the area.

Because of the limited awareness about deforestation in causing slope instability, the local residents cut trees and bushes for various purposes. This was also observed at the time of field investigation for the present research. Besides, the landslides triggered in 2010 caused destruction of the existing natural environment. Vegetation cover of the area have been extensively affected.

Plant roots and vegetation cover may stabilize the underlying slope by reducing the pore water pressure through evapotranspiration, intercept direct impact of precipitation and the plant roots tightly strengthen the underlying soils. Since the dominant slope failures of the study area are characterized by shallow soil slips, afforestation and reforestation will stabilize the unstable slopes of the study area. The big tree species if planted in the upper slope, it may increase the load over the critical slopes. Therefore, type of vegetation species to be planted over slope face, should be identified and supported with site specific scientific research.

7.4 Supporting critical slopes

The retaining walls at the side of the main road, in Wurgessa area, are affected by the slided material. Therefore, the retaining structures which will be constructed should be properly designed in such a way which resists the load imposed by the slided material and should have sufficient drainage outlets.

7.5 Constructing catch walls

The debris flow impact on the road in Wurgessa area was very devastating within short period of time. Suddenly all the cars which were found on the road were caught by the debris flow. To avoid this sudden impact of debris flow proper catch walls should be designed and implemented together with the proper drainage management and other remedial measures.

7.6 Avoiding artificial vibration

The active quarry site of ERA, which is found near Golbo Bridge in Wurgessa, has created a great disturbance on the surrounding slopes. Interview with the local residents confirmed that enormous amount of dynamite has been used for quarrying construction material. The quarry site has to be properly managed and alternative sites which are far from the roads, settlements and unstable areas should be selected.

7.7 Managing steeply cut slopes

The road construction companies have steeply cut some slopes in Wurgesssa area and dumped the excavated material down slope in unplanned manner. The poorly graded colluvial material, soils, and highly weathered basalts, become unstable in the steep rock mass cut. This loose material which is dumped down the slope in unplanned manner may easily be eroded and degraded. This may intern will make the overlying road to be affected by landslide. Therefore, it is necessary that properly slope cut should be designed and unplanned dumping of waste should be avoided.

Conducting detailed investigation on critical slopes may facilitate to evolve various remedial measures such as; benching, constructing retaining walls which may possibly stabilize the steep slope sections.

7.8 Creating awareness for impact of manmade activities on slope instability

During the field work for the present study it was observed that the awareness among the local people for adverse impact of manmade activities on slope instability was limited. In general, it was observed at several places that the slopes were cut steeply for house construction and eventually making the slope to overhang by removing the toe support of the slopes. Similar, practices were observed along the road cuts. Here it is worth mentioning that the ultimate stability condition of a given slope is greatly affected if the toe of the slope is steeply cut. Therefore, it is utmost important to create awareness among the local residents to minimize the adverse effects of mismanaged manmade activities. Further, re-vegetation on slopes may also improve the stability of slopes to certain degree.

7.8 Resettlement

From the landslide hazard zonation mapping of the study area during the present study, the slopes which fall in very high hazard and high hazard zones are susceptible for future landslide activities. Even the validation of LHZ map also revealed that all past landslide activities fall within Very high hazard and high hazard zones. Thus, such very high hazard and high hazard zones in the area should be avoided for any settlements and those who are residing in these zones must be rehabilitated to safer area.

Finally, through the present study general remedial measures such as; proper management of drainage, afforestation and reforestation, supporting critical slopes, constructing catch walls, avoiding artificial vibration through blasting, managing steep cut slopes, creating awareness on the impact of manmade activities on slope instability etc. has been forwarded. Moreover, applying integrated approach of remedial measures may be helpful to minimize the landslide hazard in the area. However, more detailed studies would be required to work out specific remedial measures for individual critical slopes.

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CHAPTER EIGHT CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The present study area is located in Mersa and Wurgessa towns, Habru Woreda of North Wollo Zonal Administration, Amhara National Regional State. The study area is situated around Mersa town along Combolcha – Woldiya road 490 km from Addis Ababa and Wurgessa area which is 465km from Addis Ababa. The study area is located along the main road which is an important corridor that links important towns in the north like Mekelle, Gonder and Bahirda to the Afar region and other important cities like Addis Ababa.

Following the heavy rain fall of summer 2010, the landslides were triggered in the study area. These landslides were extensive and devastating. In the study area, the said landslides has claimed 23 casualties, damaged bridges and infrastructure, disrupted traffic movement and in general affected greatly the overall environment.

Thus, with this alarming damage and devastation in the area the present research study was conceived. The general objective of the present study was to identify and study the possible causes of landslide which were triggered on August 2010 in the study area. Besides, to prepare a landslide hazard zonation of the area, so that the area which have the potential for similar landslide activities can be delineated. Finally, based on the findings of the present study suitable general remedial measures for the landslide prone areas have been suggested.

As a part of methodology, during the office work a thorough literature review was undertaken to develop a conceptual framework of the problem. Besides, base map was prepared which was later utilized in the field for identification and location of various field manifestations of slope instability, locating past landslide activities and locating and plotting of inherent and external causative factors which might have triggered the past landslides.

Based on field observation of the study area it was found that the slope material which has experienced failures of varied forms is mainly; residual soils, poorly graded colluvial and alluvial material. Most of the slope failures were associated with; high relative relief, steep slopes, adverse groundwater flowing conditions, kinematic structural discontinuities, bare or sparsely vegetated lands and stream bank and toe erosion.

Based on the analysis of the different causative and triggering factors in causing instabilities, it is found that in terms of order of importance structural discontinuities has greatest influence in inducing instability followed by groundwater, slope morphometry, land-use/ land-cover, slope material, relative relief, seismicity, rainfall and manmade activities.

Slope instability in the study area is manifested in the form of soil slips, translational sliding, rotational sliding, debris flow, and at some places rock fall (near to the study area). The debris flows were basically composed of soils, rock fragments of varied shape and dimension, vegetation, and plant roots.

For the present study modified technique, being developed by Raghuvanshi (2011), was adopted. In the modified technique intrinsic parameters such as; slope geometry, slope material (lithology or soil type), structural discontinuities, land use and land cover and groundwater were considered. In addition to these intrinsic parameters external parameters such as; rainfall, seismicity and manmade activities were also accounted.

As per the methodology the present study area was divided into 61 slope facets. Various intrinsic and external parameters were evaluated within each individual slope facet and assigned with the maximum ratings as per the conditions prevailed within the facet. For this thematic maps for intrinsic and external parameters were prepared. Finally, the total value of estimated hazard for individual facet was calculated, by summing up the respective ratings for all causative and triggering factors. Thus, based on the total estimated hazard value facets which have scored the value greater than 12 were considered as very high, those which scored value between 8 to12 as high and those which have scored values between 5 to 8 as moderately hazard zone. Finally, in the present study area 6% of slopes fall into very high hazard, 69% fall into high and remaining 25% slopes fall into moderate hazard zone. Later, the landslide hazard zonation prepared during the present study validates with the past landslide data as all past landslide events fall into very high and high hazard zones, as delineated during the present study.

Further, through the present study general remedial measures have been forwarded. These remedial measures include; proper management of drainage, afforestation and reforestation, supporting critical slopes, constructing catch walls, avoiding artificial vibration through blasting, managing steep cut slopes, creating awareness on the impact of manmade activities on slope instability etc. Since it has been found that in most of the slopes instability is induced due to combination of several factors therefore, applying integrated approach of remedial measures may be helpful to minimize the landslide hazard in the area. However, more detailed studies would be required to work out specific remedial measures for individual critical slopes.

7.2 Recommendation

To avoid or reduce the landslide hazard in the study area, various general remedial measures such as; proper management of drainage, afforestation and reforestation, supporting critical slopes, constructing catch walls, avoiding artificial vibration through blasting, managing steep cut slopes, creating awareness on the impact of manmade activities on slope instability etc. have been proposed (Chapter 7). The general recommendations based on the present study are;

- The causes of slope instability in the study area are wide and multi-directional, therefore integrated approach of remedial measures may be more appropriate to mitigate the possible landslide hazard in the area.

- From the present study it was deduced that the poor drainage condition on most of the critical slopes have played a significant role in inducing instability of slopes therefore, improvement in drainage condition will be an effective measure to stabilize the slopes in the area.

- Unplanned manmade activities such as poor construction practices, quarrying on slopes and conventional cultivation practices on or near to the critical slopes have induced instability of the slopes to certain degree. In this regard awareness among the local residents and construction agencies should be made through the local administration.

- Before implementing any remedial measure suggested through present study more detailed studies would be required to work out specific cost effective remedial measures for individual critical slopes.

- Very high hazard and high hazard zones, as delineated during the present study, are probable susceptible landslide prone areas. Thus, such very high hazard and high hazard zones in the area should be avoided for any settlements and those who are residing in these zones must be rehabilitated to safer area. Therefore, local administration may adhere to the recommended landslide hazard zoning and accordingly future developmental activities in the study area may be planned.

- The local administration may undertake real-time monitoring of slope instability in the area and must adopt early warning system so that the devastating hazard can be minimized or elevated before any actual activity event.

- Further, more detailed studies are mandatory to investigate individual slopes for its instability, possible causes for such activities and to work out appropriate remedial measures for critical slopes.

For the present study all efforts were made to perform research in a systematic manner well supported by actual scientific data and realistic observations. However, all these efforts were made under various constraints on time, resources and financial support. All these constrain might have affected on the quality of result and certain component of inaccuracy may not be ruled out. Therefore, it is strongly recommended that more detailed systematic study must be undertaken before implementing the recommendations made through the present study.

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DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for any degree in any university.

All the sources of materials used for the thesis have been duly acknowledged.

Name: Jemal Ibrahim

Signature: ___________________________

Date: June 2011